

Effect of Steeping Conditions on Wet-Milling Characteristics of Hard Red Winter Wheat¹

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ABSTRACT

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A batch-wise small-scale wet-processing laboratory for whole wheat kernel has been designed and constructed to produce wheat starch and gluten from wheat grains. Hard red winter wheat kernels were steeped in three steeping media: SO₂ solution, lactic acid, and hydrochloric acid. Acid concentrations of 0.1, 0.3, and 0.5%, were used for SO₂ solutions and hydrochloric acid, and 0.1, 0.6, and 3.0% for lactic acid. After 16, 20, and 24 hr of steeping, the wheat was wet-milled. Yields and protein

contents of wet-milling fractions were compared. Both high concentration of steeping media and long steeping time increased the starch yield and decreased the protein contents of the starch. However, the steeping time and acid concentration could be reduced from 24 to 20 hr and from 0.5 to 0.3%, respectively, without any statistically significant difference in starch yields or protein contents of the starch. Consistency and color of the starch were affected by both steeping time and acid concentrations of steeping media.

Wheat is one of the basic food materials in the world. Kansas is the leading wheat producing state in the United States. Most of the wheat in the United States is dry-milled into flour, germ, and bran. These dry-milling products are mixtures of protein, carbohydrates, fats, phenolics, and fiber. The complex composition of dry-milled products from wheat limits their uses and their conversion to modified products.

Wet-processed wheat or wheat flour can produce wheat protein, starch, germ, fiber, and phenolics with high degree of purity. The wet-processed products or their modified variants may find wider applications in food and nonfood products, such as paper and plastics, where they may be used as renewable resources.

Several processes are available for the wet-milling of wheat. The primary difference between these processes is in the starting material (either wheat flour or whole wheat kernel). Most commercial production processes use wheat flour as the raw material. According to Hunwick (1980), starting with whole wheat kernel can eliminate the heavy mechanical energy input associated with conventional flour milling. However, few such processes (Langford and Slotter 1944, Anderson 1963, Rodgers and Gidlow 1974) are in commercial use today, probably because of the poor quality and quantity of gluten obtained (Meuser et al 1989).

This article describes a batch-wise small-scale wet-milling laboratory process and discusses its application in wet milling of hard red winter wheat. The objectives were to develop a new laboratory process to wet-process whole wheat kernels for separation of starch and gluten and to compare the yields of starch, gluten, and other components when wheat kernels were treated with three different steeping media: sulfur dioxide, lactic acid, and hydrochloric acid, at different concentrations and steeping times.

MATERIALS AND METHODS

A commercial sample of hard red winter wheat from the 1992 crop was purchased locally and used in this investigation. The gross chemical composition of the sample was as shown in Table I. Moisture, starch, protein, and ash contents were determined by Approved Methods (AACC 1995). The test sample was first run through a Carter Day dockage tester (CEA Carter Day Co., Minneapolis, MN) to remove the foreign materials and broken kernels before wet-processing.

Experimental Design and Statistical Analysis

Wheat samples were steeped in three steeping media. The first was SO₂ at concentrations of 0.1, 0.3, and 0.5% by volume. Preliminary tests and tests from Langford and Slotter (1944) indicated that SO₂ concentration should be controlled between 0.1 and 0.5% by volume to have optimum steeping results. Many difficulties in processing and separations were encountered at concentrations <1%. Also, concentrations >0.5% decreased the viscosity of the modified starch and were economically and practically unsound. To produce the SO₂ solution, sodium disulfide was dissolved in distilled water (Watson 1964).

The second steeping solution was HCl at concentrations of 0.1, 0.3, and 0.5% by volume, prepared by diluting a solution in water. The third steeping solution was lactic acid (LA) at concentrations of 0.1, 0.6, and 3.0% by volume, prepared by diluting an 85% LA solution. Levels of 0.6 and 3.0% were used because the pH values were equivalent to 0.3 and 0.5% SO₂ solutions, respectively.

