# Milling, Rheological, and End-Use Quality of Chinese and Canadian Spring Wheat Cultivars

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ABSTRACT

Ten spring wheat cultivars from the People's Republic of China and four spring wheat cultivars from western Canada were compared by using a wide range of milling, rheological, baked bread, and steamed bread properties. Significant cultivar differences were observed for all measured traits. Whether assessed by Canadian or Chinese standards, overall performance or ranking of the cultivars was similar, indicating that the same factors determine quality for baked or steamed bread. Quality parameters were examined for their effect on steamed bread and correlation and regression coefficients are presented. Protein content and gluten strength were the most important factors determining steamed bread quality. Stepwise multiple regression of steamed bread parameters on quality parameters as independent variables indicated that from 27 to 95% of the variability in steamed bread quality can be explained by protein content and dough mixing strength parameters. Preliminary evidence suggests that the electrophoretic determination of high molecular weight glutenin and gliadin proteins might be used to predict steamed bread quality.

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Historically, Chinese wheat-breeding programs have emphasized improvement in grain yield, disease resistance, and time to maturity (Pomeranz 1977). After substantial progress in these areas, the research emphasis has gradually shifted to the improvement of wheat quality. Current wheat-breeding objectives in the Western Plateau region of the People's Republic of China include the development of cultivars with high protein content (>13.0%, 14% moisture basis) that produce satisfactory steamed bread. Although Kosmolak and Dyck (1981) and Preston et al (1986) presented some information, generally little is known about the milling, rheological, and baking quality of Chinese wheat cultivars according to Canadian standards or, conversely, about the suitability of Canadian cultivars for Chinese consumption. Since Canadian wheats are internationally recognized for their high-quality milling and baking properties, one objective in this study was to compare the quality of selected Chinese wheats with that of popular Canadian cultivars when grown and analyzed under identical conditions. Identified differences could be important to Chinese plant breeders in the development of new high-quality wheat cultivars. Another objective was to examine Chinese quality requirements for steamed bread to enable the development of North American wheat cultivars more suitable for Chinese end use. This is an important marketing concern for the North American grains industry because the People's Republic of China has been, and continues to be, a major importer of North American wheat.

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## MATERIALS AND METHODS

### Samples

Fourteen wheat cultivars (*Triticum aestivum* L.) were used in this study. Ten cultivars were obtained from the People's Republic of China. Ba Mai 18, Jin Sha Jiang 3, Jing 2148, Mian Yang 11, Plateau 182, Plateau 338, Plateau 506, Plateau 614, Qing Chun 5, and Qing Nong 524 were selected to cover the complete range of wheat types grown in northwestern China and some types grown in southwestern China (i.e., Mian Yang 11 and Ba Mai 18). Although all of the Chinese cultivars are multipurpose wheats, steamed bread production is their major end use. The Canadian cultivars Columbus and Katepwa were selected as typical of the Canada Western Red Spring class, whereas HY320 and Oslo were representative of the high-yielding, medium-strength wheats of the Canada Prairie Spring class. Canada Western Red Spring wheat is typically used for pan bread, whereas Canada Prairie Spring wheat is intended for flat breads and noodles. All cultivars had red kernel color except for Plateau 338, Plateau 506, and Plateau 614, which had white kernels.

**Methods**

Cultivars were planted in a randomized complete block design at two locations—Glenlea, Manitoba, and Swift Current, Saskatchewan—in 1987. Seed produced at each location was bulked and used as replicates.

Test weight was determined using a Schopper chondrometer with a 0.5-L container. Thousand-kernel weight was determined by electronically counting 20 g of whole seeds. Kernel hardness was determined by the time to grind 5 g of wheat on a Brabender SM1 mill (Kosmolak 1978). Protein contents (N × 5.7, 14% moisture basis) of whole meal and flours were determined by Kjeldahl according to AACC method 46-12 (1983). Flour yields were determined on a Brabender Quadramat Junior mill and a Buhler pneumatic laboratory mill after tempering wheat samples to 15.5 and 16.5% moisture, respectively. Mixograms were produced on a 10-g electronic recording mixograph (Voisey et al 1966) using a constant absorption of 60%. The rapid amylograph method was performed according to Marchylo and Kosmolak (1979). Ash content, damaged starch content, falling number values, farinograms, and sodium dodecyl sulfate (SDS)-sedimentation values were determined according to AACC approved methods (1983) 08-01, 76-30A, 56-81B, 54-21, and 56-70, respectively.

AACC straight-dough bread volumes were determined according to method 10-09 (1983), with baking absorption equal to 3% less than farinograph absorption.

Chinese steamed bread was processed and evaluated by methodology developed at Agriculture Canada in consultation with visiting scientists from the People's Republic of China. The method was designed to simulate authentic steamed bread and was based on the method of Preston et al (1986). Steamed bread was prepared by mixing 100 g of flour (14% moisture basis), 50 ml of water, 2 g of compressed yeast, 1 g of salt, and 1 g of sucrose for 6.5 min at 70 rpm and 30°C in a GRL mixer. The dough was punched seven times, rounded by hand, and rested 60 min at 30°C, 85% rh. The doughs were steamed for 12 min in a bamboo steamer that was immersed in a container of boiling water to a depth of 10 cm. Doughs were steamed directly on baking paper that rested on cotton cloth covering the steaming tray. After removal from the steamer, the bread was cooled for 1 hr. Steamed bread volume, height, and width were measured on each loaf, which was then cut in half. One-half of the loaf was used for color measurement determined on a Hunter Labscan II Spectrocolorimeter (Hunter Associates Laboratory, Reston, VA). Each steamed bread loaf was scanned in triplicate, and the

