EIGHTY PER CENT EXTRACTION FLOUR BY TAIL-END REGRINDING AND REDRESSING[1]

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ABSTRACT

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Millfeed products (bran, head shorts, and tail shorts) of a pilot mill from six hard red spring wheat samples were reground to produce an extended extraction (EE) flour of approximately 80%. In the combination flow, an Entoleter was used to grind the bran and head shorts; the tail shorts were ground in a pin mill. A correlation coefficient of 0.988 was found between the percentage extraction of the straight-grade (SG) and EE flours. Cumulative ash and protein curves from the SG flour data were good predictors of anticipated flour values above the SG flour at a given extraction for a properly flowed mill. Protein content of the EE flour was slightly underestimated because of selective cellular fractionation of the millfeed streams by the grinding procedure used, especially as it pertained to the involvement of the aleurone/subaleurone layer of the kernel. Flour ash increased and flour color became darker with increased flour extraction, but there was no significant correlation between the ash content or flour color and extraction. A significant correlation coefficient of 0.921 was found between flour color and flour ash. Thiamine and lysine content of the EE flour increased without a detrimental increase in fat or fiber content.

The amount of flour extracted from a given quantity of wheat is important to the miller. The higher the extraction rate, the more value the parcel of wheat is to both the producer and processor. The aim of the miller is to produce in the most efficient manner a flour as white and as free of the nonendosperm portions of the kernel as possible. If the amount of the wheat kernel converted to an acceptable flour product is to be increased as an aid in relieving the world food shortage, some changes may be required in the quality parameters presently used.

In 1942, British millers were prohibited from producing a flour of less than 85% extraction to help relieve their wheat shortage. Scott (1) and Fraser (2) reviewed the production of the "National Flour" in Britain from 1941 through 1950 and showed that there was a continued improvement in the flour quality (a reduction of ash and fiber content) as more experience was gained in its production.

Butcher and Stenvert (3) demonstrated that Australian wheats of different hardness did not respond in the same way to a given series of wheat conditioning treatments. The milling yield was dependent upon the efficiency in the reduction section of the mill which was critically related to the moisture levels at the interface between the aleurone/subaleurone areas of the kernel. In a later study, Lee and Stenvert (4) demonstrated, in part, that the rate of water penetration into

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grains could be attributed to the composition of the bran layers which act as a regulator in monitoring the moisture distribution. Kent (5) established that the outer endosperm layers (subaleurone) had a high protein content. Kent and Evers (6) were able to concentrate these high-protein subaleurone endosperm cells intact even after fine grinding and air classification, especially with break flours derived from the kernel sections closest to the bran.

Sibbitt[3] observed it was easier to produce a brighter flour when the break flour release was increased on the initial breaks and the rolled wheat moisture was reduced slightly. Orth and Mander (7) observed that the flour ash content, protein content, and color grade values increased with extraction rate. They found that cubic equations best described the relation between extraction and flour ash content or color grade value.

Jones and Moran (8) studied the nutrient content of the individual mill streams from which 80% extraction flour was composed. They observed higher amounts of mineral, protein, fiber, and B vitamins in the tail-end streams than inthe head-end mill streams. Sikka *et al.* (9) showed that a resultant atta flour (primarily the low-grade tail-end flour streams composed of 25–35% of the wheat kernel) had the best protein efficiency ratio, net protein retention, and amino acid balance of the mill products studied. Rajchel *et al.* (10) investigated the plausibility of adding wheat bran and middlings to cake flour to increase the amount of dietary fiber in cakes. They observed that, with the addition of the fibrous substitute, there was a decrease in the lightness of the cake crumb.

The objective of the study reported here was to develop a mill flow to augment our present pilot mill which would increase the total flour extraction by approximately 5%. The method reported in this paper used impact mills of varying grinding severity to grind the millfeed products before redressing the ground stocks to obtain the additional flour.

MATERIALS AND METHODS

Wheat Samples

Hard red spring (HRS) wheat grown in 1974 crop year on six individual plots of approximately 1 acre each located in 3 states (Minnesota, North Dakota, and Montana) was used in the tests. The semidwarf wheat varieties were Prodax, Kitt, and Era; the conventional height varieties were Chris and Waldron.

