# Computer Analysis and Plotting of Milling Data: HRS Wheat Cumulative Ash Curves[1]

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**ABSTRACT**

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A computer program was developed that uses the Statistical Analysis System (SAS), a computer software package that calculates and plots cumulative ash against cumulative extraction and then draws a cumulative ash curve in two parts. The first part of the curve (up to the inflection point) was fitted by a cubic regression model and the second part by a linear regression model. Using the regression coefficients and the intersection point of the two regression curves found by Newton's method, the program produces tables listing cumulative ash versus cumulative extraction, relative milling value, regression statistics, and a plot of cumulative ash versus cumulative extraction, with a cumulative ash curve fitted by regression. The tables and plot, including titles, legends, axes, and curves, are drawn by the computer. The program has been used to analyze data from more than 75 hard red spring wheat samples milled over 14 years on pilot and commercial mills. The lowest correlation coefficient for both the cubic and linear regressions for all samples was 0.975.

Ash has long been used as an index of milling performance. Morris et al (1946) found that the ash content of the wheat kernel is concentrated in areas adjacent to and within the bran layers. Later, Hinton (1959) demonstrated that the ash content occurs over a gradient, with the outside or bran layers having the highest ash and the endosperm the lowest. Flours from the final break rolls and from the tail end of the mill are progressively higher in ash because they contain endosperm from layers of the wheat kernel adjacent to the bran, together with greater amounts of high-ash, nonendosperm particles (Ziegler and Greer 1978).

Farrell and Ward (1965) demonstrated that the ash distribution among the various flour and feed streams, found by knowing both the quantity or flow rate and the ash content of each millstream, could be used to study the effects of various milling characteristics on milling performance. Among the characteristics that may be studied for a given sample of wheat are: roll settings, roll corrugations, roll differentials, roll speed, tempering moisture, tempering time, screen openings, and sifter size.

Cumulative ash curves made from ash determinations and quantity measurements of each millstream have been widely used as an important evaluation tool in milling. Shellenberger (1965) stated that, when properly applied, cumulative ash provides a useful appraisal of the efficiency of flour mills, comparative millability of wheats, and comparative effectiveness of milling systems.

These curves are derived by arranging the millstreams in ascending order of ash on a 14% moisture basis and tabulating cumulative ash and cumulative extraction for each successive millstream, then plotting cumulative ash against cumulative extraction, followed by drawing a smooth curve through the points, as explained by Farrell and Ward (1965). Orth and Mander (1975) found that flour ash was related to extraction by a cubic regression having a correlation coefficient of 0.94 between 66 and 82% extraction.

## MATERIALS AND METHODS

The pilot mill is a 55-cwt mill, and milling data were taken from HRS wheat samples milled over 14 years. Dry, cleaned wheat was tempered to 16 ± 0.1% moisture content for 18 hr, using special rotating stainless steel tempering drums with a 400-lb capacity. The feed rate was adjusted for each sample to 300 lb/hr. The mill consists of: 16 pairs of rolls having 10 × 3 in. of effective grinding surface; 20 sifter sections each having six sieves with a total sifter area of 23.44 sq ft; and two double-deck purifier sections with a total of 2.99 sq ft of sifter surface. The sifters of the mill have been modified slightly as reported previously by Shuey and Gilles (1968) to reduce losses and to speed cleaning between samples. Belt cleaners were replaced with Screwballs, retaining pins were added to the top of each sieve frame so that sieve cleaners could be placed on top of the sieves, and the original cleaning chains were removed. Weather stripping was also added to each sieve to prevent leakage. Figure 1 shows the flow diagram of the pilot mill with the screen openings expressed in microns.

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All ash values in this study are on a 14% moisture basis, determined by the standard AACC method (1976). Percent extractions were calculated on a total-products basis. Each stream or a combination of streams was weighed in total and a sample taken from each for ash analysis. Commercial flour mill samples were collected by sampling each millstream for a timed duration, and then weighing the sample to determine quantity or millstream flow rate. In one study, a sample of the wheat milled on a commercial mill was also tempered and milled on our pilot mill.