**TABLE I**
**Milling and Analytical Properties of Chinese and Canadian Wheat Cultivars[a]**

| Cultivar | TW | TKW | WPROT | GRT | FLY-BR | FLP-BR | FLY-BU | FLP-BU | FASH | SD | AMYL | FN | SDS-SED |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canadian | | | | | | | | | | | | | |
| Columbus | 79.3 a[b] | 34.5 de | 15.8 a | 0.55 ef | 61.9 a | 15.5 a | 73.9 ab | 15.0 ab | 0.42 e | 16.0 a | 1,190 abc | 423 ab | 85 ab |
| Katepwa | 77.5 abc | 32.1 e | 14.9 ab | 0.56 def | 62.1 a | 14.8 abc | 73.4 ab | 14.3 abc | 0.43 de | 18.0 a | 1,275 ab | 459 a | 78 abc |
| HY320 | 78.3 ab | 37.7 cde | 13.1 def | 0.79 bcde | 53.0 bcd | 12.5 fgh | 69.6 abc | 12.3 fgh | 0.47 cd | 8.0 def | 1,400 a | 466 a | 89 a |
| Oslo | 77.5 abc | 39.1 bcd | 14.2 bcd | 0.64 cdef | 60.9 ab | 14.2 bcde | 74.6 a | 13.9 bcd | 0.41 e | 10.0 bcde | 1,160 bcd | 428 ab | 93 a |
| Chinese | | | | | | | | | | | | | |
| Ba Mai 18 | 72.7 def | 38.0 bcde | 13.7 bcdef | 0.84 bc | 45.9 de | 13.5 defg | 62.9 ef | 12.6 efgh | 0.44 de | 5.8 ef | 805 ef | 270 cde | 64 cd |
| Jin Sha Jiang 3 | 75.0 abcde | 52.5 a | 15.9 a | 0.54 f | 57.9 ab | 15.8 a | 72.3 abc | 15.4 a | 0.49 bc | 15.5 ab | 955 cde | 392 abc | 91 a |
| Jing 2148 | 74.3 bcde | 41.1 bc | 13.8 bcde | 0.79 bcd | 49.4 cde | 13.1 efgh | 67.2 cde | 12.8 efg | 0.41 e | 6.5 ef | 1,135 bcd | 327 bcde | 79 abc |
| Mian Yang 11 | 73.1 cdef | 36.9 cde | 14.2 bcd | 0.87 bc | 43.5 ef | 13.8 cdef | 59.6 f | 13.1 def | 0.44 de | 5.0 ef | 960 cde | 297 cde | 86 ab |
| Plateau 182 | 72.8 cdef | 39.3 bcd | 14.6 bc | 0.69 cdef | 57.0 abc | 14.6 abcd | 72.0 abc | 14.1 bcd | 0.47 cd | 14.0 abc | 930 def | 392 abc | 71 bcd |
| Plateau 338 | 70.6 ef | 44.4 b | 12.7 ef | 0.85 bc | 58.8 ab | 12.1 h | 72.4 abc | 11.9 fgh | 0.52 b | 14.0 abc | 1,210 ab | 462 a | 67 cd |
| Plateau 506 | 75.3 abcde | 42.2 bc | 14.4 bc | 0.68 cdef | 58.4 ab | 14.4 bcd | 72.9 ab | 13.7 cde | 0.44 de | 12.5 abcd | 795 ef | 343 abcd | 59 d |
| Plateau 614 | 74.3 bcde | 42.6 bc | 12.5 f | 0.99 b | 46.2 de | 13.0 efgh | 68.7 bcd | 12.6 efgh | 0.42 de | 8.2 cdef | 960 cde | 358 abcd | 71 bcd |
| Qing Chun 5 | 76.3 abcd | 39.4 bcd | 13.6 cdef | 0.98 b | 41.4 ef | 12.2 gh | 63.6 def | 11.7 gh | 0.41 e | 3.0 f | 780 ef | 236 de | 64 cd |
| Qing Nong 524 | 69.4 f | 41.0 bc | 13.4 cdef | 1.59 a | 37.3 f | 11.9 h | 58.9 f | 11.6 h | 0.58 a | 3.5 f | 715 f | 217 e | 65 cd |

[a] Abbreviations: TW = test weight (kg/hl); TKW = thousand kernel weight (g); WPROT = wheat protein (%, 14% mb); GRT = grinding time (min); FLY-BR = Brabender mill flour yield (%, 14% mb); FLP-BR = Brabender mill flour protein (%, 14% mb); FLY-BU = Buhler mill flour yield (%, 14% mb); FLP-BU = Buhler mill flour protein (%, 14% mb); FASH = flour ash (%, 14% mb); SD = starch damage (%); AMYL = amylograph peak height (BU); FN = falling number (sec); SDS-SED = SDS-sedimentation value ($cm^3$).

[b] Values within columns followed by the same letter are not significantly different at $P = 0.05$.

