An Experimental Milling Technique for Various Flour Extraction Levels[1]

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ABSTRACT

With the objective of producing flours more representative of those milled commercially, an experimental milling technique is described to obtain 74, 76, 78, 80, and 82% flour extraction. The corresponding flow sheets presented make use of this batch type experimental milling unit. Milling results show that this technique can give high reproducibility and acceptable variance between samples. Both ash content and color grade of the straight-grade flours from hard red winter wheat showed a linear relationship with the extraction level. A methodology for evaluation of wheat milling qualities is proposed.

Milling quality of wheats has received much attention from wheat breeders, grain traders, flour millers, and others involved in the wheat production and utilization chain. Cooperation between wheat breeders and scientists who evaluate processing quality is being encouraged in the hope that wheat breeding programs can be improved by including information on wheat processing quality in addition to agronomic characteristics. For economic reasons, millers are concerned with the milling quality of wheat and wish to have it evaluated before purchase. Wheat characteristics have an impact on the return from a milling operation (Posner 1988). Experimental milling is used as a technique to provide information on milling performance of a wheat sample.

The methodology and the development of equipment for experimental milling have been explored for decades. The objective of experimental milling is to evaluate a small quantity of wheat for its performance in a down-scaled milling unit, the wheat reduction process, and qualities of the resulting flour. The experimental milling process should give the miller clues about how the wheat will perform on his commercial mill. From that aspect, only by trying to reach the outermost extraction levels from a wheat sample experimentally can its milling potential be determined.

Shellenberger and Ward (1967) presented a comprehensive review of the techniques of experimental milling, in which preference for the batch type of milling was expressed. The advantage of batch type experimental milling was confirmed by Yamazaki and Andrews (1982). The flexibility of batch type milling in the alteration of milling flow and the adjustment of the technical specifications of both milling and sifting equipment allows the simulation of commercial milling to be done on a much smaller scale with a limited amount of wheat. This technique has been successfully applied to the evaluation of soft wheats (Yamazaki and Andrews 1982) and hard wheats (Posner and Deyoe 1986).

Disintegration of the kernel during milling, quantity and quality characteristics of intermediate stocks, flour yield, and the corresponding flour ash content are some of the most important parameters used to express wheat milling quality. Although other factors, such as tempering response and grinding energy consumption, which reflect the ease of milling, have been suggested, they are difficult to measure with currently available equipment.

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A so-called "fixed system" technique, in which no adjustments are made in mill settings during the entire grinding series, was proposed and utilized for the milling evaluation of hard red wheats (Shuey and Gilles 1971). The disadvantage of this technique is that the physical and geometric differences (such as wheat hardness, kernel shape, and size distribution) are not considered. These differences have a large influence on milling results (Li and Posner 1987). It is difficult to know whether the variation in flour yield and quality from different wheats is due to the inherent properties of the wheat or to unsuitable fixed milling settings for the changing wheat characteristics. In practical commercial milling, a change of wheat characteristics is accommodated by adjusting the system accordingly.

In a "setting changed" system, milling severity is adjusted according to the milling performance of the wheat. The experimental practice, however, requires operators to have skills and experience. Logically, a setting changed system is closer to the real practice of commercial milling. Therefore, the reliability of data for predicting wheat milling behavior is raised.

The currently acceptable laboratory method for evaluating wheat milling quality is based on the comparison of flour yield and the corresponding ash level of flours from a single milling on a fully automatic unit. The data from this kind of milling do not provide any indication of the potential of the wheat in respect to flour yield. We think that potential milling quality characteristics for breeding development and for final evaluation can be established by experimental milling to different extraction levels. The delay of flour quality deterioration with an increase in flour extraction reflects the superiority of one wheat over another in terms of milling quality. The milling performance of different wheats at different extraction levels, on the other hand, indicates the ease or difficulty in obtaining certain level of flour extraction.

There is no question that experimental milling with the batch type system involves experienced personnel and is time-consuming. However, for the miller who is going to use lots of thousands of bushels to get uniform blends on the mill, this effort is compensated for by the gain of fractions of percentages in flour extraction.