The SAS computer package was used to sort and calculate cumulative ash and cumulative extraction. First, millstreams were sorted from lowest to highest percentage of ash, and the amount of total products (TOTPROD) found by adding the amount of product in each of the millstreams. Next, cumulative ash (CUMASH) and cumulative extraction (CUMEXT) were calculated on the sorted data, using the following formulas:

EXTPER = (AMOUNT/TOTPROD) (100)
CUMEXT = EXTPER + LAGCUMEXT
EXTRATIO = (EXTPER/CUMEXT) (100)
RATIO2 = (100 − EXTRATIO)
CUMASH = ({[(EXTRATIO) (ASH14)] + [(RATIO2) (LAGCUMASH)]} / 100)

where AMOUNT = amount of product in each millstream, TOTPROD = sum of all amounts over all millstreams, ASH14 = percent ash on a 14% moisture basis, LAGCUMEXT = the last value calculated for CUMEXT, and LAGCUMASH = the last value calculated for CUMASH. Slopes were then calculated between consecutive cumulative ash versus cumulative extraction coordinates from the lowest ash millstream to the highest, and the differences between successive slopes were calculated and ranked, with the largest difference ranked number 1. The point around which this largest change in slope occurred was then used as the inflection point for the cumulative ash function. Points less than and including the inflection point were fitted by a cubic regression model. Points greater than and including the inflection point were also fitted with a regression line. However, this time, a linear model was used. The mathematical intersection of the two curves, defined by the coefficients of the two solved regression equations, was found by Newton's method (Thomas 1972), using the inflection point as the starting estimate. Because the intersection of the two regression curves and the regression equation coefficients are known, cumulative ash and corresponding cumulative extraction may be mathematically estimated from the lowest ash millstream to 100% extraction.

## RESULTS AND DISCUSSION

A computer program using the Statistical Analysis System (SAS), a relatively new and widely available computer software package, was developed. The computer is used to calculate and plot cumulative ash against cumulative extraction, and then to draw a cumulative ash curve in two parts. The program fits a cubic regression curve to the portion of the data corresponding roughly to cumulative ash and cumulative extraction product values below 0.46 and 75%, respectively, and fits a straight line to the second part by linear regression. The name of the millstream, amount in each stream or the flow rate, and the ash on a 14% moisture basis are the input variables for this program. The program outputs tables listing the following: input variables sorted by increasing ash together with the calculated values for cumulative ash and cumulative extraction; continuous cumulative ash and corresponding cumulative extraction values from 30 to 100% extraction by 1% increments; the relative milling value and the amount of 0.46% ash patent or straight grade flour produced; regression statistics; and a plot of cumulative ash versus cumulative extraction with a cumulative ash curve fitted by regression. The program may also be used to calculate cumulative protein or milling value using a method similar to that of Shuey et al (1971).