Milling

The wheat samples were milled on our pilot mill by the procedure previously described by Shuey and Gilles (11) and Shuey *et al.* (12). The bran and head shorts were reground in an Entoleter EID 14 Series with M2050-18 rotor (Entoleter, Inc., New Haven, Conn.) with a speed of 3500 rpm at a rate of 1320 lb/hr, and sifted over 135 stainless-steel wire bolting (135 SS) sieve. The tail shorts were passed through an Alpine Kolloplex laboratory mill, Model 160Z (pin mill) (Alpine American Corp., Natick, Mass.) with a speed of 4000 rpm at a rate of 184 lb/hr, and sifted over a 135 SS sieve; the tail shorts overs of the 135 SS sieve were

[3]Sibbitt, L. D. Private communications. Department of Cereal Technology, North Dakota State University, Fargo (1946).

again reground in the pin mill at the same speed and sifted over a 135 SS sieve. The throughs of the 135 SS sieve were flour. The blend of the three flours obtained from regrinding the feed products with the original straight-grade (SG) flour produced on the pilot mill was designated as "extended extraction" (EE) flour.

A Jacobson Pulverizer Model 66B (Jacobson Machine Works, Minneapolis, Minn.) equipped with a 2/64-in. round-hole screen was used only in the preliminary experiments.

Bleaching

The flour samples were bleached with benzoyl peroxide bleaching powder at a rate of 1 g/20 kg of flour.

Methods of Analysis

Moisture, protein (N × 5.7), ash, fiber, and thiamine contents were obtained by standard AACC methods (13).

Agtron Color

The Agtron color value was determined by the slurry method of Patton and Dishaw (14).

Staining

An aqueous Ponceau 2R staining solution described by Flint and Moss (15) was used for detection of the protein in the milled products. A small amount of sample was placed on a microscope slide, stained with 4 drops Ponceau 2R solution for 10 min, washed twice with water, and dried with 96% ethanol. Two drops of balsam (Harleco synthetic resin from Fisher) was added to secure the sample on the slide.

Photomicrographs

The stain slides were observed on a Nikon Model L-Ke microscope (Nippon Kogaku K.K., Tokyo, Japan), equipped with a Model U Trinocular eyepiece tube, phase contrast, and a Dark Box M-35S photomicrographic attachment to make the photomicrographs.

TABLE I

Comparison of Pilot Mill and Extended Extraction Flours Produced from Three Different Mills

	Mill			
	Pilot Mill	Entoleter	Pulverizer	Pin Mill
Flour offals, %	0	2.1	3.3	4.3
Final flour extraction, %	77.2	79.3	80.5	81.5
Flour ash, %[a]	0.43	0.49	0.57	0.60
Flour protein, %[a]	12.1	12.3	12.5	12.6
Flour color value[b]	59.5	51.5	35.5	39.0

[a]14% moisture basis.
[b]Green Agtron value; Patton and Dishaw (14).

RESULTS AND DISCUSSION

The wheats used in the study were selected because of their previous wide range in total flour extraction of 69.7 to 77.9%. The samples also represented a range in genotype and environmental growing conditions maximizing the effectiveness of the milling system.

Preliminary experiments were made on a single wheat lot of Era to establish the milling equipment combination used in the final study. The Era lot was milled on the pilot mill and an aliquot of the three millfeed products (bran, head shorts, and tail shorts) was ground on three different mills of varying degrees of grinding severity. The pulverizer gave the poorest color with an intermediate extraction and flour ash (Table I). The pin mill yielded the most flour but had the highest flour ash, which was above that expected from the cumulative ash curve. The pin mill's action was too harsh for the bran and head shorts streams and produced an undesirable dark brown, high-ash flour. A combination of grinding the bran and head shorts in the Entoleter and the tail shorts twice in the pin mill gave the brightest flour color and lowest flour ash for the extraction rate gained.

The wheat data are given in Table II for the six wheat samples. There was no apparent relation between flour yield and location, test weight, 1000-kernel weight, kernel size distribution, ash, or protein content. The primary influence on yield was probably variety, as the Era samples yielded the highest extraction.

In Table III are shown the milling and flour data for the samples and the original SG flour extractions which were the basis for selecting the varieties. A correlation coefficient of 0.974 was found between the two SG flour extractions milled approximately 8 months apart. The average percentage increase in extraction for EE flours was 5.6% higher than for SG flours. A linear correlation coefficient of 0.988 was found between SG flour and EE flour and a regression equation $Y = 0.6X + 35.3$. This suggests that all samples responded in essentially the same way to the extended mill flow, even though they were of diverse germplasm and environmental growing conditions.