A three-factorial combination with nested sampling and a split-plot design was used for each of the different experiments. The three levels of steeping time were 16, 20, and 24 hr. The steeping media were whole plots. The three concentrations were subplots. Three steeping times of 16, 20, and 24 hr were sub-subplots. A general linear model (GLM) was performed on the data collected using an SAS software package (SAS Institute Inc., Cary, NC).

Wet-Milling Procedures

Figure 1 shows the flow diagram of the laboratory wet-milling system. All equipment used in this process is made of 316 stainless steel. A 1.5-kg test sample was steeped in 3 L of steeping water at 37°C in a batch-type steeping tank for 16, 20, or 24 hr. A waterbath temperature-control device (model 291, Precision) with a continuous water circulation system (MasterFlex) was used to maintain a constant temperature.

After steeping, the water was drained off. The steeped wheat kernels were ground first in a Quaker City plate mill (model 4E, The Straub Co., Hatboro, PA). This mill had one stationary plate and one rotating plate with an external plate gap adjustment. The mill was set to tear and shred the wheat without damaging the germ and starch granules. No whole kernels were left after the first grinding. This was used as qualitative measure in establishing

TABLE I
Composition of Wheat Samples

| Composition | Percentage (db) |
|-------------|-----------------|
| Moisture | 14.84 |
| Starch | 65.16 |
| Protein | 13.84 |
| Ash | 1.74 |

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TABLE II
Average Values of Product Yields (% db) Using Different Steeping Media at Different Concentrations^a

| Steeping Media | Concentration | Starch | Gluten | Fiber | TDMR ^b |
|-------------------|---------------|--------|---------|---------|-------------------|
| Sulfur dioxide | 0.1 | 50.78a | 12.93a | 27.09a | 90.81a |
| | 0.3 | 55.09b | 14.56b | 21.56b | 91.22ab |
| | 0.5 | 55.84b | 16.71b | 19.06b | 91.61ab |
| Hydrochloric acid | 0.1 | 41.83c | 22.62e | 26.34a | 90.79a |
| | 0.3 | 43.95d | 23.31e | 24.09a | 91.36a |
| | 0.5 | 44.82d | 24.16e | 22.49b | 91.47ab |
| Lactic acid | 0.1 | 32.56e | 27.21ef | 23.77b | 83.54c |
| | 0.6 | 41.87c | 24.85f | 18.15bc | 84.87d |
| | 3.0 | 43.60d | 26.64f | 17.00bc | 87.25e |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

^b Total dry matter recovery.

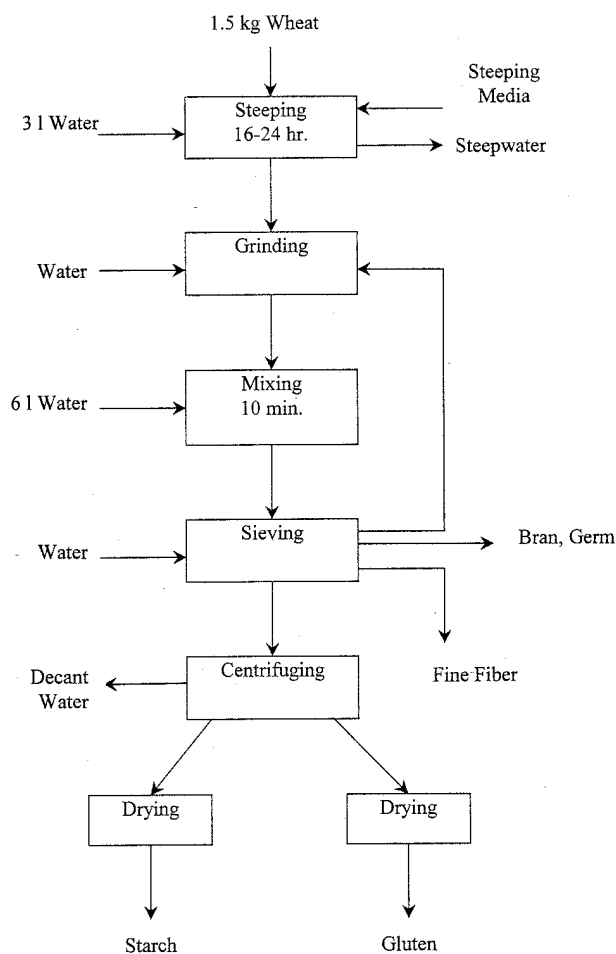


Fig. 1. Flow diagram of laboratory wet-milling process

first-grinding parameters for this procedure. The suspension was diluted with 6 L of water under continuous mixing (Hobart D300) to make a slurry.