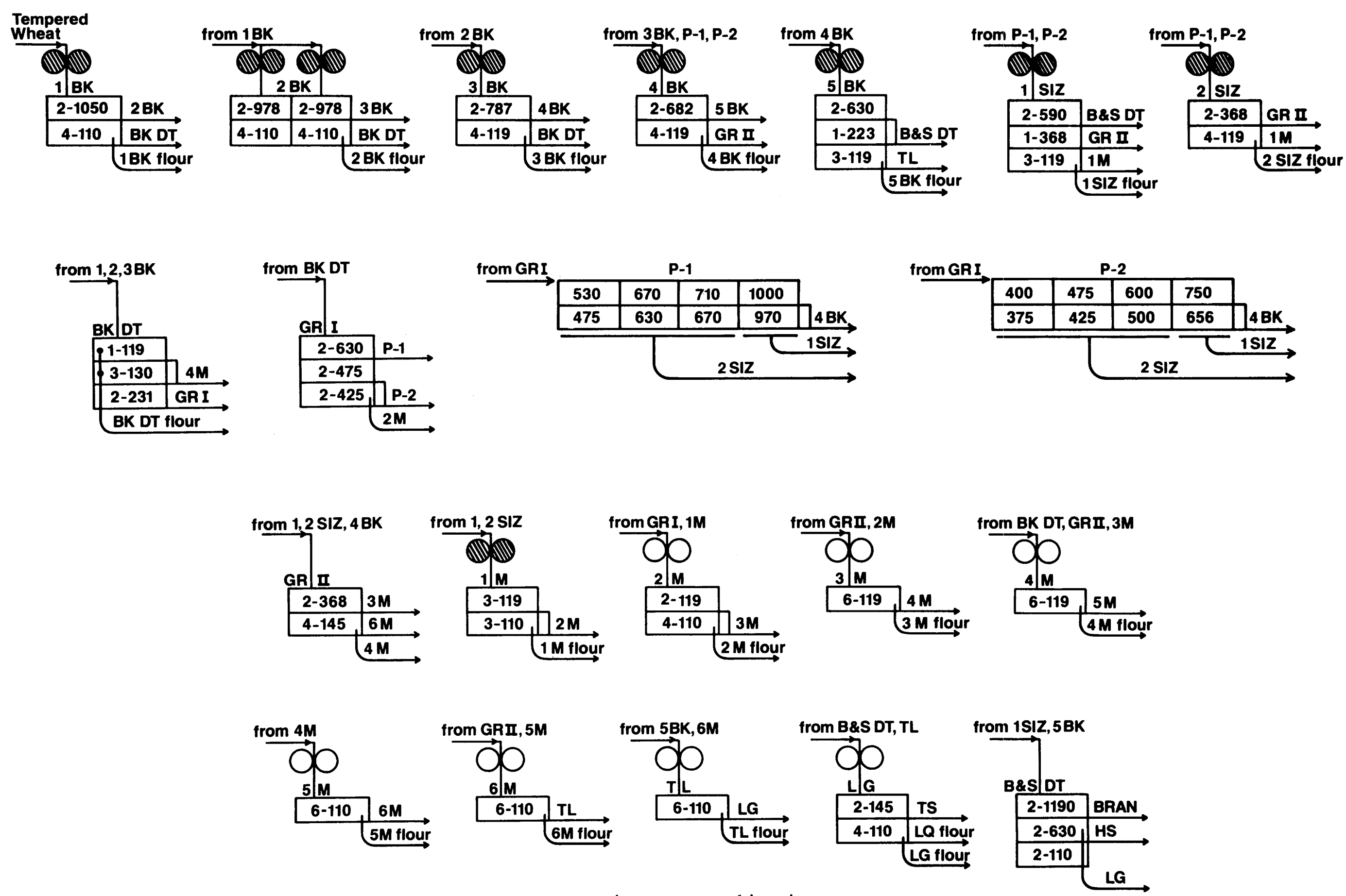


**Fig. 1.** USDA 55-cwt. pilot mill flow diagram with screen openings expressed in microns.

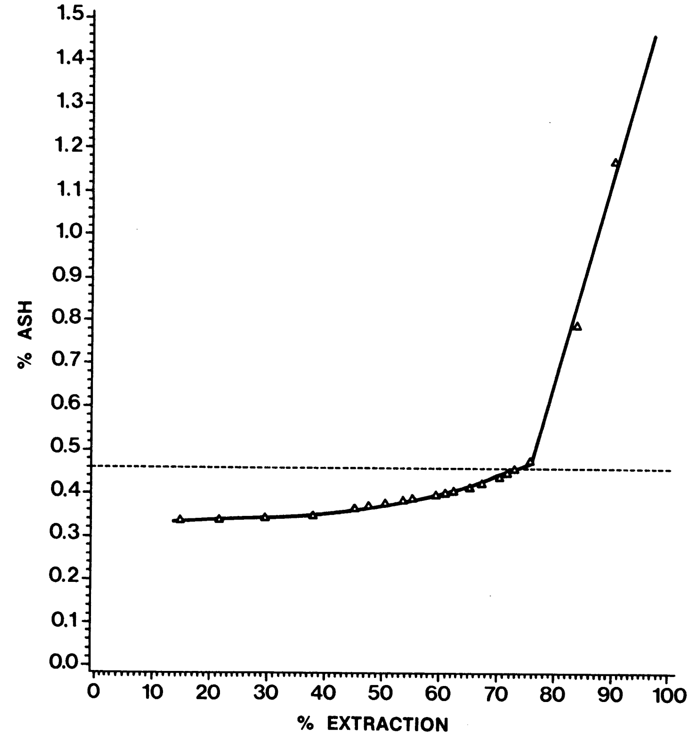


**Fig. 2.** Cumulative ash curve for an HRS wheat milled on a 55-cwt pilot mill. Δ = Actual cumulative ash data points fitted by computer-drawn cubic and linear regression curve with correlation coefficients of 0.994 and 0.993, respectively. --- = 0.46% ash.