**TABLE II**
**Rheological and End-Use Properties of Chinese and Canadian Wheat Cultivars[a]**

| | Mixograph | | Farinograph | | | | | Steamed Bread | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | MDT | PH | ABS | DT | STAB | MTI | LV | VOL | HGT | WD | COL-*L* | COL-*a* | COL-*b* | Score |
| Canadian | | | | | | | | | | | | | | |
| Columbus | 2.8 ab[b] | 65 a | 63.0 a | 8.0 a | 19.8 a | 10 f | 815 ab | 434 bc | 4.5 ab | 12.3 abcde | 79.1 ab | 0.8 ab | 21.2 c | 9.5 ab |
| Katepwa | 2.6 abc | 56 b | 60.8 ab | 6.0 abc | 19.6 a | 25 ef | 825 ab | 485 abc | 4.9 a | 12.2 cde | 82.6 a | 0.7 abc | 21.5 bc | 10.0 a |
| HY320 | 2.7 abc | 53 bcde | 56.1 cde | 5.3 bcd | 9.8 b | 35 def | 688 cde | 376 c | 3.7 b | 12.3 bcde | 79.3 ab | 0.9 a | 21.2 c | 7.5 e |
| Oslo | 3.3 a | 56 b | 58.5 bcde | 7.3 ab | 12.3 ab | 30 ef | 785 ab | 524 ab | 4.3 ab | 13.1 abc | 80.0 ab | 0.8 ab | 22.9 ab | 8.5 cd |
| Chinese | | | | | | | | | | | | | | |
| Ba Mai 18 | 1.0 g | 55 bc | 58.5 bcde | 2.5 ef | 2.0 b | 105 ab | 513 f | 453 abc | 4.9 a | 12.3 bcde | 77.7 b | 0.8 ab | 20.8 cd | 5.0 g |
| Jin Sha Jiang 3 | 2.5 abcd | 60 ab | 63.0 a | 7.0 ab | 11.5 ab | 20 ef | 870 a | 449 abc | 4.7 a | 12.0 de | 80.3 ab | 0.8 ab | 19.4 def | 10.0 a |
| Jing 2148 | 1.7 defg | 53 bcde | 57.4 bcde | 2.6 ef | 4.4 b | 80 abc | 595 ef | 446 abc | 5.0 a | 11.9 e | 78.9 b | 0.6 abc | 17.9 f | 9.0 bc |
| Mian Yang 11 | 2.4 bcde | 53 bcde | 58.6 bcde | 4.3 cdef | 7.8 b | 35 def | 640 e | 455 abc | 4.9 a | 12.2 cde | 78.3 b | 0.5 abc | 17.9 f | 8.5 cd |
| Plateau 182 | 1.6 efg | 54 bcd | 59.4 abc | 4.6 cde | 6.5 b | 40 def | 820 ab | 439 bc | 4.3 ab | 12.7 abcde | 79.5 ab | 0.7 abc | 20.6 cd | 8.8 bc |
| Plateau 338 | 1.5 fg | 45 ef | 59.0 bcd | 2.9 ef | 4.3 b | 50 cde | 775 abc | 543 ab | 5.1 a | 12.9 abcde | 81.0 ab | 0.7 abc | 24.0 a | 6.3 f |
| Plateau 506 | 1.1 g | 53 bcde | 59.7 abc | 3.8 def | 3.3 b | 75 bc | 760 bcd | 581 a | 5.1 a | 13.3 a | 80.5 ab | 0.2 c | 18.9 ef | 7.8 de |
| Plateau 614 | 1.8 cdefg | 47 cdef | 56.8 bcde | 2.8 ef | 5.1 b | 65 cd | 670 de | 550 ab | 5.0 a | 13.2 ab | 79.6 ab | 0.6 abc | 20.3 cde | 7.3 e |
| Qing Chun 5 | 1.5 efg | 46 def | 54.8 e | 2.1 f | 3.3 b | 110 a | 593 ef | 491 abc | 4.5 a | 13.1 abc | 79.3 ab | 0.3 bc | 17.8 f | 7.0 e |
| Qing Nong 524 | 2.2 bcdef | 43 f | 55.3 de | 2.9 ef | 4.4 b | 75 bc | 660 e | 512 abc | 4.8 a | 13.0 abcd | 79.0 b | 0.9 a | 20.9 cd | 7.8 de |

[a] Abbreviations: MDT = mixograph development time (min); PH = mixograph peak height (mixograph units, 0–100); ABS = farinograph absorption (%); DT = farinograph development time (min); STAB = farinograph stability (min); MTI = farinograph mixing tolerance index (BU); LV = AACC straight-dough loaf volume ($cm^3$); VOL = steamed bread loaf volume ($cm^3$); HGT = steamed bread height (cm); WD = steamed bread width (cm); COL-*L*, *a*, *b* = steamed bread color indicators *L*, *a*, and *b*, respectively.

[b] Values within columns with the same letter are not significantly different at $P = 0.05$.

mean values were reported. With a modification of the scoring method of Preston et al (1986), the other half of the loaf was scored for visual appearance, physical characteristics, and taste with a scoring range of 1 (poor) to 10 (excellent). High scores were given to steamed bread with high volume, smooth round surface, firm and fine crumb texture, and a light, white color.

SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and polyacrylamide gel electrophoresis (PAGE) were performed on an LKB 2001 vertical electrophoresis apparatus. Total gel size was 16 × 16 × 0.15 cm for both gels. Proteins were extracted from nine individual kernels for each electrophoresis technique. Gels were photographed using Kodak Technical Pan film 2415 with an orange filter.

Total kernel protein was separated by SDS-PAGE using 10% polyacrylamide gels as described previously (Payne et al 1980, Lukow et al 1989) with minor modifications. Protein extracts contained 8% (v/v) 2-mercaptoethanol and 12-$\mu$l samples were loaded on to 20-slot gels. Gels were subjected to electrophoresis for 20 hr at 15°C at a current of 20 mA per gel for the first 0.75 hr, followed by 16.25 hr at 5 mA and a final 3 hr at 8 mA. To determine the presence or absence of glutenin subunit 2* in cultivars containing subunits 2+12, a further analysis by SDS-PAGE using 5% polyacrylamide gels was performed (Lukow et al 1989). The numbering system for the high molecular weight (HMW) glutenin subunits was as used previously (Lukow et al 1989).

