Factors Affecting Flowability of Hard and Soft Wheat Flours[1]

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ABSTRACT

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Soft wheat has always been more difficult to mill than hard wheat because soft wheat flour has poor flowability. The differences in flowability between hard and soft wheat flour were studied through the comparison of physical and chemical characteristics. Hard and soft wheat flours varying in water content, particle size distribution, and presence or absence of fat were analyzed for flowability. Bridging threshold and bulking number, two flowability parameters, were obtained using the Instron Compression Tester (model 1132). Moisture content, presence or absence of fat, and particle size distribution all had the same basic effect on hard and soft wheat flour flowability. However, soft wheat flour flowability parameters were more sensitive to changes in these physical and chemical flour characteristics. Soft wheat flour's additional sensitivity to changes in these three common flour characteristics is attributed to its rough particle surface characteristics. Hard and soft wheat flour did not have the same flowability values until moisture content, presence or absence of fat, particle size distribution, and particle surface roughness were held at equivalent values. Of the characteristics affecting flowability, the presence or absence of fat had the greatest effect.

Soft wheat flour has always been more difficult to mill than hard wheat flour because soft wheat flour has poor flowability. Many of the modern methods for evaluating flowability of powders (Ashton et al 1964, Jenike 1964) use compacted specimens. Peleg (1977) reviewed the general principles of those methods and their application to food powders. The most common instrument for flowability evaluation is the flow-factor tester designed and built by Jenike (1964). Jenike's tester allows for the quantitative identification of the cohesiveness of a particulate powder.

Starch and wheat flours exhibit what is referred to as the "slip-stick" effect when used in the Jenike flow-factor tester (Peleg 1977). The slip stick effect is expressed by oscillations in the force-displacement curves, which reduces the precision of the Jenike shear cell.

Moreyra and Peleg (1980) used an Instron compression tester to study the mechanical behavior of selected food powders through compression, decompression, and stress-relaxation curves. Baruch (1974) used the Instron compression tester to identify hard and soft wheat flour samples without determining flour particle size distribution. His simple, noncontinuous test produced two basic quantitative values known as bridging threshold and bulking number. These flowability characteristics basically quantify the cohesiveness of a flour system in which particle size distribution is an important part.

The purpose of this work was to identify and quantify those physical and chemical flour characteristics that are responsible for the flowability differences of hard and soft wheat flour. We investigated the changes in bridging threshold and bulking number of hard and soft wheat flour as affected by moisture content, presence or absence of fat, particle size distribution, and flour particle shape.

MATERIALS AND METHODS

The hard wheat flour was obtained from the Kansas State University pilot mill and contained 13.0% protein, 14.1% moisture, 0.40% ash, and 1.1% fat. The soft wheat flour was a cookie flour obtained from the King Milling Company in Lowell, MI. It contained 9.0% protein, 12.9% moisture, 0.52% ash, and 1.0% fat. The soft wheat middlings were obtained from General Mills, Inc. in Chicago, IL. They contained 9.5% protein, 11.9% moisture, 0.38% ash, and 0.9% fat.

The CEM Corporation AVC model MP microwave oven was used to determine flour moisture within 7 min (Davis and Lai 1984). When correlated to the AACC oven method (AACC 1976), a correlation coefficient of 0.97 was obtained. Original flour moistures were lowered in an air oven with no heat applied or were raised in a humidity cabinet. The time of drying for each flour sample was dependent upon the relative humidity in the laboratory, which was typically 55% for drying purposes. The humidity cabinet was set to yield a relative humidity of 90%. Flour samples of various moisture contents were obtained by altering the time of exposure to either the air oven or the humidity cabinet.

The flour samples were defatted with petroleum ether using a Soxhlet extractor. Each sample was treated overnight, removed, dried, and extracted for an additional 24 hr.

The Leeds and Northrup Microtrac Particle Size Analyzer was used to produce the particle size distributions. The Microtrac uses a helium-neon laser beam to measure particle size over the range of 2–176 μm.

The Alpine pin mill was used to obtain reductions in flour particle size distributions. This impaction mill has one stationary set of pins and one rotating set of pins. The tip speeds of the impaction pins on the rotating plate can be adjusted to four distinct levels. The revolutions per minute of the rotating pins and the subsequent tip speeds of the pins are as follows: 7,000 rpm, 10,218 FPM; 9,000 rpm, 12,952 FPM; 11,000 rpm, 16,119 FPM; and 14,000 rpm, 20,140 FPM.

The system depicted in Fig. 1 was used to reduce the middlings to flour. The gap of the rolls of each stand were closed gradually as the middlings progressed through the system. This system was established by trial and error. An initial milling system was proposed and utilized. The Leeds and Northrup Microtrac Particle Size Analyzer was used to analyze the results. The particle-size distribution data provided the necessary information to adjust the rolls and to modify sieving cloth arrangements.

The bulking number and bridging threshold were measured from the compression curve drawn by the Instron model 1132 compression tester. A 20-g sample of flour was compressed in a Plexiglas cylinder (i.d. 3.75 cm) fitted with a loosely sliding plunger. The plunger is a standard attachment to the model 1132. A crosshead speed of 50 mm/min drove the plunger into the cylinder.

