

Reduced Browning in Raw Oriental Noodles by Heat and Moisture Treatment of Wheat¹

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ABSTRACT

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Flours milled from heat- and moisture-treated hard white wheat (KS-196) contained reduced levels of polyphenol oxidase (PPO), but not peroxidase (PO). With a 12-min heating period, the PPO activity decreased with increasing moisture content (MC) from 13 to 15%, whereas with 4- and 8-min heating periods, the PPO activity was insensitive to moisture level. When the tempering period was increased from 1 to 4 hr at 19% MC, PPO activity in the heat-treated wheat was unaffected. Three other wheat cultivars, tempered to 15% MC for 1 hr and then heat-treated for 8 min at 100°C, yielded flours with ≈50% reduction in PPO activity. Heating the KS-196 wheat for 12 min at 100°C reduced PPO activity in flour by as much as 76%, but destroyed the elasticity of gluten as determined by mixograms. White noodles and yellow alkaline

noodles, made from heat-treated (15% MC, 8 min, 100°C) KS-196 wheat, had improved brightness in the raw state and showed little change in cooking quality and cooked texture, except for reduced firmness. When KS-196 wheat was pearled to remove 28% of its weight, and the pearled kernels were heat- and moisture-treated at 15% MC for 8 min at 100°C, the straight-grade flour contained 75% less PPO activity than the untreated wheat flour. White noodles made from pearled, heat- and moisture-treated wheat were brighter than those made from pearled untreated wheat. A white noodle dough, made from heat- and moisture-treated wheat with aminoguanidine bicarbonate added, had the brightest dough ($L^* = 75$) after 24 hr at 25°C.

Noodles that are not precooked or dried during manufacturing are prized for their retained flavor. The appearance of noodles is important to consumers. White noodles should be bright and white; yellow alkaline noodles should be bright and yellow without specks. Raw noodles with 35% moisture (wet basis) have a high water activity. During storage, they undergo browning followed by microbiological spoilage. Much of the browning is thought to be caused by two enzymes present in wheat, *o*-diphenol oxidase, also known as polyphenol oxidase (PPO), and peroxidase (PO) (Kruger et al 1992, Baik et al 1995). Those enzymes catalyze the oxidation of free, reduced phenolic compounds to quinones, which react to form brown pigments.

PPO and PO enzymes are present largely in the bran fraction of milled wheat, and their levels in flour rise with increasing extraction rate (Marsh and Galliard 1986, Hatcher and Kruger 1993, Baik et al 1994a). Moss (1971) observed increased browning of noodle dough upon addition of 0.08% tyrosine to the flour, indicating that browning was limited by substrate concentration. PPO activity also has been implicated in the browning of pasta products (Kobrehel et al 1972, Feillet et al 1974), *chapattis* (Abrol and Uprety 1970), and vital wheat gluten (Kim et al 1991).

Preventing Enzymic Browning

PPO has a copper prosthetic group and is inhibited by chelating agents (Mayer and Harel 1979) and by zinc and calcium ions (Bolin and Huxsoll 1989), but those additives may affect flavor. Sulfite is used widely to denature PPO (Whitaker 1985), but sulfite destroys the elasticity of wheat dough (Bloksma and Bushuk 1988). L-Ascorbic acid inhibits browning by reducing quinones to phenols and by reacting with and removing oxygen. The dehydroascorbic acid formed in the reaction is unstable, however, especially in dough at pH 5-6, and may induce browning (Shin

and Feather 1990, Sawamura et al 1994). L-Ascorbic acid improves the yellow color of dried spaghetti (Walsh et al 1970, Milatovic 1985) and the brightness of raw noodle doughs (Baik et al 1995). PPO browning can be inhibited by use of modified atmosphere packaging (Faulkner 1989) and by addition of a protease enzyme (Luo and Patterson 1994).

PPO is a heat-labile enzyme and is inactivated readily by a short heat treatment at 70-90°C in fruit and vegetable tissues (Vamos-Vigyazo 1981). On the other hand, PO is a relatively heat-stable enzyme and is used as an index of adequate blanching in foods (Reed 1975). In wheat, PPO is membrane bound, and its activity is measured by the rate of oxygen consumed by the tissue in the presence of excess substrate (Marsh and Galliard 1986). However, PO in wheat is soluble, and its activity can be measured spectrophotometrically in an extract after adding excess substrate and hydrogen peroxide (Edwards et al 1989).

Heat and Moisture Treatment of Wheat

Heat treatment of wheat at 13-17% moisture content (MC) in a screw conveyer at 95-110°C for 4 to 12 min was reported to inactivate lipolytic and oxidative enzymes without altering the physical and functional properties of the flour (Bookwalter 1985). Hot air drying of wheat and the baking quality of the resulting flour has been studied by several authors (Finney et al 1962, Lupano and Anon 1987, Zamponi et al 1990). Loaf volume, crumb grain, mixing time, and protein solubility were adversely affected at grain temperatures above 71°C. Those investigators did not measure the inactivation of PPO and PO in the wheats or flours.

Wheat flour contains low levels of glucose and fructose (Williams and Bevenue 1951, Toepfer et al 1972), and those sugars may react with free amino groups of wheat proteins during heat treatment of wheat to produce Maillard browning in the endosperm. In Maillard browning, reducing sugars react with amino groups to produce 1-amino-1-deoxy-2-ketose derivatives (Amadori compounds), which undergo further degradation to give highly reactive dicarbonyl sugar derivatives as browning reaction intermediates. Aminoguanidine reacts with the dicarbonyl sugar intermediates to form a colorless stable triazine molecule that stops Maillard browning (Hirsch et al 1992).

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Moisture movement into wheat kernels using excess tritiated water has been investigated (Moss 1977). Within the first hour, water penetrated into the aleurone cells of common hard wheats, and in many cases, into the starchy endosperm to a depth of only 50–60 μm . Further penetration into the endosperm was delayed for several hours.

The objectives of this investigation were to: 1) temper wheat briefly and then rapidly heat and cool it to reduce the levels of PPO and PO with minimum damage to endosperm protein; 2) mill the heat- and moisture-treated wheat into flour and determine its dough mixing and noodle making properties; and 3) investigate other methods to reduce browning of raw noodles.

MATERIALS AND METHODS

Materials

Hard white winter (HWW) wheat (KS-196), grown in 1992, was obtained from the Dept. of Grain Science and Industry at Kansas State University, Manhattan, KS. A straight-grade flour milled from the wheat contained 11.0% protein, 0.42% ash, and 0.72% free lipids on a 14% moisture basis and had a falling number of 474 sec. Unless otherwise stated, KS-196 wheat was used throughout the investigation. The HWW wheat cultivar Arlin with 8.5% protein was obtained from the American White Wheat Growers Association, Atchison, KS. The two commercial samples of mixed hard red winter (HRW) wheats with protein contents of 11.2 and 9.3% were obtained from Cargill Flour Milling Division, Wichita, KS.

All inorganic chemicals were reagent grade from Fisher Scientific Company (Fair Lawn, NJ). Catechol, guaicol, ethylenediaminetetraacetic acid, trichloroacetic acid, kojic acid, 4-hexylresorcinol, cysteine, hemoglobin, *tris*(hydroxymethyl)amino-methane, linolenic acid, and 4-methylumbelliferone heptonate were from Sigma Chemical Co. (St. Louis, MO). Aminoguanidine bicarbonate was from Aldrich Co. (Milwaukee, WI). *Kansui* was a 9:1 (w/w) mixture of sodium and potassium carbonates.