Earlier laboratory methods for obtaining different flour extraction levels involved regrinding the bran fraction into flour. Obviously, this is not commercial milling practice. Technically speaking, the resultant flours are not representative of those milled on a commercial scale, where the miller in a gradual sequence adjusts the system to get a higher extraction.

The distinction between wheat flour milling and other industrial comminutions is the selective grinding, with the objective of avoiding the production of ground bran and inclusion of it into flour. Technically, the increase in flour extraction comes from different degrees of detachment of endosperm from the inner bran surface, which is realized by gradually scraping. To avoid under- or overgrinding, the severity of grinding must be properly adjusted for each system. This is more critical at higher flour extraction levels.

The present work suggests an experimental technique for wheat milling to various levels of flour extraction.

TABLE I
Technical Features of Mill Rolls

Flour Stream[a]	Corrugations	Differential	Action[b]
1 BK	11 Fast/11 Slow	2.5:1	D-D
2 BK	20 Fast/20 Slow	2.5:1	D-D
3 BK	20 Fast/20 Slow	2.5:1	D-D
4 BK	22 Fast/22 Slow	2.5:1	D-D
5 BK_{coarse}	22 Fast/22 Slow	2.5:1	D-D
5 BK_{fine}	26 Fast/24 Slow	2.5:1	D-D
1 T[c]	26 Fast/24 Slow	2.5:1	D-D
Red dog	···	1.5:1	···

[a] BK = break, T = tailings.
[b] D-D = dull to dull.
[c] Corrugated rolls are used in the process for 78, 80, and 82% extraction only; smooth rolls are used for other extraction levels.

MATERIALS AND METHODS

Experimental Mills and Ancillary Equipment

A combination of two Witt (Witt Corrugating, Wichita, KS) grinding roll stands and three Ross (Ross, Oklahoma City, OK) grinding roll stands were used for the batch type experimental milling. The newly designed and manufactured Witt roll stands have a few superiorities over the conventional batch type roll stands. A vibratory feeder (Eriez Mfg. Co., Erie, PA) was installed above the Witt roll stands, replacing the conventional feed gate to allow the feeding rate to be regulated and controlled more accurately. This feeder greatly improved the reproducibility and uniformity of stock feeding.

The rolls are driven, through V-belts and an intermediate shaft, by two variable speed motors, which can be set independently to a desired speed (rpm). A 3-hp motor drives the fast rolls and a 2-hp motor drives the slow rolls. The adjustable speed motors provide a wide range of milling differentials, including those normally employed in commercial mills. The roll diameter is 250 mm, which is analogous to commercial mill rolls. A screw lock device is installed to fix the milling gap (or clearance between the rolls) and to secure the stability of grinding severity preset during milling.

Because of the requirement for delicate and precise grinding and the relatively large quantity of stocks ground in the head breaks, two Witt roll stands were assigned to be the first, second, and third break rolls. One was used to perform both second and third break grinding.

The milling of other break(s), sizing, and reduction were conducted with Ross roll stands. The technical aspects of the Ross roll stands were described by Posner and Deyoe (1986) and are shown in Table I.

A Great Western (Great Western Manufacturing, Leavenworth, KS) laboratory sifter was used for sifting. Each sieve has a 12 × 12 sq. in. surface area. The sifter rotates at 160 rpm. Sifting time for each system is indicated in the following corresponding flow sheets. To facilitate the sieving-out of flour, three cotton sifter belt brushes were used in the cleaning frame beneath the 10XX flour sieve. These cleaners greatly improved the efficiency of the flour sieve, especially in the tail of the break and reduction systems, where the stock was difficult to sift because of stickiness.

A laboratory bran duster (Moore, Wichita, KS) was incorporated in the flow for milling of 80 and 82% flour extraction (Fig. 1). The machine, in which a perforated 0.75-mm diameter hole screen was inserted, ran at 1,785 rpm (2,800 feet/min tip speed). The feeding rate was controlled by hand to restrict it within 600 g/min.

