EFFECT OF ROLL TEMPERATURE ON FLOUR YIELD WITH THE BRABENDER QUADRUMAT EXPERIMENTAL MILLS

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Cereal Chem. 54(5) 1018-1025

ABSTRACT

Through the years experimental flour yield from check varieties of wheat were lower for samples milled late in the day than from those milled early in the day. Temperature of the rolls and mill housings was found to be the influencing factor. As temperature increased due to friction and use of the mill, flour yield decreased. Over a range of 24°C increase in temperature, flour yields decreased from 4 to 6%. Correlations of −0.98 to −0.99 were found between flour yield and roll temperature. Roll gaps were also correlated with temperature. As temperature increased, roll gaps widened as much as 0.00125 in. due to differences in expansion of materials in the roll housings. Coefficient of expansion of the aluminum housings is approximately double that of steel rolls. Temperature of the mill and rolls stabilized near 36°C after about 3 hr use of the mill. Thermostatically controlled heaters, permanently installed, corrected the variation in flour yield due to temperature.

Experimental flour milling can be only as meaningful as the experimental miller makes it. By the use of proven techniques, experimental milling can determine the inherent milling quality of a wheat or blend and estimate its commercial milling quality, or it may be used simply to produce flour for testing dough and baking properties.

In milling tests, the experimental error often is so large that the data have little credence. Error cannot be attributed entirely to the operator and can often be related to the shortcomings in the design and precision of the equipment. For example, two factors on the MLU202 Buhler laboratory model mill can be cited. The feeding mechanism and the sieve cleaning chains are weak points. For reproducible results, feed rate is critical, yet adjustment of the feeder for uniform rate is difficult. If the sieve cleaners are allowed to wear and work loose or are set too tightly, their action is not optimum and flour yield is reduced. These factors can be minimized or greatly improved by an observant operator (1,2).

Extensive studies have been conducted to identify sources of variance and to develop standardized procedures that improve the uniformity of experimental milling, within and between laboratories, with the Buhler laboratory mill (1–7) and others. One of the factors which has received attention in both experimental and commercial milling is roll temperature as it affects flour yield, starch

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Scientific Paper No. 4701, College of Agriculture Research Center, Washington State University.

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damage, and baking performance (1–6, 8–15). It is accepted that when the roller mill is started, the roll temperature slowly rises to its "normal temperature" which causes expansion of the rolls. Expansion, which affects the pressure and the gap, must be considered, especially for close setting of smooth rolls. Changes in roll gap caused by temperature can be compensated for by adjustment in experimental mills, such as the Buhler and Allis which have adjustable rolls. With cold rolls, Geddes and West (13) and Miller (14) always obtained elevated flour yields and they advocated warming the rolls. Ziegler (4) found that the rolls of an Allis mill required 6–8 hr of milling time to reach equilibrium and about the same time to cool to room temperature after milling stopped. He found that the smoother the roll surface, the more heat developed during milling. Also, flour temperature increased as a linear function of roll temperature between 14° and 41° C.

Seeborg and Barmore (1) found that grinding roll temperature rose for several hours, then reached equilibrium. This temperature increase may differ for each type of mill and with its operation. Under their conditions, roll temperature of the Buhler mill rose gradually from 26° C (room temperature) to 34° C in about 3–4 hr, and then remained about constant. They eliminated this change by placing light bulb heaters under each set of rolls to keep temperature uniform all night. Then one "warm-up" sample at the start of the day's milling increased the roll temperature to the maximum. Bequette and Barmore (2), who placed 400-ohm resistors under each set of Buhler rolls, reported that resistors were more satisfactory than light bulb heaters. In a 1964 AACC experimental milling collaborative study with the Brabender Quadrumat Jr., Bequette (15) reported that the operating mill temperature averaged 6° C above room temperature. Schumacher (10) advocated cooling the grinding rolls with water, especially for short-roll surfaces and high revolutions. When the temperature was reduced and kept constant, heating was minimized, setting of rolls was not changed, and uniformity was improved. Flechsig (9) found that heating increased with hardness of products. He also reported that grinding gap and product temperature gradually rose from the head to the tail of the mill, with the exception of the first break, which runs hotter than the second break. This difference could have two causes—higher relative loading of the first break rolls than of the second, and more severe cutting. The range of measured temperatures showed a variation of about 100% for the breaks and 500% or more for the reductions.