To separate the gliadin proteins, kernels were extracted with 70% (v/v) ethanol (3.3 $\mu$l per milligram of grain) for up to 3 hr at room temperature with occasional vortex mixing. The supernatant was mixed with 85% of its volume of 60% (v/v) glycerol and 0.05% (w/v) pyronin Y and centrifuged at 12,700 × *g* for 2 min. Supernatant (5 $\mu$l) was loaded onto 10-slot gels. The gels consisted of 6% (w/v) acrylamide, 0.3% *N,N'*-methylenebisacrylamide, 0.02% (w/v) ascorbic acid, 0.0025% (w/v) ferrous sulfate, and 0.25% (w/v) aluminum lactate adjusted to pH 3.1 with lactic acid. Gels were polymerized with 0.004% (v/v) hydrogen peroxide. Electrode buffer consisted of 0.25% (w/v) aluminum lactate adjusted to pH 3.1 with lactic acid. Gels were subjected to electrophoresis at 7°C, at a current of 25 mA per gel for 1.5-fold the time taken for the tracking dye, pyronin Y, to reach the gel base. Gels were stained in 9.5% (v/v) trichloroacetic acid (TCA) containing 0.05% (w/v) Coomassie Brilliant Blue R-250 and 5% (v/v) ethanol and destained in 10% (v/v) TCA. Relative mobilities (Rm) of protein bands were determined according to Bushuk and Zillman (1978) as modified by Huang and Morrison (1988).

**Statistical Analysis**

All statistics were performed using the Statistical Analysis System (SAS Institute Inc., Cary, NC). Data were analyzed using one-way analysis of variance and Duncan's multiple range test ($P = 0.05$). Correlation coefficents were generated among all variables. Stepwise multiple regression was used to generate regression equations for individual steamed bread parameters (dependent variable) using milling and baking quality parameters; a minimum 5% improvement in $R^2$ was required for parameter entry into the regression equations. The presence or absence of HMW glutenin subunits was correlated to steamed bread parameters by the use of the binary variables 1 and 0, respectively (Neter and Wasserman 1974).

## RESULTS AND DISCUSSION

Kernel and milling properties and flour composition for the Chinese and Canadian wheat cultivars are summarized in Table I, and their rheological and baking properties are presented in Table II.

**Properties Related to Canadian Quality Standards**

The Canadian wheat cultivars, Columbus and Katepwa, were characterized by high test weight, moderate 1,000-kernel weight, high protein content in whole meal and flour, hard kernels, low ash, moderate starch damage, high flour yields on Brabender and Buhler mills, strong rheological properties, and excellent breadmaking characteristics (Tables I and II). Falling number and amylograph values indicate that they are sound wheats with low $\alpha$-amylase activity.

The cultivar HY320 was characterized by significantly lower protein content of whole meal and flours than Columbus and Katepwa, with medium-hard kernels, high flour yields, and medium-strong rheological properties (Tables I and II). The cultivar Oslo had quality characteristics more similar to Columbus and Katepwa than to HY320 (Tables I and II). Cultivar variability was shown by the significant differences between Oslo and HY320 in whole meal and flour protein content, flour ash, starch damage value, amylograph value, and baking performance.

A wide range in biochemical and rheological properties was apparent in the Chinese cultivars (Tables I and II). The extremes in overall quality in terms of Canadian standards were illustrated by cultivars such as Jin Sha Jiang 3 and Qing Nong 524. Jin Sha Jiang 3 was fully equal or superior to Columbus or Katepwa in most of the measured quality parameters. Jin Sha Jiang 3 was not significantly different from Columbus or Katepwa in