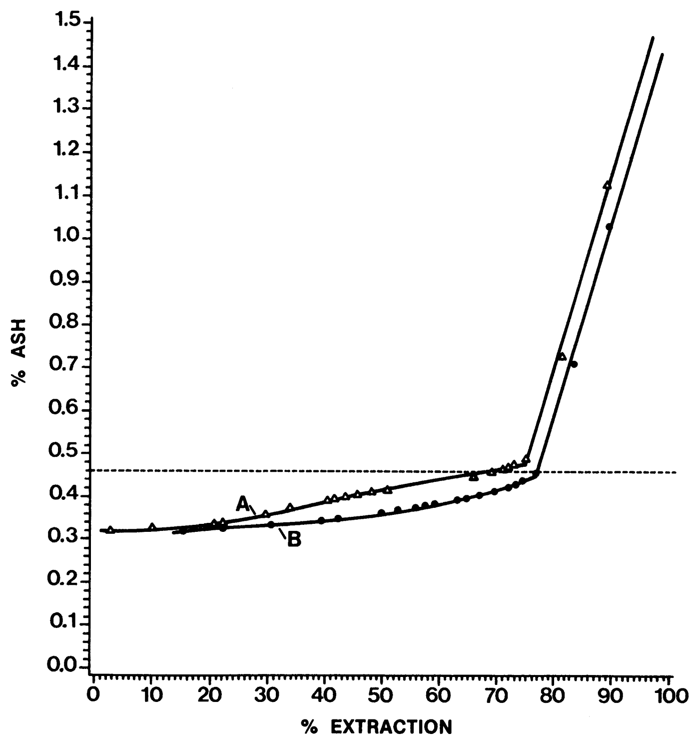


**Fig. 3.** Effect of break roll settings on cumulative ash curves. A: Δ = Actual cumulative ash data points resulting from the first four break roll gaps being too great by 0.002 ± 0.001 in. fitted by computer-drawn cubic and linear regression curve with correlation coefficients of 0.991 and 0.983, respectively. The extraction at 0.46% ash (---) equals 67.25%. B: • = Actual cumulative ash data points obtained by milling the same sample with the mill properly adjusted. The correlation coefficients for the cubic and linear regressions were 0.993 and 0.996, respectively. The extraction at 0.46% ash was 77.35%.

Figure 2 shows 21 computer-calculated and plotted cumulative ash versus cumulative extraction data points for an HRS wheat milled on our pilot mill. The data points correspond to calculated values for all 21 flour and feed streams of the pilot mill. The first portion of the data points on the graph, from the lowest ash millstreams up to the inflection point of the function, is fitted by a cubic regression model, and the second portion of the data points is fitted by a linear regression model. The intersection of the 0.46% ash line with the cumulative ash function would be the extraction at 0.46% ash, which is 73.65% in this example. The correlation coefficients for the cubic and linear regression models were 0.994 and 0.993, respectively. The graph, data points, horizontal broken line at 0.46% cumulative ash, regression lines, titles, and legends were all drawn by the computer.

Input data and computer output of the calculations from the same data plotted in Fig. 2 are shown in Table I. The table shows millstreams sorted by increasing ash, amount in each millstream, total products, percentage of ash in each millstream, cumulative ash percent, and cumulative extraction percent as each millstream is added.