In the early 1960s, the C. W. Brabender Instruments Company, Inc. introduced a small-scale experimental mill, identified as a Quadruplex or Quadrumat (hereafter called Quadrumat), in which four rolls are arranged to provide three passes of the stock by making two of the rolls perform double-duty. One model of the mill is a combination three-pass break and reduction unit designated "Quadrumat Jr." The other model, "Quadrumat Sr.," combines two Quadrumat four-roll system units. One unit is used as a break grinding unit; the other as the middling reduction unit. Both units are self-contained. The Jr. is equipped with a graduated reel sifter to separate the flour, shorts, and bran. In the Sr. mill, separation is carried out in a two-section plane sifter with two sieve sections arranged one above the other; a conveyor lifts the sized middlings from the break operation to the reduction unit. The rolls are nonadjustable and, once set at the correct grinding gap, they cannot be changed while an individual sample is milled.

Some laboratories use the Quadrumat mill for evaluating milling quality and/or production of small quantities of flour. The laboratory in this study has milled over 60,000 200-g experimental wheat samples in a modified unit during the past 12 yr without any major mechanical problems. One of this laboratory's objectives is to determine the milling quality characteristics of new experimental wheats from the breeding programs in the western U.S. On several occasions, flour yields from the check varieties milled late in the day were noted to be lower than from those milled early in the day. Other users of the Jr. and Sr. have reported similar observations[2]. The cause of the problem is a change in roll spacing due to the influence of temperature on the mill.

[2]B. L. Bruinsma, University of Idaho, and R. K. Bequette, DeKalb Agricultural Research, Inc. Personal communication.

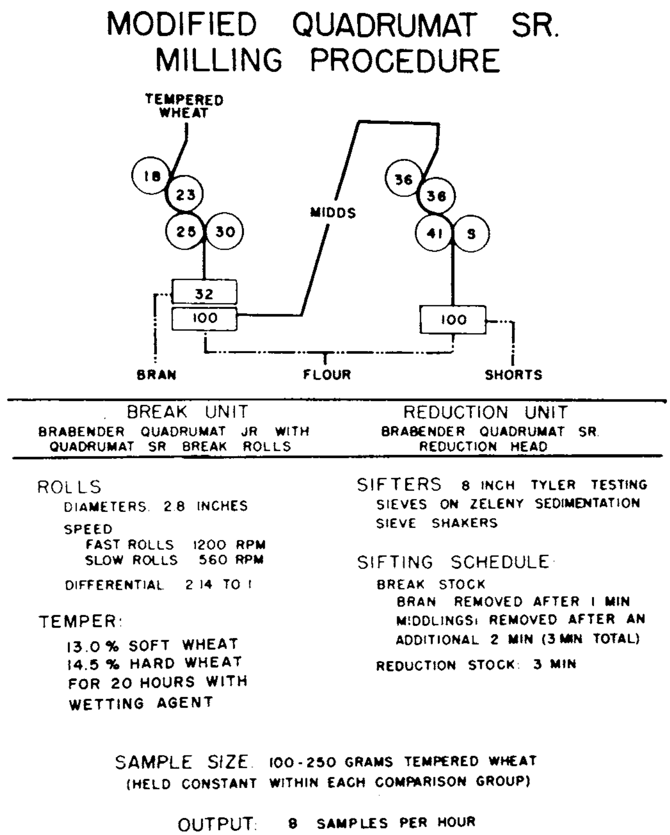

Fig. 1. Semimicro experimental mill flow with the roll corrugations/in. Roll spacings for first, second, and third break are 0.035, 0.0035, and 0.002 in., respectively. The middling rolls are set at 0.0015, 0.0020, and 0.0015 in., respectively.

The following studies were made to resolve the problem of poor reproducibility and to improve accuracy and precision of milling tests.

MATERIALS AND METHODS

Milling Procedure

The Brabender Quadrumat experimental mill was used in the modified system shown schematically in Fig. 1. The mill facing plates have been replaced with 3/8-in. clear Plexiglas drilled with holes to accommodate clean-out, between samples, with low-pressure (5 lb/in.^{2}) air. A straight-grade flour was produced by combining the break and reduction flours. Flour yield was calculated on recovered products basis. The mill room temperature was held at 22° C and relative humidity at 50%.