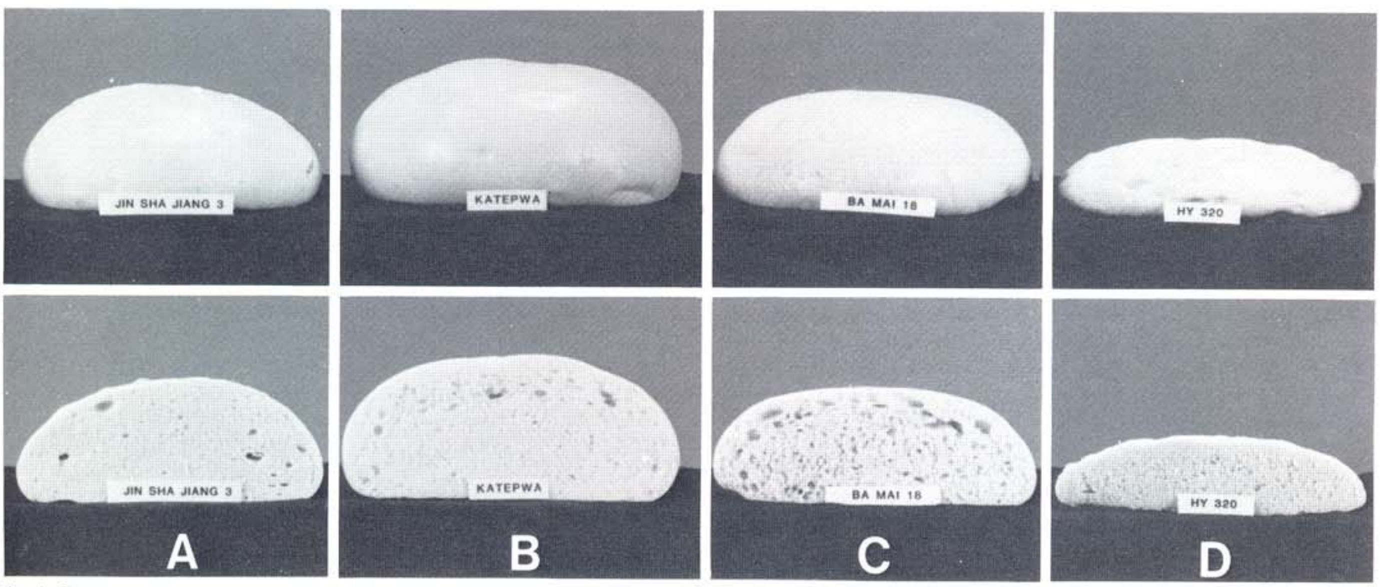


**Fig. 1.** Steamed bread produced from **A,** Jin Sha Jiang 3; **B,** Katepwa; **C,** Ba Mai 18; and **D,** HY320.

terms of test weight, 1,000-kernel weight, protein contents of whole meal and flours, kernel hardness, flour yield, starch damage content, amylograph value, falling number value, SDS-sedimentation value, mixograph development time and peak height, farinograph absorption, dough development time, stability and mixing tolerance index, and loaf volume. In contrast, Qing Nong 524 was characterized by quality properties normally associated with soft wheats. The low flour yield, whole meal and flour protein contents, weak dough-mixing properties, and low baked loaf volume of Qing Nong 524 would categorize this cultivar as a poor quality bread wheat by Canadian standards.

### Properties Related to Chinese Quality Standards

All wheat cultivars, with the exception of HY320, performed acceptably in steamed bread production (volume, height, and width) (Table II). Steamed bread quality appeared to be less sensitive to differences in flour quality than western baked bread, in agreement with Preston et al (1986). The Chinese cultivar Jin Sha Jiang 3 and the Canadian cultivars Columbus and Katepwa produced the highest steamed bread scores, whereas Ba Mai 18 had the poorest steamed bread score. A visual comparison of the steamed breads produced is given in Figure 1. There was little apparent variability in the *L* and *a* values of steamed bread color among cultivars; all cultivars produced light, grey-toned steamed bread. Cultivar differences were more apparent with the *b* value of steamed bread color. Yellow-toned crumb was higher in Plateau 338 and Oslo. Lower *b* values were noted in Jin Sha Jiang 3, Jing 2148, Mian Yang 11, Plateau 506, and Qing Chun 5.

### Influence of Quality Traits on Steamed Bread

Quality parameters were examined for their effect on steamed bread quality and correlation coefficients are given in Table III. Steamed bread score was positively correlated ($P = 0.01$) to whole meal and flour protein contents, farinograph development time, farinograph stability, and AACC loaf volume and was negatively correlated ($P = 0.01$) to mixing tolerance index. In addition, steamed bread score was positively correlated ($P = 0.05$) to the SDS-sedimentation value, mixograph development time and peak height, and farinograph absorption. In general, steamed bread score was primarily affected by factors that also influence North

**TABLE III**
**Correlation Coefficients for Technical Data and Steamed Bread Quality**

| | Quality Measurements of Steamed Bread | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter[a] | VOL | HGT | WD | COL-*L* | COL-*a* | COL-*b* | Score |
| TW | −0.311 | −0.509 | −0.192 | 0.231 | −0.012 | −0.031 | 0.438 |
| TKW | 0.243 | 0.226 | 0.122 | 0.041 | −0.049 | −0.098 | −0.036 |
| WPROT | −0.292 | −0.081 | −0.429 | 0.174 | 0.062 | −0.170 | 0.727**[b] |
| GRT | 0.241 | 0.136 | 0.382 | −0.371 | 0.079 | −0.080 | −0.448 |
| FLY-BR | 0.003 | −0.120 | −0.122 | 0.641* | 0.105 | 0.491 | 0.461 |
| FLP-BR | −0.178 | −0.023 | −0.348 | 0.264 | 0.077 | −0.037 | 0.681** |
| FLY-BU | 0.107 | −0.157 | 0.062 | 0.662** | 0.045 | 0.472 | 0.409 |
| FLP-BU | −0.179 | −0.070 | −0.338 | 0.327 | 0.127 | 0.030 | 0.740** |
| FASH | 0.073 | 0.055 | 0.099 | 0.039 | 0.400 | 0.318 | −0.149 |
| SD | 0.021 | 0.042 | −0.169 | 0.714** | 0.136 | 0.442 | 0.531 |
| AMYL | −0.383 | −0.394 | −0.410 | 0.395 | 0.365 | 0.472 | 0.325 |
| FN | −0.149 | −0.300 | −0.180 | 0.612* | 0.296 | 0.613* | 0.357 |
| SDS-SED | −0.535* | −0.504 | −0.532* | 0.034 | 0.474 | 0.109 | 0.601* |
| MDT | −0.305 | −0.516 | −0.229 | 0.202 | 0.520 | 0.287 | 0.626* |
| PH | −0.469 | −0.267 | −0.553* | 0.018 | 0.255 | 0.007 | 0.554* |
| ABS | −0.106 | 0.159 | −0.401 | 0.360 | 0.145 | 0.191 | 0.545* |
| DT | −0.313 | −0.438 | −0.298 | 0.310 | 0.419 | 0.312 | 0.698** |
| STAB | −0.315 | −0.307 | −0.384 | 0.451 | 0.389 | 0.304 | 0.724** |
| MTI | 0.290 | 0.318 | 0.330 | −0.399 | −0.423 | −0.387 | −0.704** |
| LV | 0.079 | −0.130 | 0.027 | 0.696** | 0.162 | 0.419 | 0.662** |
| VOL | | 0.655* | 0.782** | 0.387 | −0.452 | 0.155 | −0.243 |
| HGT | | | 0.120 | 0.187 | −0.437 | −0.165 | −0.133 |
| WD | | | | 0.156 | −0.345 | 0.207 | −0.379 |
| COL-*L* | | | | | −0.100 | 0.391 | 0.400 |
| COL-*a* | | | | | | 0.600* | 0.076 |
| COL-*b* | | | | | | | −0.165 |