Preparation of Wheat

A commercial mill grist of hard red winter wheat was used to evaluate the feasibility of the milling flow sheets and the milling methods designed to obtain different flour extraction levels. The wheat sample was free from damaged and diseased kernels. Wheat characteristics were as follows: test weight 60.25 lb/bu; 1,000-kernel weight 24.1 g; pearling value 60.78%; ash content 1.50%;

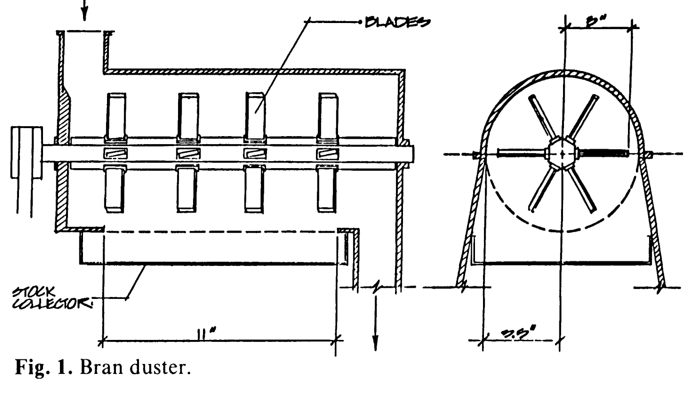

Fig. 1. Bran duster.

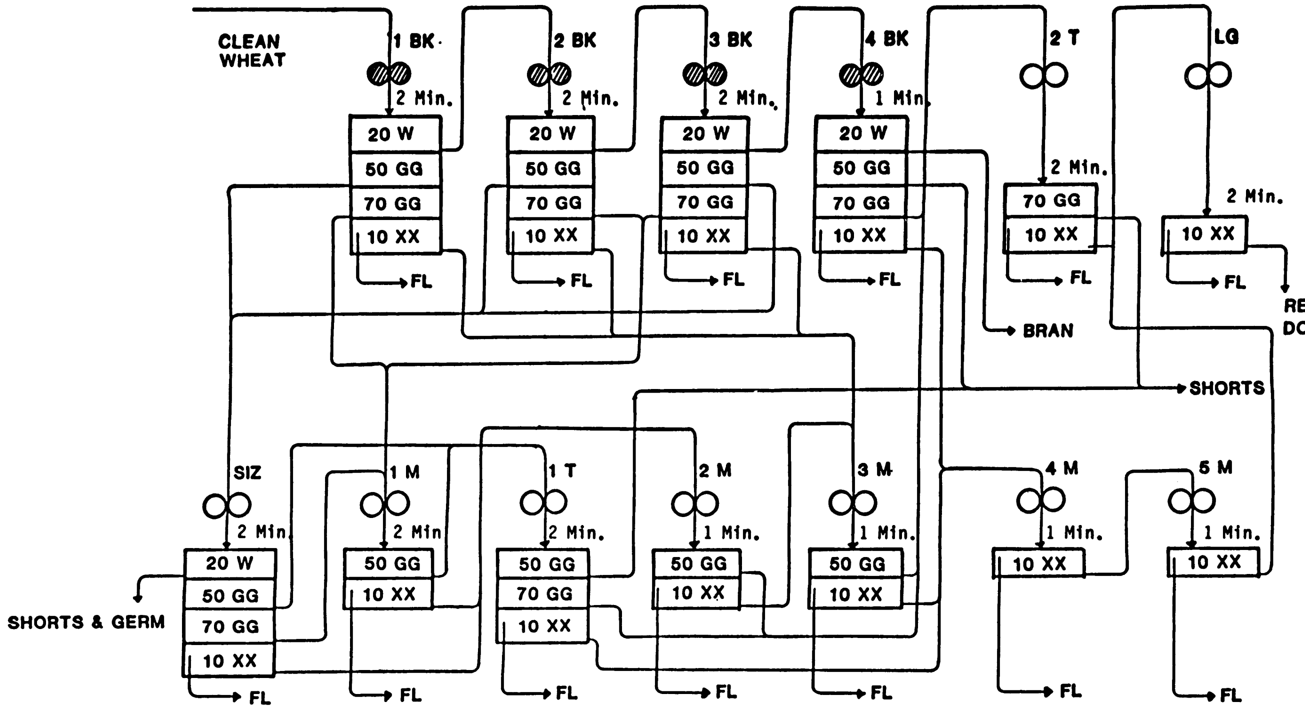

Fig. 2. Milling flow sheet for 74 and 76% extraction.