Roll Measurements

Roll spacings were measured by standard feeler gauges, specially built tapered feeler gauges, and Artus color-coded plastic gauge material. These measurements were taken throughout the study at the same points on each set of rolls.

Temperature values of the roll housings were obtained by inserting a

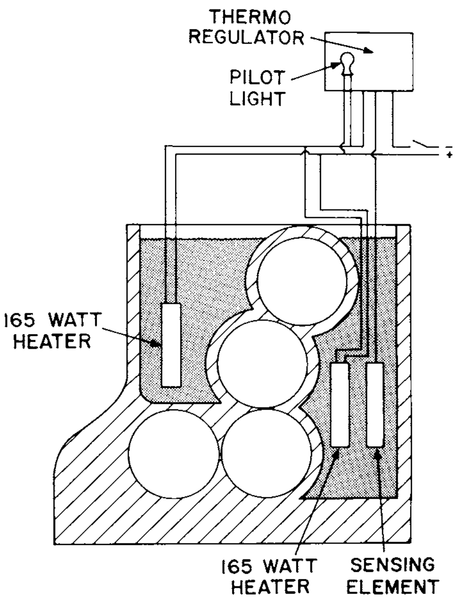

Fig. 2. Schematic diagram showing placement of heating and control elements in the back side of the Quadrumat break and reduction units. The shaded areas are cavities filled with Carbofrax #5. The thermostatic control box is mounted in a convenient position on the outside.

thermometer into the hollow journal of the second roll of the break and reduction units. The thermometers were inserted through rubber stoppers which held them in place.

Roll Housing Heaters and Thermostat

Two 165-watt Chromalox CIR-2024-075 heaters were inserted into the cavities of the roll housings from the back side of each of the Quadrumat break and reduction head units (Fig. 2). A Robertshaw SE5210 (B10) commercial electric thermostat with a 6-in. sensing bulb was mounted on each head to regulate the temperature of the roll area and mill housing to about 36° C. The control sensing element was inserted into one of the cavities. Carbofrax #5 (Silicone Carbine Base), a thermal conductive powder, was placed in the cavities around the heaters and sensing element to uniformly conduct heat to all parts of the mill. The cavities were filled to within 0.5 in. of the top. A 2×2×4 in. control box, which contained the electric thermostat, was mounted to the left side of the mill housing on each unit. A pilot light was incorporated in the system to indicate when the heaters were on.

Analytical Procedures

Ash and moisture contents of flour were determined by AACC Approved Methods (7).

Wheat

Six commercial wheat varieties grown in experimental plots (1974) at Lind, Washington were used in this study. They were Nugaines, Wanser, Paha, Wared, Marfed, and Twin representing soft white winter, hard red winter, club, hard red spring, and soft white spring classes, respectively.

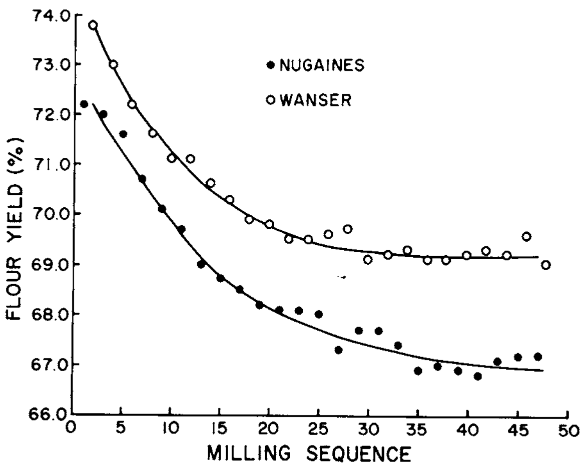

Fig. 3. Flour yields over a continuous period of 6 hr starting with an unheated mill.