Heat and Moisture Treatment of Wheat

KS-196 wheat (400 g) was placed in a small rotating drum (diameter = 30 cm, length = 45 cm) at 25°C. Water (6–21 g) was added slowly to the tumbling grain. After tumbling for 10 min, the moistened grain with 13–19% MC (wet basis) was held in a sealed polyethylene bag at 25°C for 1–4 hr. The tempered wheat (400–430 g) was placed in a Miag laboratory wheat conditioner (Fig. 1) with the drum rotating at 6 rpm, while the flow rate of air through the drum was set at 20 m^3/hr (334 L/min). The drum and the inlet air temperatures were maintained at 80 or 100°C, and the residence time of the wheat in the drum was 4–12 min. The temperature of heat- and moisture-treated wheat was measured by a thermocouple inserted into a portion (25 g) of the grain that had been removed from the drum and placed in a small dewar flask. The treated wheat was removed from the hot drum within 15 sec and was cooled immediately by blending with powdered dry ice. A portion (25 g) of the cooled wheat was sealed rapidly in a polyethylene bag with a small head space and was used to determine the moisture content. The remainder of the wheat was dried at ambient conditions for ≈ 6 hr and placed in polyethylene bags.

Experiments were performed in a 2 \times 3 \times 4 factorial design consisting of temperature (80 and 100°C); time (4, 8, and 12 min); and moisture level (13, 15, 17, and 19%). All experiments were done in triplicate. Analysis of variance was conducted with SAS (1986) using the general linear model.

Two commercial HRW wheats and another HWW wheat (Arlin) were tempered for 1 hr to 15% MC, heat-treated at 100°C for 8 min, and then cooled rapidly. After drying, the wheats were tempered again and milled into flour, and PPO activities of the flours were measured. The experiments were done in triplicate.

Heat and Moisture Treatment of Pearled HWW Wheat

KS-196 wheat (40 g per batch) was pearled in a Strong and Scott barley pearler (Seedburo Inc., Chicago, IL) for 90 sec. The material abraded from the surface was 11.2 g. Pearled wheat (400 g) was placed in the small rotating drum and brought to 15% MC by adding water and tumbling the mixture for 10 min. The moistened pearled wheat was heated immediately at 100°C for 8 min in the Miag wheat conditioner and then cooled rapidly. After drying, the sample was tempered again and milled into flour, which was then assayed for PPO activity and made into white noodles. The experiments were done in duplicate.

General Methods

Protein ($N \times 5.7$), moisture, and ash in wheat flours were determined according to AACC Methods 46-11, 44-15A, and 08-11, respectively (AACC 1983). Free lipids from flours were extracted according to AACC Method 30-25. Analytical data for flour are reported on a 14% moisture basis. Falling number, using flour, was determined by a Falling Number 1400 instrument (Perten Instruments, Reno, NV) (AACC Method 56-81B); gluten was determined with a Glutomatic 2200 instrument (Falling Number, Stockholm, Sweden) (ICC 1988); and mixograms determined on a 10-g mixograph (AACC Method 54-60). Whole wheat flour was produced by grinding grain (50 g) on a 1093 Cyclotech (Tecator Inc., Sweden) mill to pass through a wire mesh with openings of 0.5 mm. Straight-grade flour of $\approx 66\%$ extraction was milled from tempered wheat (200 g) using two Quadrumat junior mills in tandem (C. W. Brabender Instruments Co., South Hackensack, NJ). The wheat was tempered to 15% MC for 16 hr at 25°C before milling. Statistical analysis of data was done using SAS (1986).

Enzyme Assays

PPO activity was measured in flour, whole meal, and bran by monitoring the rate of oxygen uptake using a Biological Oxygen Monitor (model 5300, Yellow Springs Instrument Co. Inc., Yellow Springs, OH) equipped with a Clark polarographic electrode (Lamkin et al 1981). PO activity in ground whole meal and in white flour was determined according to Edwards et al (1989). Activities of PPO and PO were expressed as means of triplicate determinations and are reported, respectively, in units of nmol O_2 consumed/min/g of dry sample and $\text{mmol of H}_2\text{O}_2$ consumed/min/g of dry sample.

Lipoxygenase was measured by modifying the assay procedure

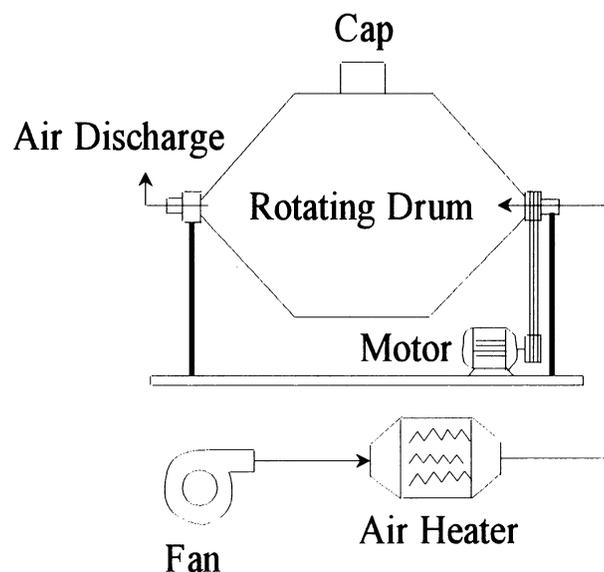


Fig. 1. Side-view drawing of Miag Laboratory wheat conditioner. The air-flow meter and temperature controller and recorder are not shown.

of Edwards et al (1989) using flour (0.2 g) in place of enzyme extract. Lipase activity was measured by the fluorometric measurement of 4-methylumbelliferone, released by the action of lipase on 4-methylumbelliferone heptonate (Heltved 1984). Lipoxygenase and lipase activities were expressed as means of duplicate determinations and were reported in units of nmol O₂ consumed/min/g and the change in fluorescence intensity with time, respectively.

Protease activity in flour was determined according to the procedure of Jones and Marinac (1991). Flour (10.0 g) was placed in a 50-ml centrifuge tube with 0.1M (pH 4.7) acetate buffer (20 ml) containing 2 mM cysteine and 0.1 mM EDTA. The blend was mixed vigorously at 25°C for 1 min with an Ultra Turrax mixer (Tekmar Co., Cincinnati, OH), and the mixture was allowed to stand 1 min. After the mixing and standing steps were repeated twice, the homogenate was cooled to 4°C and centrifuged for 20 min at 12,000 × g. An aliquot (8 ml) of the supernatant was dialyzed at 4°C overnight in a Spectra/Por 1 membrane (Fisher Scientific Company, Fair Lawn, NJ) against 5 mM (pH 4.7) acetate buffer (400 ml), and the dialyzed extract was made to volume (10 ml) with water. An aliquot (0.5 ml) of the solution was mixed with 250 µl of 6 mM cysteine, and 1% (w/v) hemoglobin solution in 100 mM (pH 3.8) acetate buffer (4.25 ml) was added, then the digestion was allowed to proceed for 1 hr at 40°C. The reaction was stopped by adding 7% (w/v) trichloroacetic acid (TCA) (5 ml) and holding the mixture for 15 min at 0°C. Precipitated protein was removed by centrifugation (1500 × g, 15 min), and the absorbance of the supernatant was measured at 280 nm against a blank. The blank was prepared identically to a sample, except that TCA solution was added before the hemoglobin solution. Protease activity was reported as the change of absorbance at 280 nm. The determinations were made in duplicate.