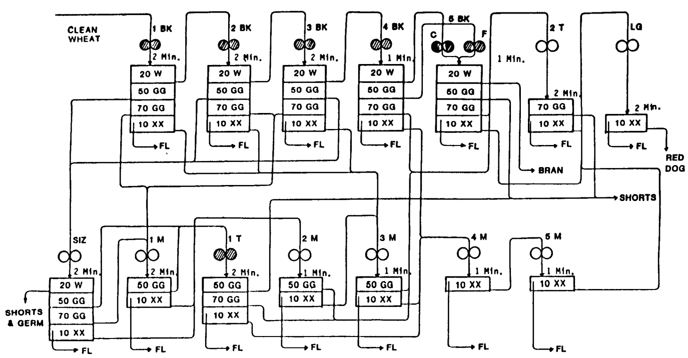

Fig. 3. Milling flow sheet for 78% extraction.

protein content 13.17%; wheat size over 7W 29.4%, over 9W 68.0%, over 12W 2.5%.

Before being tempered, the wheat was cleaned with a dockage tester (Carter-Day Co., Minneapolis, MN) to remove nonwheat grains and light and small impurities. The cleaned wheat samples then were tempered for 24 hr to 16% moisture before milling. For precise water addition, wheat samples were kept in plastic bags during mixing to minimize moisture loss. The samples were mixed by setting the plastic bags in a drum rotating at 45 rpm for 15 min.

Methods of Milling

For each milling, 6,000 g of tempered wheat (16% moisture) was used. The milling results were expressed as an average of duplicate runs. Flour extraction was the percent of wheat entering the first break, corrected to 14% moisture basis.

Milling Flow Sheets

Because batch type experimental milling is a time-consuming process, the design of flow sheets should avoid complication. The shortened experimental time helps to minimize moisture and dust loss and, therefore, improves the reproducibility of milling.

Milling flow sheet for 74 and 76% flour extraction. This flow sheet consists of flour breaks, one sizing, two tailings, and five reductions (Fig. 2). The function of the sizing roll is to reduce the sizings particle size and flake the embryo. Special care in adjusting the grinding severity must be taken to avoid flaking endosperm particles. To recover the endosperm fraction left in overs from the 10XX flour sieve of 5M and 2T (Fig. 2), a low-grade milling stage is employed. These overs are sticky and difficult to sift. Without further grinding, prolonged sifting time does not help the sieving-out of the endosperm fraction.

Milling flow sheet for 78% flour extraction. On the basis of the flow sheet for 74 and 76% extraction, a fifth break coarse and a fifth break fine are added to elongate the break system and increase the level of endosperm separation from bran (Fig. 3). The division of the fifth break into coarse and fine rolls allows the grinding to be more easily controlled so that the endosperm can be scraped off and the pulverization of bran can be minimized. In this flow sheet, the first tailing (1T) smooth rolls are replaced by a pair of corrugated rolls. The surface features of the corrugated roll are shown in Table I. The stocks from 50 GG of sizing system to 1T consists of mainly flaky bran with endosperm adhered to it. The change to corrugated rolls increases the scraping action on the flaky bran fraction.

Flow sheet for 80 and 82% flour extraction. To obtain a high level of flour extraction, the cleanness of bran is extremely important. For experimental milling, the wheat sample is limited, and the quantity of stock going to tail breaks is relatively small. This restricts the further elongation of break grinding. Two bran dusters (Fig. 1) were incorporated into this flow sheet to have overs on 20 W and 50 GG of 5 BK to be further cleaned (Fig. 4).

Milling Operations

In this study, different break releases, resulting from the elaborate control of roller mill settings, were chosen for each extraction level according to the previous, preliminary milling experiments. Table II presents the break releases used in the first three break systems for each extraction level. The following method was used to calculate break releases:

$$\text{Break release (\%)} = [(W_1 - W_2)/W_1] \times 100\%$$

where W_1 is the total weight of stocks (or wheat for the first break) entering the break rolls, and W_2 is the total weight of overs on the 20 W sieve in the break system after sifting. The break release values are actually the percentages of the stock passing through the 20 W wire.