The percentage extraction, ash, and protein content of the individual extended flour streams are given in Table IV. The actual cumulated ash and protein data are given in Table V, along with the predicted values derived from the cumulative curves of the SG milling data. Significant correlation coefficients of 0.991, 0.994, and 0.921 were found between the actual and predicted ash, the actual and

TABLE II
Wheat Data for Six HRS Wheat Samples Milled to an 80% Extraction Flour

Variety	Origin	Test Weight lb/Bu	1000-Kernel Weight g	Kernel Size Lg. %	Kernel Size Med. %	Kernel Size Sm. %	Wheat Ash[a] %	Wheat Protein[a] %
Prodax	Casselton, N. Dak.	57.5	33.2	62	37	1	1.88	15.5
Waldron	Casselton, N. Dak.	57.3	29.6	51	48	1	1.86	16.0
Kitt	Plentywood, Mont.	56.1	33.1	69	29	2	1.44	13.8
Chris	Crookston, Minn.	58.1	28.2	47	52	1	1.70	15.8
Era	Minot, N. Dak.	60.8	33.8	42	57	1	1.41	12.5
Era	Crookston, Minn.	58.3	26.1	21	76	3	1.79	13.9

[a]14% moisture basis.

TABLE III
Milling Data for Six HRS Wheat Samples Milled to an 80% Extraction Flour

		Straight-Grade Flour[a]					Extended Extraction Flour			
		% Extraction								
Variety	Origin	10/74 %	6/75 %	Ash[b] %	Protein[b] %	Agtron color[c]	% Extraction %	Ash[b] %	Protein[b] %	Agtron color[c]
Prodax	Casselton, N. Dak.	69.6	70.5	0.50	14.5	50.5	77.4	0.72	15.0	24.5
Waldron	Casselton, N. Dak.	72.0	72.4	0.47	14.9	53.5	78.7	0.70	15.4	29.0
Kitt	Plentywood, Mont.	73.7	73.9	0.42	12.9	70.0	79.7	0.54	13.2	53.5
Chris	Crookston, Minn.	74.8	73.9	0.42	14.7	58.0	80.1	0.63	15.5	34.0
Era	Minot, N. Dak.	76.5	77.3	0.42	11.3	63.5	81.5	0.54	11.7	41.5
Era	Crookston, Minn.	77.8	77.2	0.44	12.1	70.5	81.6	0.59	12.5	53.0

[a]10/74: Date of original milling and percentage extraction for which the sample was selected; 6/75 is milling date of sample for other data given.
[b]Ash and protein at 14% moisture basis.
[c]Green Agtron value; Patton and Dishaw (14).

TABLE IV
Percentage Extraction, Flour Ash, and Protein Content of Individual Extended Flour Streams[a]

	Sample																	
	Prodax			Waldron			Kitt			Chris			Era (N. Dak.)			Era (Minn.)		
Stream[b]	Extr.	Ash	Prot.	Extr.	Ash	Prot.	Extr.	Ash	Prot.	Extr.	Ash	Prot.	Extr.	Ash	Prot.	Extr.	Ash	Prot.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Bran & H.S.	1.1	2.57	25.8	1.7	2.91	26.5	1.3	1.58	22.0	1.1	2.93	26.0	0.9	2.29	21.1	0.9	3.00	23.2
1st P.M.	3.6	3.04	19.7	2.7	3.67	21.4	3.2	2.21	16.7	3.3	3.07	20.5	2.3	2.93	17.8	2.4	3.48	18.8
2nd P.M.	2.1	3.50	20.0	1.9	3.93	21.1	1.3	3.04	17.6	1.7	3.56	20.9	1.0	3.71	19.3	1.0	4.33	20.1

[a]Ash and protein at 14% moisture basis.
[b]H.S. = Head shorts; 1st P.M. = first pass of tail shorts through pin mill; 2nd P.M. = second pass of tail shorts through pin mill.