[a] Abbreviations: TW = test weight (kg/hl); TKW = thousand kernel weight (g); WPROT = wheat protein (%, 14% mb); GRT = grinding time (min); FLY-BR = Brabender mill flour yield (%, 14% mb); FLP-BR = Brabender mill flour protein (%, 14% mb); FLY-BU = Buhler mill flour yield (%, 14% mb); FLP-BU = Buhler mill flour protein (%, 14% mb); FASH = flour ash (%, 14% mb); SD = starch damage (%); AMYL = amylograph peak height (BU); FN = falling number (sec); SDS-SED = SDS-sedimentation value ($cm^3$); MDT = mixograph development time (min); PH = mixograph peak height (mixograph units, 0–100); ABS = farinograph absorption (%); DT = farinograph development time (min); STAB = farinograph stability (min); MTI = farinograph mixing tolerance index (BU); LV = AACC straight-dough loaf volume ($cm^3$); VOL = steamed bread loaf volume ($cm^3$); HGT = steamed bread height (cm); WD = steamed bread width (cm); COL-*L*, -*a*, -*b* = steamed bread color indicators *L*, *a*, and *b*, respectively.
[b] Significantly different at $*P = 0.05$, $**P = 0.01$.

**TABLE IV**
**Regression Coefficients, Intercept, $R^2$, $F$, and Probability of $F$ of the Prediction Equations for Steamed Bread Parameters**

| Parameter[a] | Regression Coefficients | Intercept | $R^2$ | $F$ | Prob>$F$ |
|---|---|---|---|---|---|
| Steamed bread | | | | | |
| VOL | −2.59 (SDS-SED) | 677.32 | 0.29 | 4.80 | 0.0489 |
| HGT | −0.30 (MDT) | 5.30 | 0.27 | 4.37 | 0.0490 |
| WD | −0.05 (PH) + 0.08 (FLY-BU) − 0.002 (AMYL) + 0.07 (TW) + 0.95 (GRT) | 4.87 | 0.82 | 7.44 | 0.0071 |
| COL-*L* | 0.26 (SD) − 0.17 (PH) + 0.18 (TW) | 72.76 | 0.84 | 17.14 | 0.0003 |
| COL-*a* | 0.17 (MDT) + 1.85 (FASH) | −0.53 | 0.48 | 5.07 | 0.0276 |
| COL-*b* | 0.01 (FN) + 7.10 (GRT) + 0.19 (FLY-BR) | 0.08 | 0.69 | 7.51 | 0.0064 |
| Score | 0.19 (FLP-BU) + 4.11 (MDT) − 2.59 (DT) + 0.02 (LV) + 0.91 (WPROT) + 0.31 (PH) | −33.22 | 0.95 | 20.90 | 0.0004 |

[a] Abbreviations as for Tables I, II, and III.

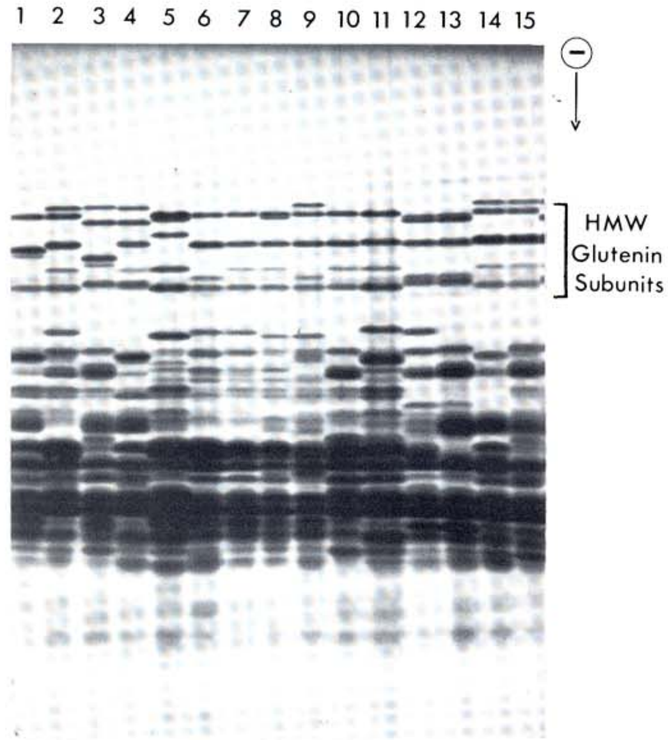


**Fig. 2.** Sodium dodecyl sulfate polyacrylamide gel electrophoregrams: Ba Mai 18 (**1**); Jing 2148 (**2**); Jin Sha Jiang 3 (**3**); Mian Yang 11 (**4**); Plateau 182 (**5**); Plateau 338 (**6**); Plateau 506 (**7**); Plateau 614 (**8**); Qing Nong 524 (**9**); Qing Chun 5 (**10**); Chinese Spring (standard) (**11**); Columbus (**12**); Katepwa (**13**); HY320 (**14**); Oslo (**15**).