The regression equation coefficients may be used to calculate relative milling value as illustrated in Table II, since, for each selected cumulative ash value the corresponding cumulative extraction and material value may be easily calculated. In this example, the relative milling value for milling 100 lb of wheat is $1.93, the total material value ($9.40) minus the cost of the wheat ($7.47). The product values and cost of wheat were arbitrarily chosen to approximate the current HRS wheat and flour market in

**TABLE I**
**Cumulative Ash Data**

| Millstream | Amount (lb) | Ash (%) | Cumulative Ash (%) | Cumulative Extraction (%) |
|---|---|---|---|---|
| 1 Midds | 14.5 | 0.336 | 0.336 | 14.602 |
| 2 Midds | 6.6 | 0.339 | 0.337 | 21.249 |
| 2 Sizing | 7.9 | 0.355 | 0.342 | 29.204 |
| 3 Midds | 8.6 | 0.370 | 0.348 | 37.865 |
| 4 Midds | 7.0 | 0.450 | 0.364 | 44.914 |
| 1 Sizing | 2.6 | 0.474 | 0.370 | 47.533 |
| 3 Break | 2.9 | 0.483 | 0.377 | 50.453 |
| Break dust | 3.0 | 0.497 | 0.384 | 53.474 |
| 2 Break #2 | 1.6 | 0.516 | 0.387 | 55.086 |
| 5 Midds | 4.0 | 0.527 | 0.397 | 59.114 |
| 2 Break #1 | 1.7 | 0.529 | 0.401 | 60.826 |
| 1 Break | 1.4 | 0.607 | 0.405 | 62.236 |
| 6 Midds | 2.8 | 0.644 | 0.416 | 65.055 |
| 4 Break | 2.2 | 0.653 | 0.424 | 67.271 |
| Tail | 2.9 | 0.795 | 0.439 | 70.191 |
| Low quality | 1.4 | 0.861 | 0.447 | 71.601 |
| 5 Break | 1.2 | 1.010 | 0.457 | 72.810 |
| Low grade | 2.6 | 1.032 | 0.477 | 75.428 |
| Tail shorts | 7.9 | 3.762 | 0.790 | 83.384 |
| Head shorts | 6.5 | 6.044 | 1.173 | 89.930 |
| Bran | 10.0 | 6.843 | 1.744 | 100.000 |
| Total products | 99.3 | | | |

**TABLE II**
**Relative Milling Value**

| Product | Ash (%) | Percent of Total Products | Dollar value (per 100 lb) | Material value (dollars) |
|---|---|---|---|---|
| Short patent | 0.400 | 60.15 | 10.50 | 6.32 |
| Patent or straight grade | 0.460 | 13.50 | 10.25 | 1.38 |
| First clear | 0.700 | 6.95 | 10.00 | 0.69 |
| Second clear | 1.200 | 9.55 | 6.75 | 0.64 |
| Feed | >1.200 | 9.85 | 3.70 | 0.36 |
| Total material value[a] | 9.40 | | | |
| Cost of wheat[a] | −7.47 | | | |
| Relative milling value[a] | 1.93 | | | |

[a]In dollars.

the United States. The term relative milling value is used because milling losses, milling cost, or other costs were not enumerated in this example. However, it may still be used as an estimate of milling quality for samples milled on the same mill.

Figure 3 shows two cumulative ash curves determined by milling and analyzing identical samples from an HRS standard wheat blend milled on the pilot mill. Cumulative ash curve A is the result of the mill being improperly adjusted. In this example, the gap 0.002 ± .001 in. is too great for each pair of the first four break rolls. Correlation coefficients for the cubic and linear regressions in curve A were 0.991 and 0.983, respectively. Cumulative ash curve B was the result of the mill being properly adjusted based on cumulative ash and extraction data from prior milling of the standards. Correlation coefficients for the cubic and linear regressions for curve B were 0.993 and 0.996, respectively. This slight increase in the roll gap of the first four break rolls caused a dramatic change in the shape and position of the cumulative ash curve and the percentage extraction at 0.46% cumulative ash. The extraction at 0.46% cumulative ash was 67.25% when the mill was improperly adjusted (Fig. 3, A) compared to 77.35% (Fig. 3, B), when the mill was properly adjusted.