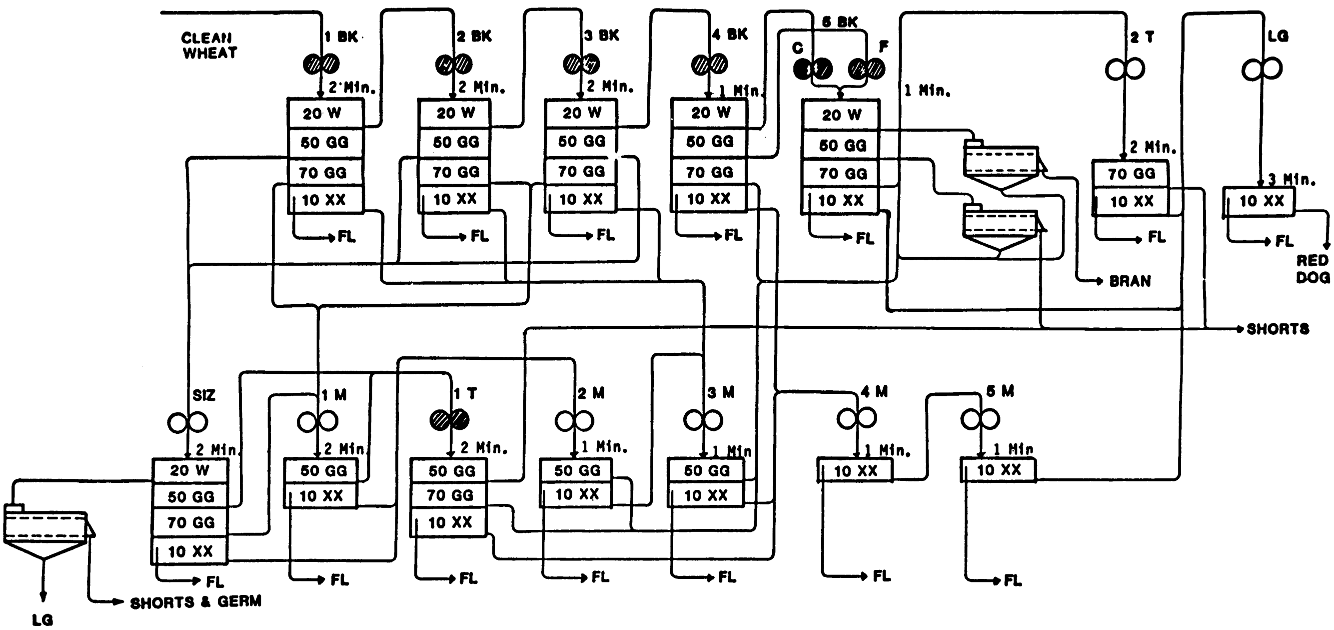

Fig. 4. Milling flow sheet for 80 and 82% extraction.

The gaps between the rolls to obtain the release values were determined by preliminary trials. A 100-g sample of stock (or wheat in the first break) was ground and sifted for 20 sec. The release value thus obtained was taken as the real break release. If it was off, the clearance was adjusted accordingly until the desired release value was obtained.

In the first break, the break releases were increased about 2% for each 2% increase in flour extraction. Relatively small changes in the break releases of the second and third breaks were employed, although the releases in the second break were decreased as the extraction level was increased. This practice was believed to be technically reasonable, since very fine clearances were used for the fourth and fifth breaks, and to some extent the adjustment was subjective. If higher break releases were not used in the first break during higher flour extractions, the endosperm quantity in the stock flowing to the tail breaks would be increased. To extract this part of the endosperm, the application of strong grinding action in the fourth and fifth breaks would be necessary, which could result in a great deterioration of flour quality.

The clearance of fourth and fifth break rolls was controlled to scrape off the endosperm and keep the bran intact at the same time. The adjustment of the roll clearance was based on trial and error.