RESULTS AND DISCUSSION

In a preliminary study with Nugaines and Wanser wheat, no heat was applied to the rolls. The milling room was air-conditioned overnight. Break and reduction roll temperatures were recorded at the beginning of each milling. For each variety, 24 samples were milled on an alternating sequence. Figure 3 is a plot of flour yield *vs.* milling sequence for a continuous milling period of 6 hr. Flour yield declined rapidly during the milling of the first 24 samples, which represents about 3 hr of continuous milling. As the temperature of the mill housing and rolls approached 36° C, flour yield and mill temperature became stabilized; 36° C was used in the latter part of the study. The correlation coefficient was −0.99 between

TABLE I
Flour Ash[a] of Six Varieties Milled in Sets, Each Replicated Eight Times (Milling Was Begun with an Unheated Mill)

Rep. No.	Nugaines	Wanser	Paha	Marfed	Wared	Twin
1	0.37	0.35	0.40	0.42	0.43	0.46
2	0.37	0.34	0.38	0.39	0.43	0.47
3	0.34	0.33	0.41	0.38	0.41	0.45
4	0.35	0.34	0.39	0.39	0.41	0.44
5	0.34	0.32	0.39	0.39	0.40	0.43
6	0.33	0.33	0.37	0.37	0.40	0.43
7	0.34	0.33	0.38	0.39	0.41	0.43
8	0.34	0.33	0.38	0.38	0.39	0.43

[a]14% mb.

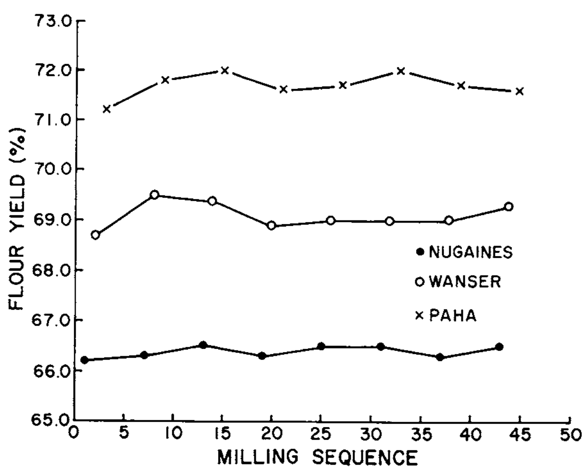

Fig. 4. Flour yields of three varieties over a continuous period of 6 hr starting with the mill heated to 36° C.

TABLE II
Effect of Temperature on Roll Spacings of Break and Reduction Units in Experimental Mills

	Break Temperature				Reduction Temperature		
	18°C	36°C	Difference		18°C	36°C	Difference
1B	0.02850 in.	0.02900 in.	0.00050 in.	1R	0.00125 in.	0.00175 in.	0.0005 in.
2B	0.00400 in.	0.00525 in.	0.00125 in.	2R	0.00225 in.	0.00275 in.	0.0005 in.
3B	0.00250 in.	0.00275 in.	0.00025 in.	3R	0.00175 in.	0.00225 in.	0.0005 in.

flour yield and roll temperature.

Six varieties that have distinctly different milling performances were then milled in sets, each replicated eight times throughout the day, starting with a cold mill. All demonstrated similar reduction in flour yield with increasing roll temperature. As expected, ash data from these millings decreased with flour yield (Table I). Correlation coefficients were −0.98 to −0.99 between flour yield and roll temperature.

Eight sets of the six varieties were then milled as above with the mill heated to 36° C. The heaters were operated overnight, so that a constant temperature of 36° C was reached before the milling began. The flour yields of each individual variety remained nearly stable over the milling period; with constant temperature within the rolls and housing, yields were uniform. Figure 4 shows the milling results of Nugaines, Wanser, and Paha when flour yield is plotted with the milling sequence; results for the other three varieties were similar. Ash data of the flours milled at constant temperature (36° C) were essentially the same from beginning to end. Roll gaps were measured at intervals of 2° C from 18° (cold mill) to 42° C, and differed between the rolls. Measurements were taken at the same points on each pair of rolls. Table II shows the roll spacings taken at 18° and 36° C.

These changes in roll spacings with temperature apparently result from differences in the coefficients of expansion between metals in the mill. The housing of the Quadrumat mills is cast aluminum while the rolls are chilled steel. Coefficient of expansion is 12.44×10^{-6} for aluminum and 6.33×10^{-6} for steel.

Other users of these mills may improve their experimental milling results by maintaining the operating temperature of their mills at about 36° C. Additionally, flour yield could be increased 2.0–2.5% if the roll spacings are adjusted at operating (36° C) rather than at ambient room temperature.

Acknowledgments

The authors thank John Guptill and Martin Williams of the Instrument Shop (Technical Services, Division of Sciences) of Washington State University for their technical services and assistance with the heating and control system used on the Quadrumat mills.

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[Received January 19, 1977. Accepted February 15, 1977]