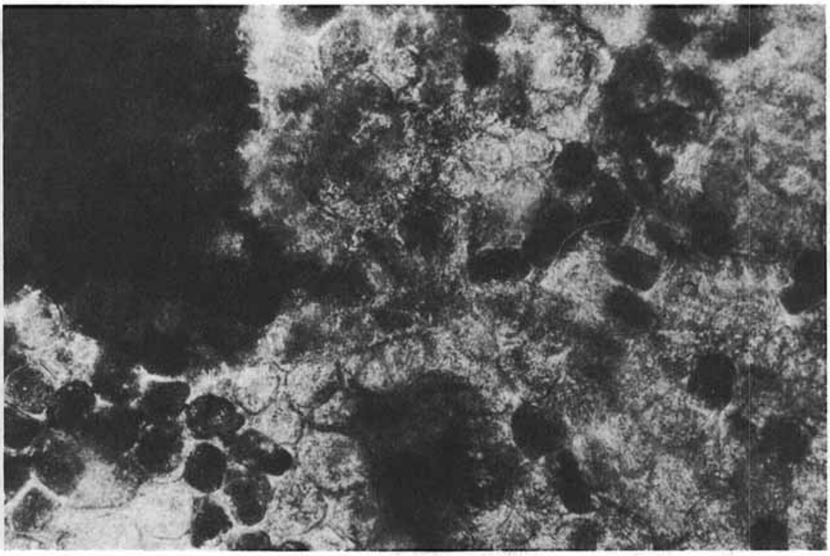
predicted protein, and the flour color and ash, respectively, and corresponding regression equations $Y = 0.97X + 0.02$, $Y = 1.06X - 0.7$, and $Y = -0.007X + 0.86$. There was no significant correlation between flour ash or flour color and flour extraction. The predicted ashes were slightly higher for the lower ash flours and slightly lower for the higher ash flours when calculated from the regression equation. This indicates that it is possible to accurately predict flour ash at any desired percentage extraction from the cumulative ash curve derived from the SG flour milling data.

The predicted flour protein content was essentially the same as the actual protein content for the low-protein flours, but was approximately 0.3% low for the high-protein flour (Table V). This suggests a selective cellular fractionation of millfeeds by the grinding procedure used that favors a protein bonus in the flour with minimal ash increase and darkening color. Of course, this difference would eventually disappear when the high-protein aleurone/subaleurone layers are depleted. This is demonstrated in Fig. 1, which shows how only the aleurone/subaleurone layer of the bran was depleted after grinding, leaving the empty cellular pockets. This high-protein section of the kernel did not appear intact in the EE flour but was apparent from the increased intensity of the stain

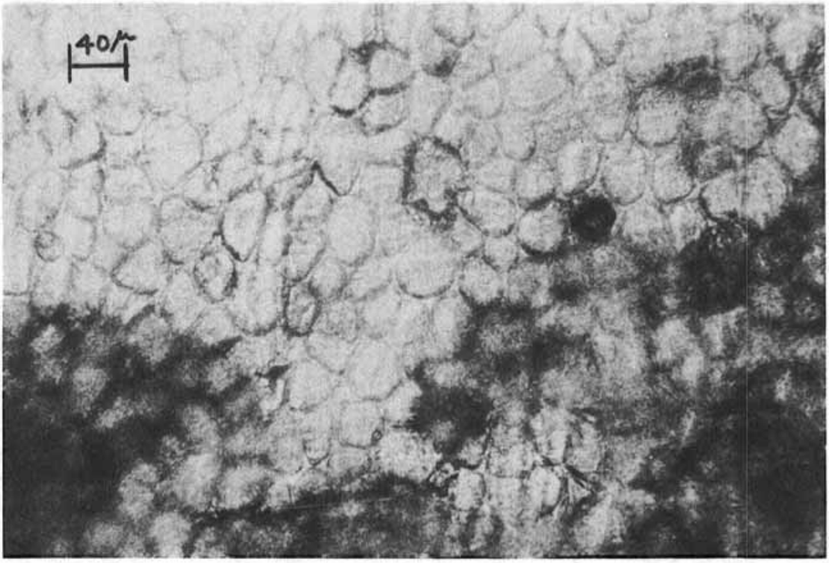
TABLE V
Actual and Predicted Cumulative Flour Ash and Protein Content at a Given Extraction[a]