The program was used to generate cumulative ash curves from millstream analysis of several different commercial flour mills (Fig. 4, 5, and 6). The curves for commercial mill A, Fig. 4, and mill B, Fig. 5, were derived from the analysis of 66 and 62 millstreams, respectively. The correlation coefficients for the cubic and linear regressions were 0.995 and 0.999 for the cumulative ash curve obtained from an HRS wheat milled in mill A and 0.991 and 0.999 for the cumulative ash curve obtained from an HRS wheat milled in mill B, respectively. The percentage extractions at 0.46% cumulative ash were 68.05 and 71.8% for the cumulative ash curves from commercial mill A and B, respectively. The effect of milling an identical HRS wheat sample on a commercial mill and our pilot mill is shown by the cumulative ash curves in Fig. 6. The percentage extraction at 0.46% cumulative ash was 62.7% for the sample milled on the commercial mill (Fig. 6, A) compared to 73.2% for the same sample milled on our pilot mill (Fig. 6, B). The correlation coefficients for the cubic and linear regressions for the two

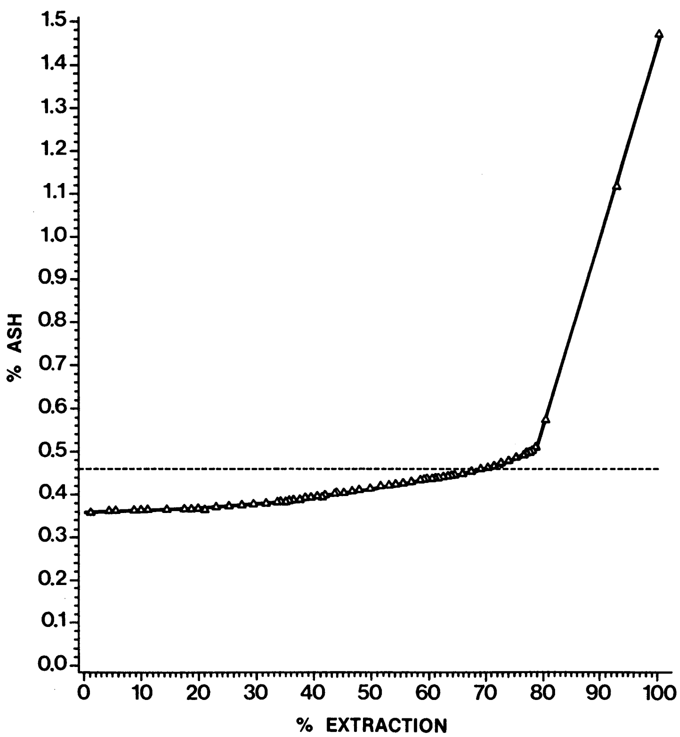


**Fig. 4.** Cumulative ash curve for an HRS wheat milled on a commercial mill. Δ = Actual cumulative ash data points (66) fitted by computer-drawn cubic and linear regression curve with correlation coefficients of 0.995 and 0.999, respectively.