A single Ross roll stand was used for grinding all reductions. The severity was adjusted to obtain as much flour as possible without flaking endosperm particles. Once the setting was chosen, it was fixed during the whole process. Protein and ash contents of flour or wheat were determined according to AACC methods 46-13 and 08-01, respectively (AACC 1983). Moisture content of flour was determined according to AACC method 44-15A (AACC 1983).

Flour color grade was measured using a Kent-Jones and Martin flour color grader (Simon Foods, Stockport, U.K.) with 30 g of flour, 50 ml of distilled water, and 120 sec mixing time.

RESULTS AND DISCUSSION

The design of the milling flow sheets described above was based on one that has been used for a series of wheat millability experiments in our laboratory. Modifications of the basic flow sheet (Fig. 2) for different extraction levels were the result of a series of trials evaluating the proper technical specifications of equipment and resultant milling data.

Overs on 20 W of the sizing system are composed of flaked embryo and bran flakes with a significant amount of endosperm. The grinding of this stock with finely corrugated rolls could be effective for separation. However, this practice would unavoidably pulverize the flaked embryo and introduce it into the flour. To eliminate cutting action, smooth rolls were used for sizing reduction, and a bran duster was used for the treatment of this stock. The bran duster is effective in endosperm separation, without breaking embryo flakes.

TABLE II
Break (BK) Releases (%)

Extraction Level	1 BK	2 BK	3 BK
74	46.2	58.6	48.7
76	48.9	59.6	50.5
78	51.4	57.4	51.0
80	52.2	56.8	52.1
82	54.9	56.4	40.3

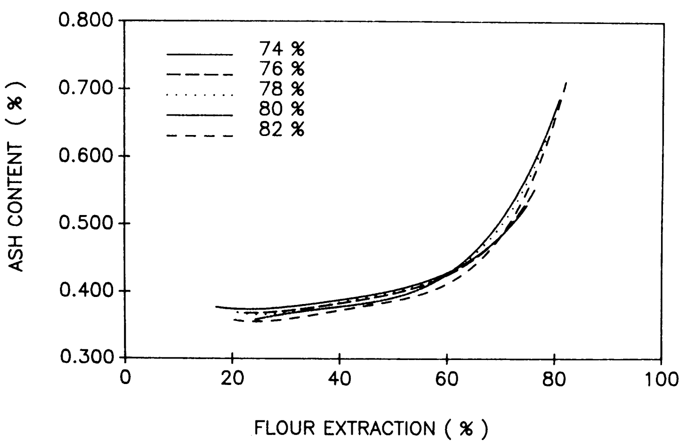

Fig. 5. Cumulative ash curves of flours.

The cumulative ash curves of flours from different extraction levels are presented in Figure 5. These curves are the regression lines from the curves of duplicate millings. A similar trend can be seen: the ash curves appear flat and parallel with each other below 60% extraction and increase sharply after 60% extraction. This same ash curve pattern is usually seen in commercial milling, which indicates the similarity of the experimental process to the commercial one.

It is also interesting that the ash curves were lower for higher extraction levels (below 60%). This indicates that the employment

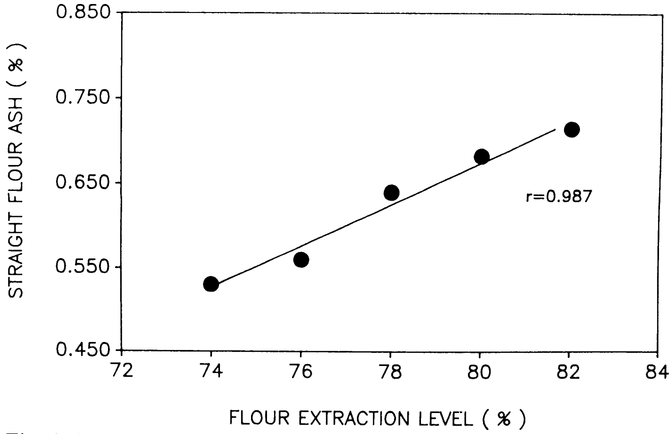

Fig. 6. Ash content versus flour extraction level.