The slurry was pumped into a vibration sieve shaker (Vorti-Siv RBF-15) on which a stack of four sieves of 1,000, 500, 250, and 50 μm was mounted. Fresh tap water was sprinkled over the top of the sieve while the sieve shaker was running. The slurry was separated into five fractions. The material retained on the 1,000- and 500- μm sieve was considered coarse fiber. The fractions remaining on the top of 250- and 50- μm sieves were the germ and fine fiber, respectively. The slurry contained the starch and gluten passed through all four sieves which were collected for further processing.

Coarse fiber fractions were ground again with a closer setting on the plate mill. This fine grinding released more endosperm from the bran. Again, it was mixed by adding more water and sieved on the shaker. Then, fiber fractions were dried overnight in a conventional oven at 60°C.

TABLE III
Average Values (% db) of Products Yields from Different Steeping Times^a

| Steeping Times (hr) | Starch | Gluten | Fiber | TDMR |
|---------------------|--------|--------|--------|--------|
| 16 | 43.49a | 21.26a | 23.89a | 88.64a |
| 20 | 45.86b | 21.64a | 21.82b | 89.23a |
| 24 | 47.43b | 21.43a | 20.82c | 89.68a |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

The starch and gluten were separated with a centrifuge. The slurry was transferred to 250-mL centrifuge bottles and centrifuged for 10 min at 10,000 rpm in a laboratory centrifuge (model J2-21 Beckman). After centrifugation, the water was decanted, and the protein layer was scraped off carefully from the starch layer. The starch fraction was centrifuged again to achieve high purity. Starch and gluten also were dried overnight in a conventional oven at 60°C (Langford and Slotter 1944, Anderson 1963, Steinke and Johnson 1991).

The total water usage in the process is eight parts by weight of water per one part of wheat. This includes 3 L (2 parts) of water for steeping, 8 L (5.4 parts) for washing, and 1 L (0.6 parts) for grinding and sieving.

Starch paste viscosity analysis (Rapid Visco-Analyzer, Newport Scientific Pty Ltd., Australia) was used to test the starch consistency. A starch sample, containing 3 g of dry starch (12% moisture basis) and 25 mL of distilled water was analyzed for peak consistency. Starch color was measured with a chromameter (model CR-210, Minolta), which gave the tristimulus color scale L , a , and b (L is degree of lightness, a and b indicate a two-color axis, with a the red-green axis, and b the yellow-blue). All samples were run twice. Only L and b values were compared in present study.

RESULTS AND DISCUSSION

Starch Yield and Protein Contents

Table II shows that the highest starch yield was obtained from the SO_2 treatments and the lowest from the LA steeping treatments. Statistical analysis showed that the difference in starch yield between the three steeping treatments was significant. This indicated that the steeping treatments with SO_2 solution had considerably more capability to disperse the wheat gluten than the others.

A significant increase occurred in starch yields in each of three steeping media when the concentrations were increased from 0.1 to 0.3% (0.1–0.6% for LA). Also, a significant increase occurred with the LA steeping when the concentration was increased from 0.6 to 3%. However, no significant difference was observed in starch yields when the concentrations of the SO_2 and HCl steeping were increased from 0.3 to 0.5%.

Table III shows the effect of different steeping times on starch yield. For all three steeping media, a significant increase in the starch yield was observed when the steeping time was increased from 16 to 20 hr. No significant change was recorded when the steeping time increased from 20 to 24 hr.