TABLE I
Polyphenol Oxidase (PPO) and Peroxidase (PO) Activities in Hard White Winter (HWW) Wheat Milling Fractions and in Dissected Endosperm^a

Wheat Fraction	PPO (nmol O ₂ /min/g)	PO (mmol H ₂ O ₂ /min/g)
Whole meal	372 ± 3	3.6 ± 0.02
Bran, milled	650 ± 5	7.1 ± 0.03
Flour, milled	104 ± 3	2.3 ± 0.03
Dissected endosperm	20 ± 2	ND ^b
Autoclaved flour ^c	0	0

^a Means of three replicates.

^b Not determined.

^c Wheat flour was autoclaved at 121°C for 6 min.

TABLE II
Grain Temperature (°C) and Grain Moisture Loss (%) in Heat- and Moisture-Treated Hard White Winter (HWW) Wheat and Loss (%) of Polyphenol Oxidase (PPO) Activity in Flour^a

Variable	80°C at Initial Moisture Content, %				100°C at Initial Moisture Content, %			
	13	15	17	19	13	15	17	19
	<i>Heating Period, 4 min</i>							
Grain temperature	50	54	54	51	61	60	59	59
Grain moisture loss	1.3	2.1	3.4	4.0	1.8	2.3	3.9	5.3
Flour PPO loss	0 a	0 a	0 a	0 a	18 a	26 b	32 c	28 bc
	<i>Heating Period, 8 min</i>							
Grain temperature	68	64	65	62	76	73	71	70
Grain moisture loss	1.6	2.9	4.0	4.9	2.3	3.9	5.4	6.1
Flour PPO loss	14 b	15 b	16 b	13 b	32 c	55 d	56 d	51 d
	<i>Heating Period, 12 min</i>							
Grain temperature	71	68	66	64	82 ^b	78 ^b	76 ^b	75 ^b
Grain moisture loss	2.0	3.5	5.3	6.4	3.1	4.3	5.7	7.8
Flour PPO loss	22 c	26 d	20 c	22 c	53 d	76 e	68 f	58 d

^a Means of three replicates. All samples of HWW wheat (KS-196) were tempered at 25°C for 1hr before heat-treatment. PPO activities within a treatment followed by the same letter are not significantly different at *P* = 0.05.

^b Flour plus water (0.6 part) did not form a viscoelastic dough in the mixograph.

Raw Noodles and Their Color

Optimum water absorption of flours for noodle making was estimated according to the method of Oh et al (1986). The color of a noodle dough was determined. Flour (25 g) and the optimum amount of water (8.5 ml) containing 0.5 g of sodium chloride or 0.5 g of *kansui* was mixed with a spatula for 1 min to form an elastic dough, which was sheeted to a final thickness of 2.5 mm using a rolling pin. The dough sheets were cut into pieces and stored in polyolefin bags for one to seven days at 5 and 25°C. The dough was removed from its bag, and color measurements were taken immediately with a Minolta chroma meter (model CR 210, Minolta Corporation, Ramsey, NJ) with a 50-mm measurement aperture on duplicate samples. The CIE-Lab *L**, *a**, and *b** values denote brightness, redness-greenness, and yellowness-blueness, respectively (Hunter and Harold 1987).

Cooked Noodles

Noodles were made with flour (100 g, 14% mb), water (32–34 g), and sodium chloride or *kansui* (2 g) (Rho et al 1988). The ingredients were blended for 1 min at speed 1 and 4 min at speed 2 in a Hobart mixer fitted with a cake paddle. The crumbly dough was pressed into a thick sheet (5.5 mm), which was rested for 20 min in a polyethylene bag and then reduced in seven steps in thickness from 5.5 to 1.1 mm. The thin dough sheet was cut into noodles (2.5 mm wide) and stored in polyethylene bags at 5°C. Optimum cooking time, cooking loss, and cooked weight gain of noodles were measured as described by Rho et al (1988). Texture profile analysis of cooked noodles was done according to Kim and Seib (1993). The coefficients of variation of the various parameters were: firmness <5.0%; cohesiveness <4.0%; adhesiveness <20%; and recovery <2.5%.

Inhibition of Browning of Noodle Dough by Various Additives

White noodle doughs were prepared from flour (100 g), sodium chloride (2 g), and water (34%). For control, flour was milled from untreated wheat, whereas test flour was milled from heat- and moisture-treated wheat (15% MC, 8 min, 100°C). Doughs were hand-mixed from blank flour that contained up to 1.0 g of calcium chloride, kojic acid, or 4-hexylresorcinol or from test flour that contained 0.1–1.0 g of aminoguanidine bicarbonate. The white noodle doughs were stored at 25°C in polyethylene bags, and color measurements were taken on duplicate samples at regular intervals using the Minolta chroma meter.

RESULTS AND DISCUSSION

PPO and PO Activities in Heat- and Moisture-Treated Wheat

Dissected endosperm from KS-196 HWW wheat had PPO activity of 20 nmol O₂/min/g (Table I). Marsh and Galliard (1986) reported PPO activities of 10–30 nmol O₂/min/g for dissected endosperm and 600–640 for dissected bran, in agreement with recent findings of Hatcher and Kruger (1993). The straight-grade flour, milled from KS-196 wheat had five times the level of PPO activity found in pure endosperm because of contamination with bran (Table I). The PPO activity in the milled bran was six times higher than the level of milled flour, and PO activity was three times greater. No PPO and PO activities were found in autoclaved (121°C for 6 min) flour. Baik et al (1994a) reported PPO activities in wheat that averaged twice the level found in the KS-196 wheat used in this study. Moreover, those workers found only 3% of the total PPO retention in 60% (or less) extraction flour from their wheats, compared to the 30% retention we found in the straight-grade flour.

Heating KS-196 wheat, previously tempered for 1 hr at 25°C to 13 to 19% moisture, for 4, 8, and 12 min at 80°C resulted in reductions of ≈0, 15, and 25% of PPO activity, respectively (Table II). For a given heating period at 80°C, wheat moisture had little effect on denaturation of PPO. Denaturation of PPO in the treated wheat was greater and more variable at 100°C than at 80°C, and as the moisture in the wheat was varied, the loss of PPO at 100°C proceeded through a maximum for each heating period (Table II). The maximum losses were 32% at 17% MC after 4 min of heating, 56% at 17% MC after 8 min of heating and 76% at 15% MC after 12 min of heating.

The low heat inactivation of PPO in wheat at 13% MC versus 15–17% MC may result from reduced mobility of the enzyme whereas at 19% MC, the low inactivation was attributed to evaporative cooling of the grain and the increased heat capacity of the grain. Water did evaporate from the grain at all heating conditions, but evaporative cooling was especially high at 19% MC and 100°C (Table II). An initial moisture level of 15–17% appeared to be optimum to destroy PPO activity in wheat kernels at 80 and 100°C. Maximally, 50% of PPO activity was destroyed in straight-grade flour that retained dough properties. Our optimum conditions were: wheat tempered to 15–17% MC for 1 hr at 25°C and then heat-treated for 8 min at 100°C. In contrast to PPO, PO

activity (2.3 mmol H₂O₂/min/g) in the heat- and moisture-treated flour showed no reduction, even beyond 8 min of heating (data not shown). Bookwalter (1985) reported that conductive heat treatment of wheat at 13–17% moisture and 95–110°C for 4–12 min inactivated lipolytic and oxidative enzymes without altering the physical and functional properties of flour. Data on the protein quality of the flour were not given.