Sample	Stream[b]	Cum. Extr.[c] %	Actual Ash %	Actual Protein %	Predicted Ash %	Predicted Protein %
Prodax	Bran & H.S.	71.7	0.52	14.9	0.50	14.8
Prodax	1st P.M.	75.3	0.64	15.1	0.63	14.9
Prodax	2nd P.M.	77.4	0.72	15.2	0.71	15.0
Waldron	Bran & H.S.	74.1	0.52	15.2	0.51	14.9
Waldron	1st P.M.	76.8	0.63	15.4	0.62	15.0
Waldron	2nd P.M.	78.7	0.71	15.5	0.72	15.1
Kitt	Bran & H.S.	75.2	0.43	13.1	0.43	12.9
Kitt	1st P.M.	78.4	0.50	13.2	0.50	13.0
Kitt	2nd P.M.	79.7	0.54	13.3	0.55	13.1
Chris	Bran & H.S.	75.1	0.45	14.9	0.45	14.7
Chris	1st P.M.	78.4	0.56	15.1	0.53	14.8
Chris	2nd P.M.	80.1	0.63	15.2	0.62	14.9
Era (N. Dak.)	Bran & H.S.	78.1	0.45	11.5	0.44	11.5
Era	1st P.M.	80.5	0.52	11.7	0.51	11.6
Era	2nd P.M.	81.5	0.56	11.8	0.56	11.6
Era (Minn.)	Bran & H.S.	78.1	0.47	12.1	0.46	12.2
Era	1st P.M.	80.5	0.56	12.3	0.56	12.3
Era	2nd P.M.	81.6	0.61	12.4	0.63	12.3

[a]Ash and protein at 14% moisture basis.
[b]H.S. = Head shorts; 1st P.M. = first pass of tail shorts through pin mill; 2nd P.M. = second pass of tail shorts through pin mill.
[c]Cumulated extraction beyond the straight-grade flour in ascending ash.



A



B

Fig. 1. Photomicrographs of bran stained with Ponceau 2R. A = Bran section before regrinding in Entoleter; B = bran section after regrinding in Entoleter.

between the SG flour and EE flour due to the higher protein content in the EE flour (Fig. 2). It was observed that the protein fibriform structures encapsulating the starch granules were of different sizes and associated with variety. There appeared to be a greater disassociation for the Waldron flour (Fig. 2, A and B), because of the discontinuity of fibral structure. The largest capsules were observed for the Prodax flour (Fig. 2, C and D), and smallest capsules for the Era flour (Fig. 2, E and F).

The nutrient data given in Table VI compare favorably with those reported elsewhere (1,2,9,10,16). Ziegler and Greer (17) in their summary table of the composition of flours of various extractions showed for an 80% extraction flour a range in percentage flour protein of 8.3 to 13.4% for experimental and commercial milled flours.

The flour protein in our study ranged from 11.7 to 15.5%, which suggests that we had more vitreous wheats than in their study. We found less increase in fiber content per increase in extraction for the conventional height wheat varieties than for the semidwarf varieties. There was no pattern for fat increase, which was minimal. For the semidwarf varieties, Prodax had the greatest thiamine content but lowest extraction for the EE flour, Era was intermediate with the greatest extraction, and Kitt had the lowest quantity of thiamine. The conventional height varieties were intermediate for both extraction and thiamine content. Lysine content was approximately 8% higher for the EE flours than for SG flours. The data reveal that the EE flour samples would be more nutritional because of the increased thiamine and lysine content without an undue increase in fat or fiber content.

The flour extraction obtained from a given quantity of wheat can be increased by regrinding the millfeed products without changing the mill settings or the procedure for regular flour production. Extension of the mill flow with an Entoleter and pin mill made it possible to obtain an additional 5% flour extraction. Although EE flour had a slightly darker color and higher average ash (0.175%) than SG flour, the additional quantity of flour and nutritional improvement may offset these disadvantages. The additional flour produced by the EE flour procedure increases the total amount of flour obtained from a given parcel of wheat which, in turn, substantially increases the value of the wheat lot. Also, the nutritional gain would reduce the cost of enriching the flour. These

TABLE VI
Fiber, Fat, Thiamine, and Lysine Content for the Straight-Grade (SG) and Extended Extraction (EE) Flours[a]

Variety	Fiber		Fat		Thiamine		Lysine	
	SG %	EE %	SG %	EE %	SG μg/g	EE μg/g	SG g/16 g N	EE g/16 g N
Prodax	0.3	0.6	1.1	1.4	1.46	3.75	1.94	2.04
Waldron	0.3	0.4	1.2	1.2	1.55	3.22	1.75	2.00
Kitt	0.3	0.5	1.1	1.2	1.06	2.43	1.87	1.94
Chris	0.4	0.4	1.3	1.4	1.59	3.60	1.75	2.09
Era (N. Dak.)	0.3	0.6	1.1	1.2	1.39	2.91	2.13	2.28
Era (Minn.)	0.3	0.6	1.2	1.2	1.74	2.96	1.91	1.99

[a]14% moisture basis.