TABLE IV
Protein Content in Different Fractions from Different Steeping Media at Different Concentrations^a

| Steeping Media | Concentration | Protein Content | | |
|-------------------|---------------|-----------------|--------|--------|
| | | Starch | Gluten | Fiber |
| Sulfur dioxide | 0.1 | 0.67a | 34.49a | 11.23a |
| | 0.3 | 0.58b | 36.39a | 10.93a |
| | 0.5 | 0.56b | 36.62a | 11.01a |
| Hydrochloric acid | 0.1 | 1.02c | 25.57b | 11.33a |
| | 0.3 | 0.87d | 26.09b | 11.62a |
| | 0.5 | 0.73a | 26.25b | 11.65a |
| Lactic acid | 0.1 | 1.09e | 25.06b | 12.22a |
| | 0.6 | 0.93d | 26.17b | 11.70a |
| | 3.0 | 0.75a | 26.54b | 11.77a |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE V
Protein Contents in Different Fractions from Different Times^a

| Steeping Times (hr) | Starch | Gluten | Fiber |
|---------------------|--------|--------|--------|
| 16 | 0.99a | 27.36a | 11.46a |
| 20 | 0.79b | 29.47b | 11.55a |
| 24 | 0.64c | 30.91c | 11.48a |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE VI
Starch Consistency and Color from Different Steeping Media^a

| Steeping Media | Starch Consistency | Color | |
|-------------------|--------------------|---------|---------|
| | | L Value | b Value |
| Sulfur dioxide | 210.2a | 94.16a | 1.62a |
| Hydrochloric acid | 211.9b | 94.97b | 1.24b |
| Lactic acid | 200.3c | 92.91c | 1.78c |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

Table IV shows that the SO₂ treatment gave the lowest average protein content in starch, whereas the LA treatment gave the highest. As shown in Tables IV and V, the protein content in starch decreased significantly with increasing concentrations of steeping media and longer steeping time, except when the concentrations of the SO₂ steeping media was increased from 0.3 to 0.5%. This indicated that separation was not due to acidity of the steeping media, but instead might be due to its reducing action. Sulfites are known to have considerable dispersing action on wheat protein (Olcott et al 1943).

Starch Consistency and Starch Color

Starch consistency dropped significantly with increases in the concentration of steeping media or steeping time, as shown in Tables VI, VII, and VIII. The higher L-value and lower b-value shown in these tables indicate that all the L-values are >90, thereby indicating that the degree of lightness of starch is very good. Results also indicated that the starch color could be improved by either increasing the concentration of the steeping media or lengthening the steeping time.

Gluten Yield and Its Protein Content

Significant differences in gluten yields were observed among the three steeping treatments (Table II). The highest and lowest average yields were from the LA and SO₂ treatments, respectively. However, the differences among concentrations and steeping times (Table III) were not significant.

The highest average protein content in gluten was observed from SO₂ treatment. As shown in Table IV, no significant changes were observed in protein content with different concentration of steeping media. Table V shows that a higher protein content in gluten was obtained from longer steeping time.

TABLE VII
Starch Consistency and Color from Different Steeping Media at Different Concentration^a

| Steeping Media | Concentration | Consistency | Color | |
|-------------------|---------------|-------------|---------|---------|
| | | | L Value | b Value |
| Sulfur dioxide | 0.1 | 233.2a | 93.51a | 1.82a |
| | 0.3 | 211.8b | 93.92a | 1.57b |
| | 0.5 | 185.8c | 95.04b | 1.47c |
| Hydrochloric acid | 0.1 | 244.2e | 94.40b | 1.22d |
| | 0.3 | 219.8f | 95.68c | 1.29d |
| | 0.5 | 171.8c | 94.82b | 1.20d |
| Lactic acid | 0.1 | 220.0f | 94.49b | 1.93e |
| | 0.6 | 203.7g | 93.19a | 1.75a |
| | 3.0 | 177.3c | 94.07a | 1.66b |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE VIII
Starch Consistency and Color from Different Steeping Times^a

| Steeping Time (hr) | Consistency | Color | |
|--------------------|-------------|---------|---------|
| | | L Value | b Value |
| 16 | 219.7a | 93.57a | 1.65a |
| 20 | 207.7b | 94.12b | 1.55b |
| 24 | 195.2c | 94.35c | 1.44c |

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

Fiber Yield and Protein Content

The lowest average fiber yield was observed from LA treatment (Table II). The HCl treatment gave the highest fiber yield. Fiber yields decreased significantly with increasing the steeping time (Table III). No significant difference of protein content in fiber was found between three steeping treatments.