The factor limiting the denaturation of PPO to 50% in the heat- and moisture-treated wheat, while preserving the vitality of gluten in the endosperm, is not known. Abbreviated tempering of the wheat should add moisture predominantly to the kernels' pericarp and aleurone layer (Moss 1977). Rapidly increasing the surface temperature of tempered wheat should cause heat to be conducted first into the aleurone layer where PPO activity is localized, and following rapid cooling of the hot and moist kernels, this should minimize protein damage in the internal zone (endosperm).

Increasing the tempering time from 1 to 4 hr before heating, even at 19% MC, gave no further denaturation of PPO in the flour from the treated wheat (Fig. 2), which indicated that 1 hr of tempering was sufficient to hydrate the aleurone layer. The PPO molecules in the bran layers are known to be membrane-bound (Marsh and Galliard 1986), which may limit accessibility to water. In addition, wheat PPO may have unexpected stability to heat. Soluble PPO extracted from wheat underwent only 20–50% loss of activity when heated at 60°C for 1 hr (Tikoo et al 1973). In our laboratory, wheat PPO in pH 6.6 phosphate buffer (0.05 M) retained 50% activity after the solution was heated at 70°C for 10 min.

Pearling KS-196 wheat to remove bran gave approximately a 70% yield of pearled kernels, whose milled flour showed a PPO activity of 53 nmol/min/g, or one-half the level of the straight-grade flour milled from the intact kernels. Heat- and moisture-treatment (15% MC, 100°C for 8 min) of the pearled wheat followed by milling gave straight-grade flour with PPO activity of only 23 nmol/min/g, or 6.2% of the activity in the wheat.

Heat- and moisture-treatment of three additional wheats under the optimum conditions to inhibit PPO (100°C /15% MC/8 min) in the KS-196 wheat caused a 45–55% reduction of activity in all flours (Table III). Once again, PO activities (1.6 ± 0.2 mmol H₂O₂/min/g) in those flours were unchanged as compared to the blank samples.

Lipoxygenase activity of the flour from the heat- and moisture-treated KS-196 wheat was reduced by 30% as compared to the control (7,350 vs. 5,165 nmol O₂/min/g), whereas protease was reduced by 70% ($\Delta A_{280} = 0.07$ units). Lipase activity was unchanged ($\Delta F/\Delta T = 0.03$ fluorescence units/min). Once again, the autoclaved flour contained no lipoxygenase, protease, or lipase activities.

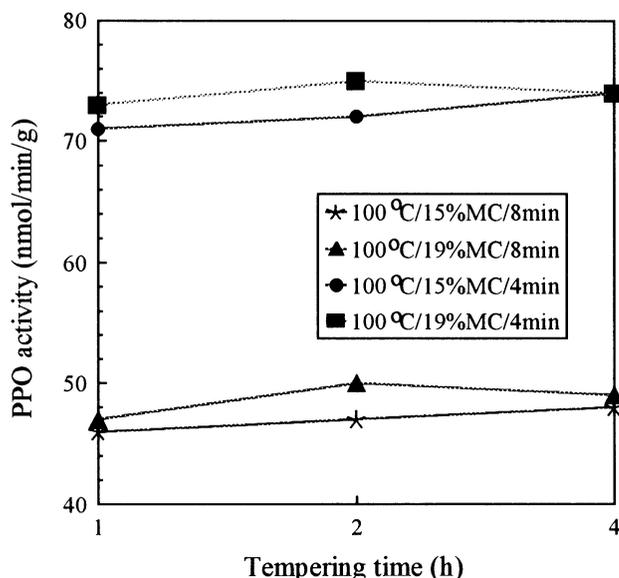


Fig. 2. Polyphenol oxidase (PPO) activity in wheat tempered for various time periods to 15–19% MC at 25°C, then heated by a combination of conduction and convection at 100°C for 4 and 8 min.

TABLE III
Denaturation of Polyphenol Oxidase (PPO) with Heat and Moisture Treatment of Various Wheats^a Under Optimum Conditions

Wheat Variety ^b	Flour ^c		Flour PPO ^d		Loss of Activity (%)
	Protein (%)	Ash (%)	Untreated (nmol O ₂ /min/g)	Treated (nmol O ₂ /min/g)	
Mixed HRW	11.2	0.35	96	42	46
Mixed HRW	9.3	0.44	108	49	
HWW Arlin	8.5	0.41	73	40	55
HWW KS 196	11.0	0.42	100	46	54

^a Samples were tempered 1 hr at 15% moisture content, then heat treated for 8 min at 100°C.

^b HRW = hard red winter, HWW = hard white winter.

^c All flours gave falling numbers above 400 sec.

^d Means of three replicates.

Properties of Flour Milled from the Heat- and Moisture-Treated KS-196 Wheat

Wet gluten yields isolated from the flours of treated (100°C/15% MC/8 min) and untreated KS-196 wheat were 29.9 and 33.4%, respectively, whereas dry gluten yields were 10.8 and 12.3%. The reduction in gluten yield was indicative of some damage to the gluten in the heat- and moisture-treated wheat. Flour from the treated wheat gave a mixogram (Fig. 3) with increased mixing time (5.5 min vs. 4 min for control) and increased stability to overmixing. These parameters confirm that the gluten had been affected. Excessive heat- and moisture-treatment of the KS-196 wheat at 13–19% MC for >8 min at 100°C yielded flour that showed an essentially flat mixograph curve (not shown).

Finney et al (1962) harvested wheats at high moisture levels and studied the effect of drying temperature (forced convection oven) on the baking properties of the flours. Those workers found that drying wheat >70°C caused gluten damage when wheat MC was between 15 and 27%. In the present investigation, the final temperature of the KS-196 wheat heated at an initial MC of 15% for 8 min at 100°C was 73°C (Table II), which was slightly above the critical temperature of 70°C cited by Finney et al (1962). Those workers found that the mixing time of a flour dough always increased when its gluten was heat-damaged.

Water absorptions of noodle doughs are typically 30–35%. The optimum absorption of noodle dough (Oh et al 1986) made with flour from the treated KS-196 wheat was 2% less than that of the dough made with flour from the untreated wheat. Oh et al (1985) and Baik et al (1995) showed that decreased water absorption

resulted in decreased browning of noodles, possibly because of a less compact noodle structure or reduced enzymic oxidation. Perhaps heat- and moisture-treatment of wheat at 100°C can improve raw noodle color (see below) not only by inhibiting PPO, but also by reducing flour absorption during noodle making.

Color of Noodle Dough Made from Heat- and Moisture-treated KS-196 Wheat

The changes in color of white and yellow alkaline noodle doughs stored for up to 24 hr at room temperature are shown in Figures 4–6. The color changes for raw noodle doughs stored for up to seven days at 5°C are not shown because they were similar to those observed near 25°C. To avoid differences in brightness caused by varying water absorption, all wheat flours were made into noodle doughs at the same absorption of 34%. Visual differences in brightness are generally ascertained when L^* values differ by 0.5 units.