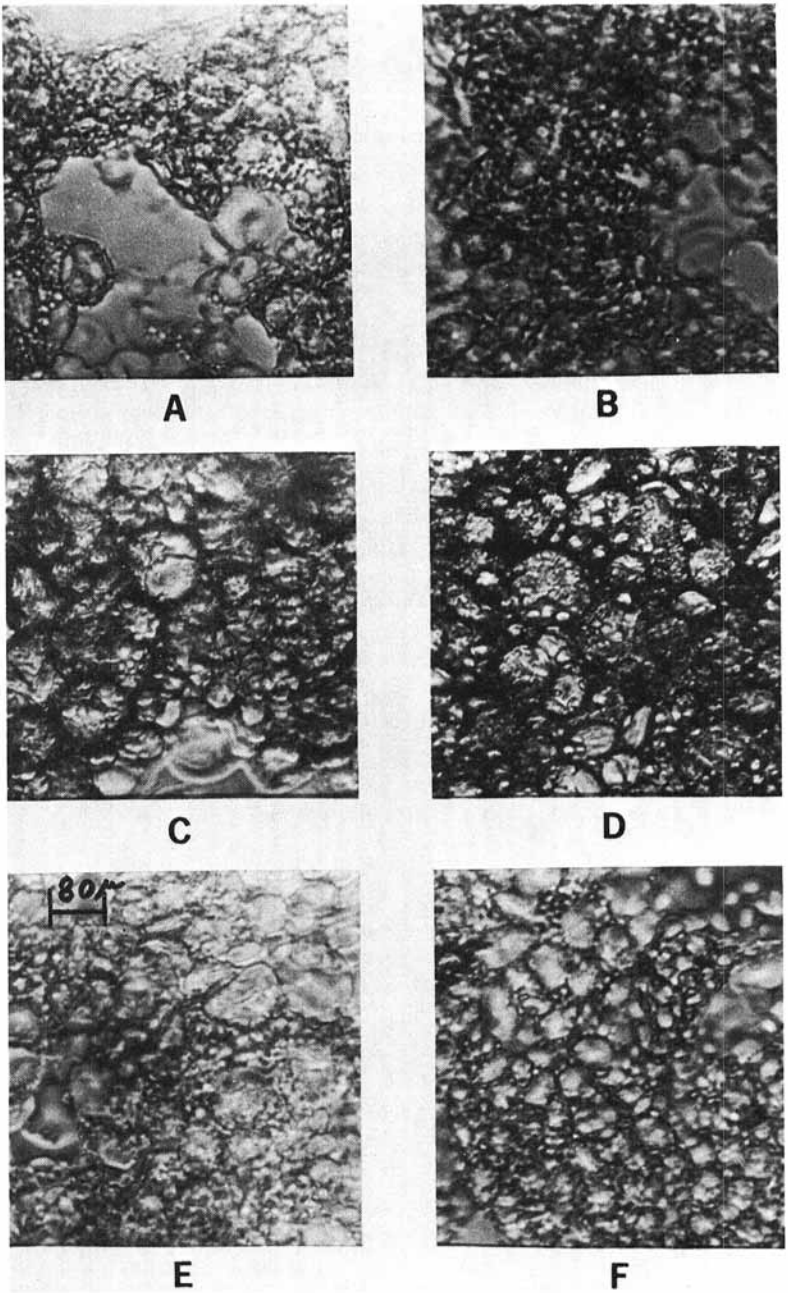


Fig. 2. Photomicrographs of flour particles stained with Ponceau 2R. A = Waldron straight-grade flour; B = Waldron extended extraction flour; C = Prodax straight-grade flour; D = Prodax extended extraction flour; E = Era straight-grade flour; F = Era extended extraction flour.

monetary advantages should enhance the attractiveness of adopting such a milling technique. Thus, use of and consumer acceptance of EE flour may require some alteration of certain quality parameters.

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