Total Dry Matter Recovery

The total dry matter recovery is the total weight of the dry products divided by the original weight of the wheat. The LA treatment gave a significantly lower total dry matter recovery than HCl and SO₂ treatments. As shown in Tables II and III, increasing the steeping media concentration and steeping time did not change the total dry matter recovery, except in LA treatments.

Comparison with Previous Study

The results from the present study with 0.3% SO₂ concentration and 24 hr of steeping were compared with the corresponding results from a laboratory method (Anderson 1963) under the same steeping conditions (Table IX).

The most important criteria for judging wet-milling processing are yield of starch and protein content and the yield of gluten and protein content. Because different kinds of wheat were used as raw materials in the two studies, and each of them had different starch contents, starch recovery was introduced to replace starch

TABLE IX
Comparisons Between Two Studies

| | Present Study | Anderson (1963) |
|----------------------------|-----------------------|------------------|
| Raw material | Hard red winter wheat | Soft white wheat |
| Capacity, kg/batch | 1.5 | 1.5 |
| Steeping | | |
| Medium | SO ₂ | SO ₂ |
| Concentration, % | 0.3 | 0.3 |
| Temperature, °C | 37 | 38 |
| Time | 24 | 24 |
| Water-to-wheat ratio (w/w) | 8 | 12 |
| Processing time, hr | 4 | 8 |
| Equipment | | |
| Steeping tank | 1 | 1 |
| Grinder | 1 | 1 |
| Vibrating sieve shaker | 1 | Not applicable |
| Screen | Not applicable | 2 |
| Pump | 1 | Not applicable |
| Centrifuge | 1 | Not applicable |
| Starch table | Not applicable | 1 |
| Dryer | 1 | 1 |
| Product | | |
| Starch | | |
| Yield, % | 56.1 | 51.2 |
| Recovery, % | 86.1 | 76.0 |
| Protein content, % | 0.34 | 0.22 |
| Gluten | | |
| Yield, % | 16.1 | 22.4 |
| Protein content, % | 37.5 | 28.8 |
| Fiber | | |
| Yield, % | 19.3 | 12.3 |
| Protein content, % | 11.1 | 11.3 |
| Total dry matter recovery | | |
| Yield, % | 91.5 | 85.9 |

yield for comparison. Starch recovery was defined as: Starch recovery = starch yield/starch content of wheat × 100%.

A higher starch recovery was obtained in this investigation than the Anderson (1963). However, the protein content (0.34%) was higher than the value from the previous study. Gluten yields were ≈6% lower, but the protein content (37.5%) was higher than that from previous study. This is probably why the total dry matter recovery in present study was higher.

In the previous study by Anderson (1963), a substantial amount of fresh water, ≈12 parts, by weight, of water per part of wheat, was required. The processing time was >8 hr, and this did not include the processing time required by operating the starch table.

In the present study, water usage was reduced to 8 parts, by weight, of water per part of wheat and processing time was reduced to 4 hr, after steeping. This process is easily controlled, and only minimum manual handling of the process is needed.

CONCLUSIONS

A higher yield of starch with lower protein content from hard red winter wheat was achieved with steeping with SO₂ than with LA and HCl. This indicated that the SO₂ solution has a special effect on disintegration and dispersal of the wheat protein matrix. The optimum steeping parameters obtained were 24 hr steeping at 37°C, which gave average starch yield and protein content in starch of 56.1 and 0.34%, respectively. The SO₂ treatment also gave a highest protein content in gluten, but with lowest gluten yield.

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