Brightness (L^*) values decreased continuously with time at room temperature for white and yellow alkaline noodle doughs made with the flours from both untreated and heat- and moisture-

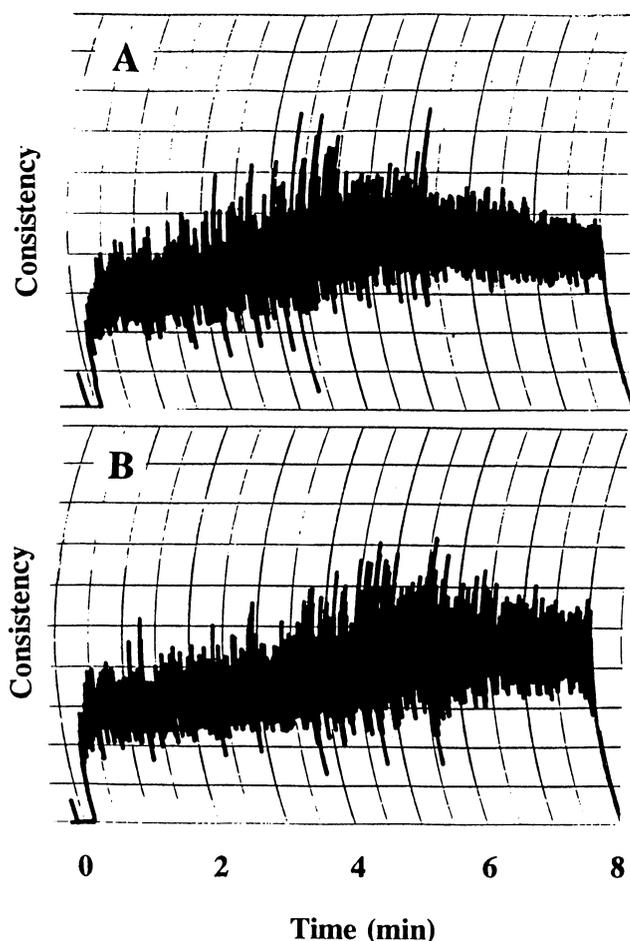


Fig. 3. Mixograms at 63% absorption of flours milled from an untreated hard white winter wheat (A) and a heat- and moisture-treated (100°C/15% MC/8 min) hard white winter wheat (B).

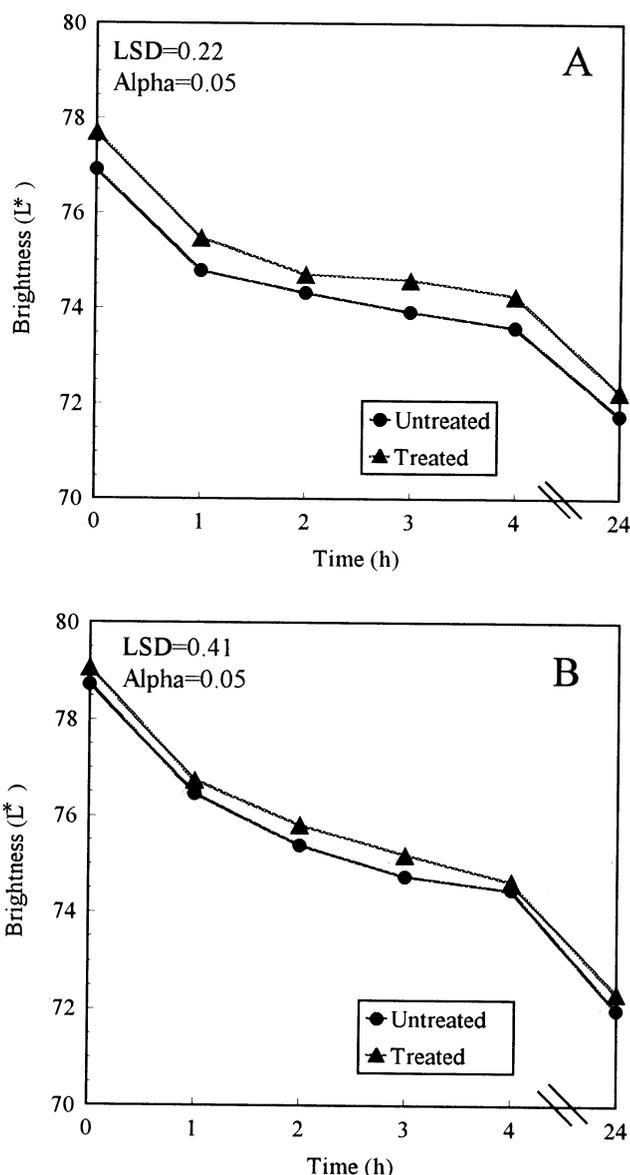


Fig. 4. Brightness (L^*) of white (A) and yellow (B) alkaline noodle doughs stored at 25°C. The flours were from a heat- and moisture-treated (100°C/15% MC/8 min) hard white winter wheat and an untreated blank. LSD = least significant difference.

treated wheat (Fig. 4). The decrease in brightness with time was probably caused by PPO. Kruger et al 1992 and Baik et al 1995 showed that the rate of change of brightness was correlated with different levels of PPO activity and with various phenolic compounds in dough. The role of PO in browning of noodles may be minor because of the lack of H_2O_2 in wheat dough (Lillard 1980).

The white noodle dough from the heat- and moisture-treated HWW wheat stored at 25°C was brighter than the untreated sample (Fig. 4). In contrast to white noodle doughs, yellow alkaline noodle doughs showed little or no improvement in brightness during storage (Fig. 4B), probably because PPO activity was low at pH 10.5 (Lamkin et al 1981). Baik et al (1995) did find that brightness of Cantonese noodle doughs correlated with PPO in flour, but the change in brightness was less for stored Cantonese noodles than for stored Udon noodles. Visual differences in brightness are generally ascertained when L^* values differ by 0.5 units.

Figure 5A illustrates the changes with time in yellowness (b^*) of white doughs made from the flours of the untreated and the heat- and moisture-treated KS-196 wheat. No change in yellowness was observed in yellow alkaline noodles made from the treated HWW wheat (Fig. 5B). The yellow hue of a white noodle

dough was less intense (b^* value of 14–18) than the hue of a yellow alkaline noodle dough (b^* value of 19–21). Browning of white noodle doughs made from untreated wheat apparently masked their slight yellowness (Fig. 5A). Surprisingly, the yellowness of white and yellow alkaline noodle doughs stored at 5°C for one to seven days was unaltered by heat- and moisture-treatment of the HWW wheat (data not shown). The reason for that observation is not clear. The redness (a^*) values increased with time and showed slight or insignificant differences in white and yellow alkaline noodle doughs for both treatments (Fig. 6A and B).

White noodle doughs made from pearled HWW wheat that was subsequently heat- and moisture-treated gave noodle doughs that were brighter in color than those made from wheat that was pearled only (Fig. 7). The noodle doughs made from the heat-treated pearled wheat were especially bright after storage for 1–3 hr at 25°C.