**TABLE V**
**High Molecular Weight (HMW) Glutenin Subunit Composition of Chinese and Canadian Wheat Cultivars**

| | Chromosome-Encoded HMW Subunits | | | |
|---|---|---|---|---|
| **Cultivar** | **1A** | **1B** | **1D** | ***Glu-1* Score**[a] |
| Columbus | 2* | 7+9 | 5+10 | 9 |
| Katepwa | 2* | 7+9 | 5+10 | 9 |
| HY320 | 1 | 7+8 | 2+12 | 8 |
| Oslo | 1 | 7+8 | 2+12 | 8 |
| Ba Mai 18 | N[b] | 20 | 2+12 | 4 |
| Jin Sha Jiang 3 | 1 | 17+18 | 5+10 | 10 |
| Jing 2148 | 1 | 7+8 | 2+12 | 8 |
| Mian Yang 11 | 1 | 7+8 | 5+10 | 10 |
| Plateau 182 | 2* | 6+8 | 2+12 | 6 |
| Plateau 338 | N | 7+9 | 2+12 | 5 |
| Plateau 506 | N | 7+9 | 2+12 | 5 |
| Plateau 614 | 2* | 7+8 | 2+12 | 8 |
| Oing Chun 5 | N | 7+8 | 2+12 | 6 |
| Qing Nong 524 | 1 | 7+9 | 2+12 | 7 |

[a] *Glu-1* score according to Lukow et al (1989).
[b] N = null.

American breadmaking, that is, protein content and dough-mixing strength.

The physical dimensions of steamed bread were unaffected by protein content, but volume and width were negatively correlated ($P = 0.05$) to SDS-sedimentation value. The positive correlations between the *L* value of steamed bread color and flour yields are indicative of greater extractability of flour from bran in wheats with high flour yields. The *L* and *b* values were both positively correlated ($P = 0.05$) to falling number values, which may be an indirect consequence of the association of red kernel color with higher falling number values. *L* value was positively correlated ($P = 0.01$) to starch damage and AACC straight-dough loaf volume. Unknown factors that contribute to high baked loaf volumes also contribute to the light color of steamed bread.

Stepwise multiple regression was used to generate regression equations for the prediction of steamed bread quality from other quality parameters (Table IV). The regression equations for steamed bread volume, height, and *a* color values were significant (5% level), and steamed bread width, *L* and *b* color values, and score were highly significant (1% level). Only one variable was required for steamed bread volume and height prediction. Both SDS-sedimentation value and mixograph development time are associated with dough mixing strength. Values of $R^2$ ranged from 0.27 to 0.95; in the latter case, 95% of the variability in steamed bread score could be explained by six quality variables. Variables associated with protein content and dough-mixing strength predominate in this regression equation.

## Protein Fractionation

The HMW glutenin subunit composition of all Chinese and Canadian wheat cultivars was determined (Fig. 2), which permitted the calculation of *Glu-1* scores according to Lukow et al (1989) (Table V). Canadian cultivars were homogeneous in their respective subunit compositions and had high *Glu-1* scores. In contrast, Chinese cultivars displayed a wide range in glutenin subunit composition that was reflected in *Glu-1* scores from 4 to 10. This range in the *Glu-1* score is a reflection of the variability of the 1A and 1B chromosome encoded HMW glutenin subunits. A limited range of different HMW glutenin subunits coded by genes located on chromosome 1D was evident among the Chinese cultivars (Table V). All cultivars contained HMW glutenin subunits 2+12, with the exception of Jin Sha Jiang 3 and Mian Yang 11, which contained subunits 5+10.

The value of predicting breadmaking quality from the HMW glutenin subunit composition and *Glu-1* score has been demonstrated in many studies (Payne et al 1987, Ng and Bushuk 1988, Lukow et al 1989). Quality parameters were examined for their possible association with the *Glu-1* score. The *Glu-1* score was positively correlated ($P = 0.01$) to the mixograph development time ($r = 0.786$), SDS-sedimentation value ($r = 0.809$), farinograph stability ($r = 0.672$), and steamed bread score ($r = 0.787$) and also positively correlated ($P = 0.05$) to the farinograph development time ($r = 0.612$). These results substantiate the findings of Payne et al (1987) and Lukow et al (1989) that the HMW glutenin subunits and hence the *Glu-1* score are indicators

**TABLE VI**
**Correlation Coefficients for Steamed Bread Quality and High Molecular Weight Glutenin Subunits**

| | Subunit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter**[a] | **N**[b] | **1** | **2*** | **7** | **8** | **9** | **5+10** | **2+12** |
| Steamed Bread | | | | | | | | |
| VOL | 0.421 | −0.337 | −0.052 | 0.337 | −0.233 | 0.413 | −0.302 | 0.302 |
| HGT | 0.372 | −0.302 | −0.041 | 0.074 | −0.416 | 0.356 | 0.093 | −0.093 |
| WD | 0.358 | −0.343 | 0.018 | 0.291 | 0.084 | 0.204 | −0.585*[c] | 0.585* |
| COL-*L* | −0.009 | −0.263 | 0.297 | 0.217 | −0.330 | 0.507 | 0.232 | −0.232 |
| COL-*a* | −0.506 | 0.358 | 0.114 | −0.267 | −0.198 | −0.021 | 0.130 | −0.130 |
| COL-*b* | −0.007 | −0.166 | 0.189 | 0.035 | −0.322 | 0.388 | −0.134 | 0.134 |
| Score | −0.717** | 0.309 | 0.379 | 0.052 | 0.013 | 0.107 | 0.668** | −0.668** |