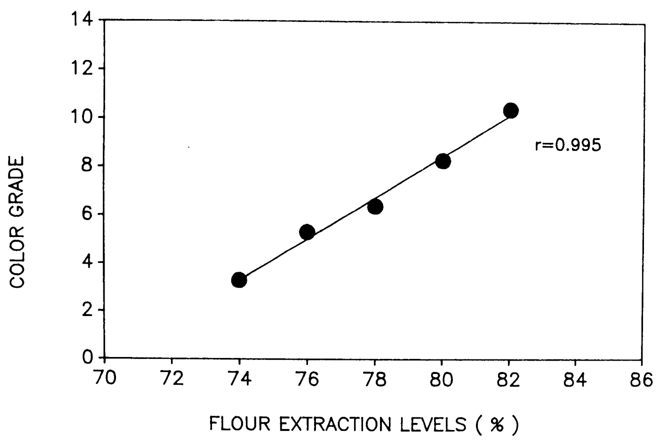

Fig. 7. Color grade versus flour extraction level.

of higher break releases for higher extraction millings does not impair the quality of sizing stocks produced in the first three breaks or the extraction of low ash flour. Therefore, in the process proposed, a higher flour extraction can be obtained without sacrificing the yield of low ash patent flour, which is technically desirable.

The increase of ash content in flour as the level of extraction was raised was expected. This increase in ash content comes from the incorporation of endosperm close to the bran and the aleurone layer, which inherently contains a higher level of minerals. The proportion of bran included in flour can also be increased as the extraction level goes higher. The present experimental milling technique aims at controlling the incorporation of the high ash content endosperm by adjusting the degree of detachment from the bran and minimizing production and inclusion of the bran fraction in the flour.

Figure 6 shows the relationship between the ash content of straight grade flours and the flour extraction levels. This linear relation ($r = 0.987$) indicates that the flour quality of wheats can be compared by the slope of each regression line.

Flour color is regarded as a major quality parameter, having importance in control of the production process. The sensitivity of color grade to the presence of wheat tissues other than starchy endosperm has prompted wheat breeders to select varieties with light colored kernels, when other characteristics are equal.

As far as the economic benefit is concerned, wheats with light colored bran are desirable because the inclusion of the bran fraction would have less effect on the color of the flour. The linear relationship ($r = 0.995$) between flour color grade and extraction shown in Figure 7 indicates that the superiority of wheats, in terms of flour color degradation, can be compared. A slower rise in flour color grade as the flour extraction is increased indicates a better wheat.

The final milling data (not shown here) are highly reproducible. The largest absolute difference in flour yield is 0.5% between the randomly sequenced duplicate millings of the same extraction level, and the smallest is 0.01%. The ash contents of flours at the same extraction level have a highest absolute difference of 0.036% and a lowest of 0.001% on 14% mb. Milling loss has an average value of 2.5% with a standard deviation of 0.2%.

The experimental milling technique described provides a technical solution for obtaining various flour extraction levels on the laboratory scale that would be more representative of flours milled commercially, but also provides a method for evaluation of wheat milling potential. This method of evaluation is proposed below.

Wheats to be tested and a reference wheat with well-known milling properties are milled to different extraction levels. Qualities (ash, color grade, and baking test) of the resultant flours at each level are compared correspondingly. The wheats are evaluated from a comparison of their quality spectrum (or the rate of quality deterioration as extraction increases). Because the gradient of quality deterioration is available for each wheat, the maximum flour yield to meet the predetermined quality parameters or to be equal to the quality of reference wheat can be determined. The yield is regarded as the flour yield potential of the wheat evaluated.

CONCLUSIONS

An experimental, batch type milling technique used with corresponding flow sheets can mill wheats for different extraction levels with high reproducibility of milling results.

Employing higher break releases for higher extraction levels facilitates the milling process without lessening the yield of low ash flour. Ash content and color grade of the straight-grade flours have a linear relationship with extraction, providing a basis for the comparison of milling quality and yield potential of tested wheats.

It was shown that, with controlled adjustments, an experimental milling process can produce flours at different extraction levels and could accentuate differences in milling properties between wheats.

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