Quality of Cooked Noodles Made from Heat- and Moisture Treated KS-196 Wheat

No effect was observed on the cooking characteristics of raw noodles made from the flour of heat- and moisture-treated HWW

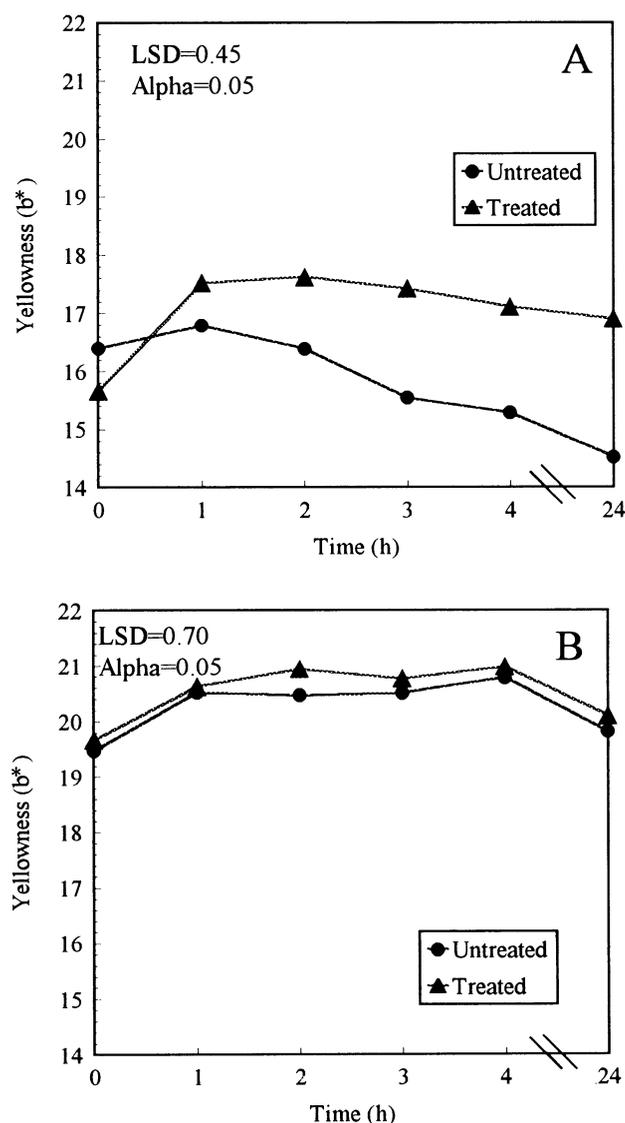


Fig. 5. Yellowness (b^*) of white (A) and yellow (B) alkaline noodle doughs stored at 25°C. The flours were from a heat- and moisture-treated (100°C/15% MC/8 min) hard white winter wheat and an untreated blank. LSD = least significant difference.

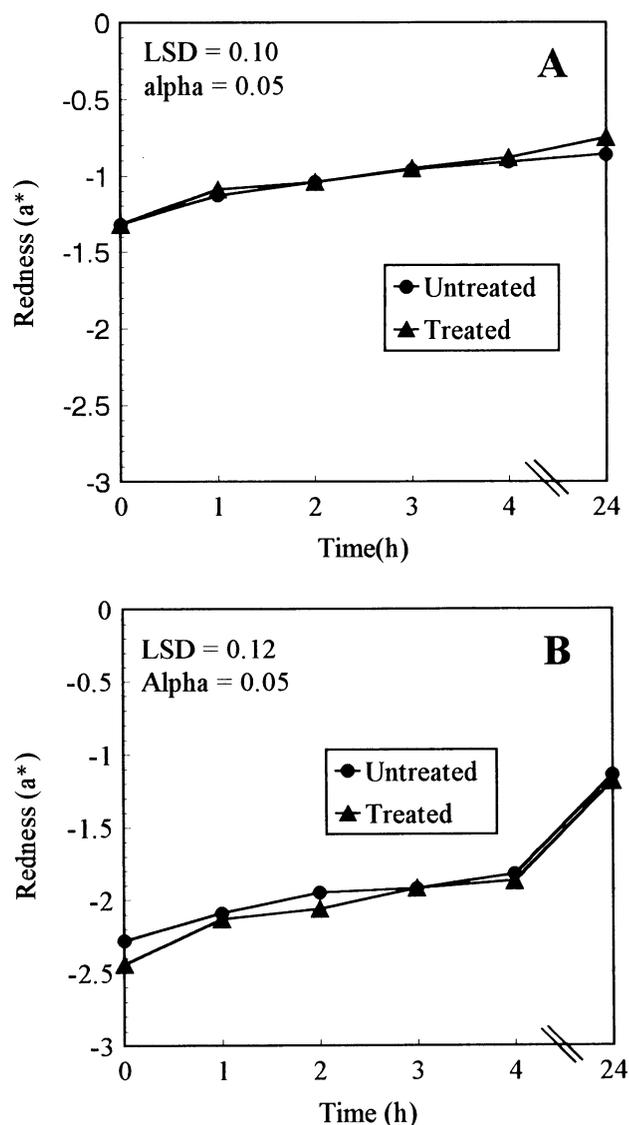


Fig. 6. Redness (a^*) of white (A) and yellow (B) alkaline noodle doughs stored at 25°C. The flours were from a heat- and moisture-treated (100°C/15% MC/8 min) hard white winter wheat and an untreated blank. LSD = least significant difference.

wheat (Table IV). As expected from the results of Moss et al (1986), yellow alkaline noodles were observed to have a 50% longer cooking time than white noodles (Table IV). The cooking losses of yellow alkaline noodles were twice as high as those of white noodles, and the cooked weight of yellow alkaline noodles also was low compared to that of white noodles. The components lost from yellow alkaline noodles have not been identified.

Texture profile analysis parameters are given in Table V for the cooked white and yellow alkaline noodles made from flours of the untreated and the heat- and moisture-treated KS-196 wheat. The firmness values indicate that noodles made with the flour from treated wheat were somewhat softer in bite than those made with flour from the untreated wheat. The importance of protein quality and quantity to the cooking quality of pasta and noodles

has been emphasized by previous investigators (Dexter and Matsuo 1980, Oh et al 1985, Baik et al 1994b). The reduced firmness and elasticity of noodles from heat- and moisture-treated wheat can be attributed to the partial heat damage to the gluten. Stickiness, cohesiveness, and recovery (%) of noodles were not affected by heat and moisture treatment of the wheat.

Inhibition of Maillard Browning in a Noodle Dough

When 0.1% (based on flour) aminoguanidine bicarbonate was mixed in a white noodle dough made with flour from heat- and moisture-treated HWW wheat, the brightness (L^*) improved significantly at all storage periods (Fig. 8). Those results indicate that Maillard intermediates were produced during the heat and moisture treatment, and that those intermediates probably partially nullified the improvement in dough color caused by destruction of PPO. Aminoguanidine is a nontoxic substance (Brownlee et al 1986) but is not an approved food additive.

PPO Inhibitors in Noodle Dough

Calcium chloride, kojic acid, and 4-hexylresorcinol have been reported to inhibit PPO (Bolin and Huxsoll 1989, Chen et al 1991, McEvily et al 1991). Calcium chloride had no effect on enzymic browning of raw salt noodles, whereas kojic acid and 4-hexylresorcinol imparted respectively undesirable yellow and brown colors to noodle dough (data not shown). Baik et al (1995) reported that 4-hexylresorcinol at 50 ppm (based on flour) did not improve the brightness of white or instant fried noodle doughs.