[a] Abbreviations as in Table II.
[b] N = null.
[c] Significantly different at * $P = 0.05$, ** $P = 0.01$.

of dough-mixing strength. In addition, the highly significant positive correlation of the *Glu-1* score with the steamed bread score suggests that the analysis of the HMW glutenin subunits may be a useful screening procedure to predict steamed bread quality. Approximately 62% of the variation in the steamed bread score between cultivars can be accounted for solely by variation in the *Glu-1* score. This value compares favorably with the degree of variation of breadmaking quality explained by the *Glu-1* score (about 69%) (Lukow et al 1989).

The relationship between individual HMW glutenin subunits and steamed bread quality was examined in greater detail (Table VI). The genetic linkage of subunits 5+10 and of 2+12 permits their treatment as units. Subunits 20, 6, 17, and 18 were not included in the statistical analysis because of their low frequency in the population. Steamed bread score was postively correlated ($P = 0.01$) to subunits 5+10 and negatively correlated ($P = 0.01$) to subunits 2+12 and the null allele. In addition, subunits 2+12 and 5+10 affected the steamed bread width positively and negatively ($P = 0.05$), respectively, probably as a consequence of their opposing effects on dough strength. The association of subunits 5+10 with good breadmaking quality and subunits 2+12 and the null allele with poor breadmaking quality as reported by Payne et al (1981) also appears to hold true for steamed bread quality.

In light of the established importance of specific gliadin bands to pasta (Damidaux et al 1978), breadmaking (Pogna et al 1982) and Chinese noodle (Huang and Morrison 1988) quality, the gliadin proteins were fractionated by PAGE (Fig. 3A and B). On the basis of the presence or absence of $\gamma$-gliadin bands of Rm 41.0, 44.5, and 45.5, all test cultivars were classified into three groups as designated by Huang and Morrison (1988). All Chinese and Canadian cultivars were characterized by the presence of band 45.5. Group 1 cultivars contained an additional intense band 41.0 (HY320, Ba Mai 18, Mian Yang 11) or a faint band 41.0 (Qing Nong 524). Group 2 cultivars did not contain band 41.0 but instead had an intense band 44.5 (Columbus, Jing 2148, Plateau 182, Plateau 338, Plateau 506, Plateau 614, Qing Chun 5). In group 3 cultivars, bands 41.0 and 44.5 were absent (Katepwa, Oslo, Jing Sha Jiang 3). Steamed bread quality was ranked from best to poorest by the mean steamed bread score of each gliadin group as follows: group 3 (9.5), group 2 (8.0), and group 1 (7.2). In contrast to the findings of Huang and Morrison (1988) that only group 2 cultivars had good noodle quality, group 3 cultivars of this study showed superior steamed bread performance. Bands 41.0 and 44.5 were associated with weak and strong gluten, respectively, in agreement with others (Pogna et al 1982, Huang and Morrison 1988). In this study, however, band 45.5 was also associated with strong gluten. Further research involving a greater number of cultivars is required to substantiate these observed associations between both gliadin and glutenin proteins and steamed bread quality.

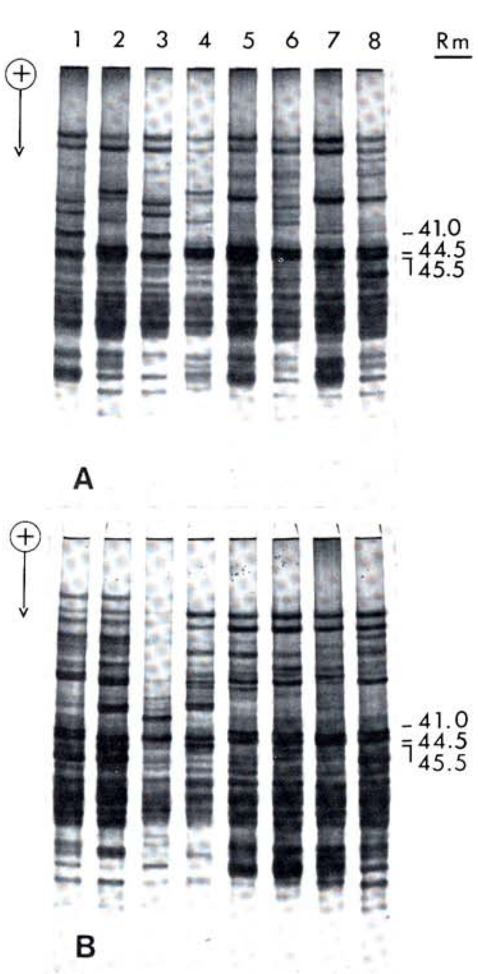

**Fig. 3.** Polyacrylamide gel electrophoregrams. **A,** Ba Mai 18 (**1**); Jing 2148 (**2**); Mian Yang 11 (**3**); Plateau 338 (**4**); Plateau 614 (**5**); Qing Chun 5 (**6**); Qing Nong 524 (**7**); Marquis (standard) (**8**). **B,** Columbus (**1**); Katepwa (**2**); HY320 (**3**); Oslo (**4**); Jin Sha Jiang 3 (**5**); Plateau 182 (**6**); Plateau 506 (**7**); Marquis (standard) (**8**).

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