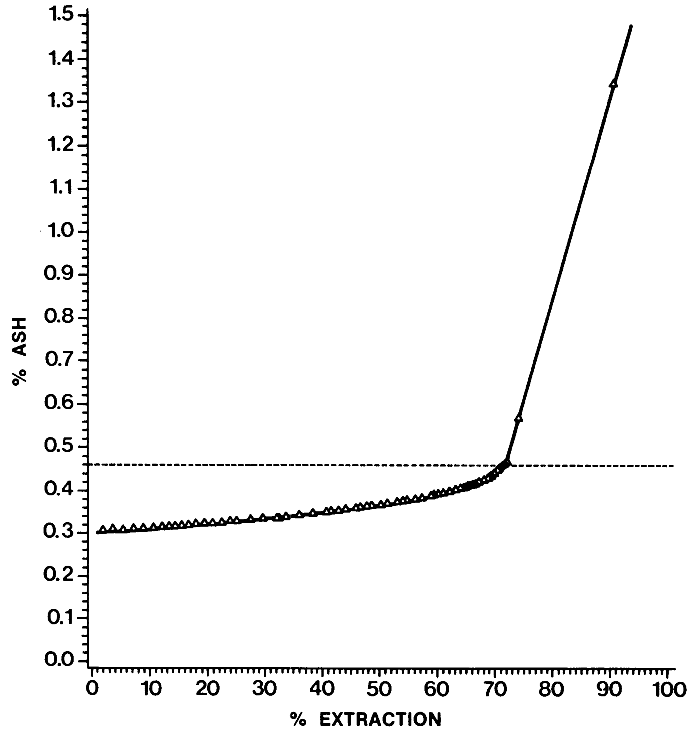


**Fig. 5.** Cumulative ash curve for an HRS wheat milled on a commercial mill. Δ = Actual cumulative ash data points (62) fitted by a computer-drawn cubic and linear regression curve with correlation coefficients of 0.991 and 0.999, respectively.

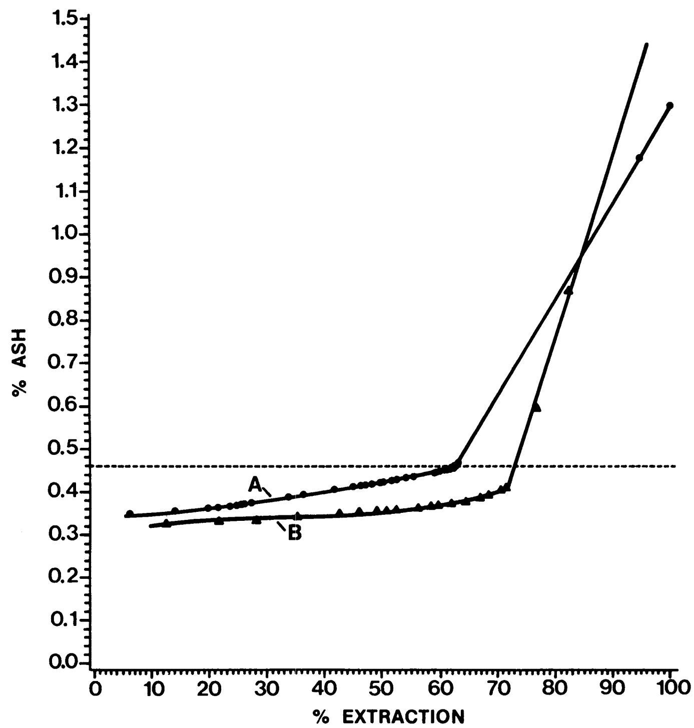


**Fig. 6.** Cumulative ash curves determined from milling an identical HRS wheat sample on a commercial mill (A) and a pilot mill (B). A: ● = Actual cumulative ash data points fitted by a computer-drawn cubic and linear regression curve with correlation coefficients of 0.996 and 1.000, respectively. B: Δ = actual cumulative ash data points fitted by a computer-drawn cubic and linear regression curve with correlation coefficients of 0.983 and 0.998,respectively. The percentage extraction at 0.46% ash was 62.3% for the commercially milled sample compared to 73.2% for the same sample milled on the pilot mill.

cumulative ash curves were 0.996 and 1.000 for the commercial milled sample and 0.983 and 0.998 for the pilot-milled sample, respectively. We would normally expect nearly identical ash values at 100% extraction for the same wheat milled on different mills. In this example (Fig. 6, A and B), this was not the case. One explanation might be differences between the two mills in the degree of cleaning. Also, in some commercial mills, feedstream flow rates are sometimes difficult to quantitate because the material flow of those particular streams is usually high and bulky.

Data have been successfully analyzed from over 75 different HRS wheat samples spanning 14 years from our pilot mill as well as data from several commercial flour mills. The correlation coefficients for both the cubic and linear regressions for all samples analyzed using this computer program have been greater than 0.975.

The program was also used to evaluate the milling quality of 26 samples together with a Waldron check grown at four locations in Minnesota, North Dakota, and Montana. The analysis was part of a cooperative study between the USDA Wheat Quality Laboratory and the Crop Quality Council to assess the quality of new HRS wheat selections or potential HRS varieties. As an index of the performance of our computer program, in this study the average correlation coefficient for all cubic and linear regressions was 0.994, the standard deviation 0.0053, and the range 0.978–1.000.

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