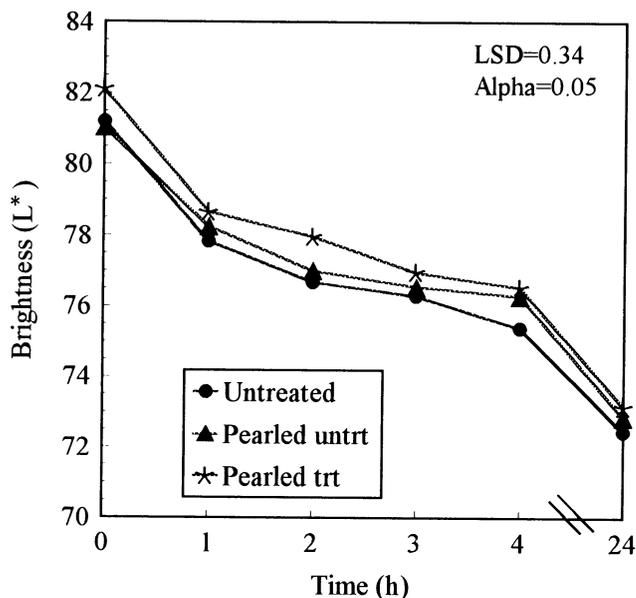


Fig. 7. Brightness (L^*) of white noodle doughs stored at 25°C. The flours were from a pearled hard white winter wheat (HWW), a pearled HWW wheat followed by heat and moisture treatment (100°C/15% MC/8 min) and an untreated HWW wheat. LSD = least significant difference.

TABLE IV
Cooking Characteristics of Salt and Alkaline Noodles Made from Untreated and Heat- and Moisture-Treated Hard White Winter (HWW) Wheat^a

Noodle	Flour from HWW Wheat	Cooking Time (min)	Cooking Loss (%)	Cooked Weight Gain (%)
Salt	Untreated	4.0 ± 0.05	5.7 ± 0.3	100 ± 0.5
Salt	Treated	4.0 ± 0.08	5.7 ± 0.5	99 ± 0.7
Alkaline	Untreated	6.0 ± 0.03	12.1 ± 0.5	76 ± 0.4
Alkaline	Treated	6.0 ± 0.06	12.6 ± 0.7	75 ± 0.5

^a Values represent an average of three measurements.

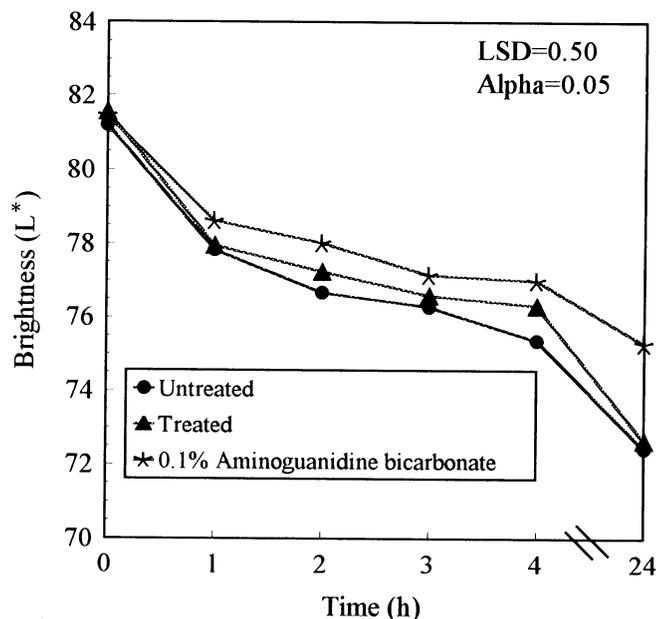


Fig. 8. Brightness (L^*) of white noodle dough containing aminoguanidine bicarbonate (0.1% of flour weight) and stored at 25°C. The flours were from a heat- and moisture-treated (100°C/15% MC/8 min) hard white winter wheat and an untreated blank. LSD = least significant difference.

TABLE V
Texture Profile Analysis of Cooked White and Yellow Alkaline Noodles Made from Untreated and Heat- and Moisture-Treated Hard White Winter (HWW) Wheat^a

Noodle	Flour from HWW Wheat	Firmness (N)			Stickiness (N-Sec)	Recovery (%)
		First Stroke	Second Stroke	Cohesiveness		
Salt	Untreated	3.65 a	3.35 a	0.56 a	0.20 a	88.2 a
Salt	Treated	3.31 b	3.15 b	0.55 a	0.16 a	87.9 a
Alkaline	Untreated	4.48 c	3.88 c	0.59 b	0.23 b	89.6 b
Alkaline	Treated	3.82 d	3.45 d	0.59 b	0.21 b	88.9 b

^a Values represent an average of eight measurements. Values in a column with different letters are significantly different at $P = 0.05$.

CONCLUSIONS

Flour with up to 50% reduced PPO level and with limited damage to its gluten can be milled from wheat that has been tempered briefly and then heated and cooled rapidly by conduction and convection. Alternatively, pearled wheat kernels can be heat- and moisture-treated and then milled to obtain vital flour with 75% reduced PPO. Noodle doughs made with the flour from heat- and moisture-treated wheat have improved brightness, but still brown upon storage, partly because of the Maillard reaction.

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LITERATURE CITED

- AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. The Association: St. Paul, MN.
- ABROL, Y. P., and UPRETY, D. C. 1970. Studies on darkening of whole wheat meal dough. *Curr. Sci.* 40:21.
- BAIK, B. K., CZUCHAJOWSKA, Z., and POMERANZ, Y. 1995. Discoloration of dough for Oriental noodles. *Cereal Chem.* 72:198.
- BAIK, B. K., CZUCHAJOWSKA, Z., and POMERANZ, Y. 1994a. Comparison of polyphenol oxidase activities in wheats and flours from Australian and U. S. cultivars. *J. Cereal Sci.* 19:291.
- BAIK, B. K., CZUCHAJOWSKA, Z., and POMERANZ, Y. 1994b. Role and contribution of starch and protein contents and quality to texture profile analysis of Oriental noodles. *Cereal Chem.* 71:315.
- BLOKSMA, A. H., and BUSHUK, W. 1988. Rheology and chemistry of dough. Page 131 in *Wheat: Chemistry and Technology*, Vol. II. Y. P. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
- BOOKWALTER, G. N. 1985. Process for stabilizing whole cereal grains. U.S. patent. 4,544,564.
- BOLIN, H. R., and HUXOLL, C. C. 1989. Storage stability of minimally processed fruit. *J. Food Proc. Preserv.* 13:281.
- BROWNLEE, M., VLASSARA, H., KOONEY, A., ULRICH, P., and CERAMI, A. 1986. Aminoguanidine prevents diabetes-induced arterial cell protein cross-linking. *Science* 232:1629.
- CHEN, J. S., CHEN-I-WEI, and MARSHALL, M. R. 1991. Inhibition of kojic acid on polyphenol oxidase. *J. Agric. Food Chem.* 39:1897.
- 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.* 28:899.
- EDWARDS, R. A., ROBS, A. S., MARES, D. J., ALLICIN, F. W., and TOMKINSON, J. D. 1989. Enzymes from rain-damaged and laboratory germinated wheat. I. Effects on product quality. *J. Cereal Sci.* 10:157.
- FAULKNER, D. 1989. The novel noodle. *Can. Packaging* 42(5):47.
- FEILLET, P., JEANJEAN, M. F., KOBREHEL, K., and LAIGNELET, B. 1974. Le brunissement des pâtes alimentaires. *Comite Internationale des Industries Cerealières*: Athens.
- FINNEY, K. F., SHORGEN, M. D., HOSENEY, R. C., BOLTE, L. C., and HEYNE, E. G. 1962. Chemical, physical, and baking properties of pre-ripe wheat dried at varying temperatures. *Agron. J.* 54:244.
- HATCHER, D. W., and KRUGER, J. E. 1993. Distribution of polyphenol oxidase in flour mill streams of Canadian common wheat classes milled to three extraction rates. *Cereal Chem.* 70:51.
- HELTVED, F. 1984. Spectrofluorimetric assays for hydrolytic activity in germinating wheat. *J. Cereal Sci.* 2:179.
- HIRSCH, J., PETROKOVA, E., and FEATHER, M. S. 1992. The reaction of some dicarbonyl sugars with aminoguanidine. *Carbohydr. Res.* 232:125.
- HUNTER, R. S., and HAROLD, R. W. 1987. *The Measurement of Appearance*. 2nd ed. John Wiley and Sons: New York.
- ICC. 1988. Standard Method 137. *Intl. Assoc. Cereal Sci. Technol.*: Vienna.
- JONES, B. L., and MARINAC, L. A. 1991. Partial purification and characterization of two barley fractions that inhibit malt endoproteins. *J. Am. Soc. Brewing Chem.* 49:158.
- KIM, W. S., and SEIB, P. A. 1993. Flour lipids appear to restrict swelling of starch in Japanese salt noodle. *Cereal Chem.* 70:367.
- KIM, W. S., SEIB, P. A., and CHUNG, O. K. 1991. Origin of color in vital wheat gluten. *Cereal Foods World* 36:954.
- KOBREHEL, K., LAIGNELET, B., and FEILLET, P. 1972. Study of some biochemical factors of macaroni brownness. (Abstr.) *Cereal Sci.* Today 17:105.
- KRUGER, J. E., MATSUO, R. R., and PRESTON, K. 1992. A comparison of methods for the prediction of Cantonese noodle color. *Can. J. Plant Sci.* 72:1021.
- LAMKIN, W. M., MILLER, B. S., NELSON, S. W., TAYLOR, D. D., and LEE, M. S. 1981. Polyphenol oxidase activities of hard red winter, soft red winter, hard red spring, white common club and durum wheat cultivars. *Cereal Chem.* 58:27.
- LILLARD, D. 1980. Use of dough spread test to measure the rheological effects of ascorbic acid. PhD dissertation. Kansas State University: Manhattan.
- LUO, Y., and PATTERSON, M. E. 1994. Enhanced control of enzymic browning in apple slices. Abstr. 125 in: Abstracts of 208th National Meeting of the Am. Chem. Soc., Div. Ag and Food Chem. ACS: Washington, DC.
- LUPANO, C. E., and ANON, M. C. 1987. Denaturation of wheat endosperm proteins during drying. *Cereal Chem.* 64:437.
- MARSH, D. R., and GALLIARD, T. 1986. Measurement of PPO activity in wheat milling fractions. *J. Cereal Sci.* 4:241.
- MAYER, A. M., and HAREL, E. 1979. Review: Polyphenol oxidases in plants. *Phytochemistry* 18:193.
- McEVILY, A. J., IYENGAR, R., and OTWELL, S. 1991. Sulfite alternative prevents shrimp melanosis. *Food Technol.* 45:80.
- MILATOVIC, L. 1985. The use of L-ascorbic acid in improving the quality of pasta. *Int. J. Vit. Nutr. Res.* 27(Suppl.):345.
- MOSS, H. J., MISKELLY, D. M., and MOSS, R. 1986. The effect of alkaline conditions on the properties of wheat flour dough and Cantonese-style noodles. *J. Cereal Sci.* 4:261.
- MOSS, R. 1977. The autoradiographic technique for the location of conditioning water in wheat at the cellular level. *J. Sci. Food Agric.* 28:23.
- MOSS, H. J. 1971. The quality of noodles prepared from the flour of some Australian wheats. *Aust. J. Exp. Agric. Anim. Husb.* 11:243.
- OH, N. H., SEIB, P. A., WARD, A. B., and DEYOE, C. W. 1985. Noodles. IV. Influence of flour protein, extraction rate, particle size, and starch damage on the quality characteristics of dry noodles. *Cereal Chem.* 62:441.
- OH, N. H., SEIB, P. A., FINNEY, K. F., and POMERANZ, Y. 1986. Noodles. V. Determination of optimum water absorption of flour to prepare Oriental noodles. *Cereal Chem.* 63:96.
- REED, G. 1975. Oxidoreductases. Page 216 in: *Enzymes in Food Processing*. Academic Press: New York.
- RHO, K. L., SEIB, P. A., CHUNG, O. K., and DEYOE, C. W. 1988. Noodles. VII. Investigating the surface firmness of cooked Oriental dry noodles made from hard red winter wheat flours. *Cereal Chem.* 65:320.
- SAS. 1986. *User's Guide: Statistics*. SAS Institute Inc.: Cary, NC.
- SAWAMURA, M., TAKEMOTO, K., MATSUZAKI, Y., UKEDA, M., and KUSUNOSE, H. 1994. Identification of two degradation products from aqueous dehydroascorbic acid. *J. Agric. Food Chem.* 42:1200.
- SHIN, D. B., and FEATHER, M. S. 1990. The degradation of L-ascorbic acid in neutral solutions containing oxygen. *J. Carbohydr. Chem.* 9:461.
- TIKOO, S., SINGH, J. P., ABROL, Y. P., and SACHAR, R. C. 1973. Studies on polyphenol oxidase in wheat grains. *Cereal Chem.* 50:520.
- TOEPFER, E. W., POLANSKY, M. M., EHEART, J. F., SLOVER, H. T., MORRIS, E. R., HEPBURN, F. N., and QUACKENBUSH, F. W. 1972. Nutrient composition of selected wheats and wheat products. XI. Summary. *Cereal Chem.* 49:173.
- VAMOS-VIGYAZO, L. 1981. Polyphenol oxidase and peroxidase in fruits and vegetables. *CRC Crit. Rev. Food Sci. Nutr.* 15:49.
- WALSH, D. E., YOUNGS, V. L., and GILLES, K. A. 1970. Inhibition of durum wheat lipoxidase with L-ascorbic acid. *Cereal Chem.* 47:119.
- WHITAKER, J. R. 1985. Mechanisms of oxidoreductases important in food component modification. Page 121 in: *Chemical Changes in Food During Processing*. T. Richardson and J. W. Finely, eds. AVI: Westport, CT.
- WILLIAMS, K. T., and BEVENUE, A. 1951. The chromatographic examination of sugars in wheat flour. *Cereal Chem.* 28:416.
- ZAMPONI, R. A., GINER, S. A., LUPANO, C. E., and ANON, M. C. 1990. Effect of heat on thermal and functional properties of wheat. *J. Cereal Sci.* 12:279.

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