The bridging threshold was determined by allowing the plunger to compress the flour sample to a predetermined force, at which point the pressure was immediately removed from the plunger. The plunger was then removed from the cylinder, and the cylinder was lifted from its base. If the flour fell out of the cylinder, a new sample was prepared. The cylinder was refilled, and a higher force was applied. This method was continued until the minimum force required to bridge the flour in the Plexiglas tube was determined. The minimum force was determined on at least three samples and was accurate to ±5 g.

The bulking number was the length of the plunger stroke (in millimeters) necessary to cause a pressure of 50 g of force. This value was obtained by measuring from the initiation of force on the

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compression curve to the point where the 50-g force level was breached. The value (in millimeters) then was divided by the ratio of the chart speed to crosshead or plunger speed. The 50-g force level used for bulking number determinations was chosen arbitrarily.

Scanning Electron Micrographs

The flour samples were sprinkled onto double-sided adhesive tape attached to specimen stubs; they were coated in vacao with approximately 60Å of carbon and then with about 100Å of gold-palladium. Samples were viewed and photographed with an ETEC Autoscan at 10 kV of accelerating voltage. Polaroid film type 55 was used.

RESULTS AND DISCUSSION

Hard Wheat Flour

The results for hard wheat flour bridging thresholds versus percent moisture content are given in Fig. 2. As moisture content was increased, the bridging threshold decreased up to approximately 13% moisture content, then leveled out at 55 g of force. Additional moisture did not reduce the bridging threshold further. The initial bulking number for the lowest-moisture hard wheat flour (5.9%) was 11.9 mm. The bulking number values increased in a reasonably steady progression with increased moisture content (Table I). The highest moisture hard wheat flour (17.2%) had a bulking number of 15.7 mm.

Soft Wheat Flour

The results for soft wheat flour bridging threshold versus percent moisture content are depicted in Fig. 2. The curve is similar to that for hard wheat flour. Bridging threshold values decreased as moisture content increased. At the 12% moisture level, the bridging threshold for soft wheat flour reached its minimum (35 g of force), and any additional moisture added was ineffective in lowering the bridging threshold beyond that point. However, the bulking numbers did not change when additional moisture was added (Table I). The lowest-moisture soft wheat flour (6.4%) had a bulking number of 17.2 mm. This value was considerably higher than any bulking number recorded for hard wheat flour. All other soft wheat flours tested had higher moisture contents, but their bulking numbers were all approximately 19.5 mm. Moisture level did not seem to affect bulking number for soft wheat flour except at low moisture contents.

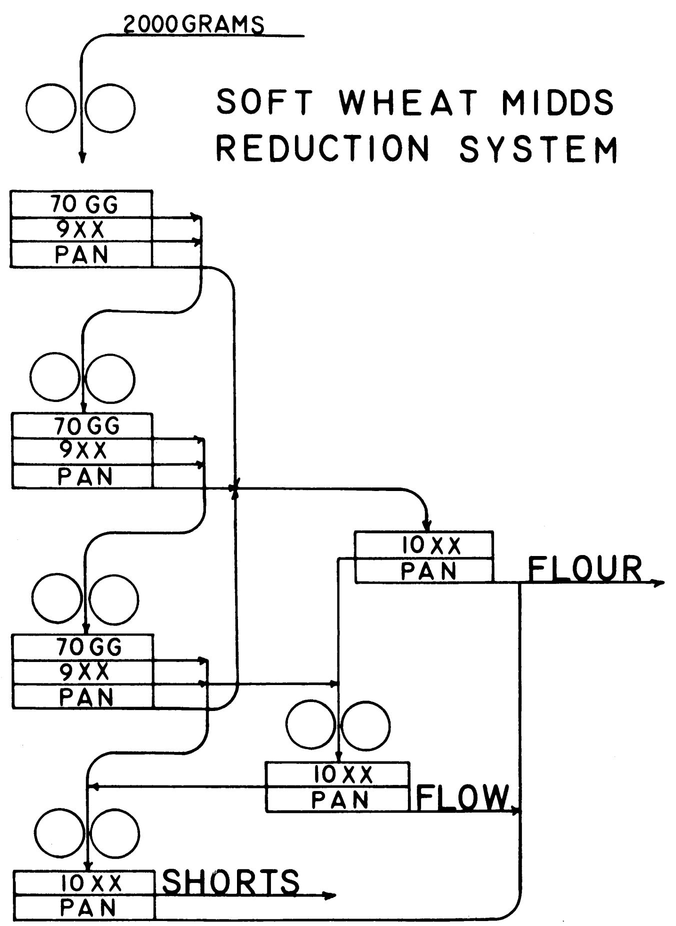

Fig. 1. Smooth roll reduction system used to produce soft wheat flour with a hard wheat flour particle size distribution.

Conclusion from Bridging Threshold and Bulking Number Values

The bridging threshold values indicated that soft wheat flour was more cohesive than hard wheat flour. At the lowest flour moisture level (6.5%), the bridging threshold of hard wheat flour was almost twice that of soft wheat flour. This fact indicated that the effect of moisture on bridging threshold was removed as the moisture content was reduced. Other differences in the flours could explain the twofold differences in bridging threshold at low moisture contents. As the flour moisture level was increased, the bridging threshold leveled off to 55 g of force for hard wheat flour and 35 g of force for soft wheat flour. A 20-g force differential still existed, which indicated that the moisture content effect on bridging threshold could only compensate for about two-thirds of the difference in the flour systems. This concurred with the work reported by Sandstedt (1948). He found that durum wheat flour would flow and act like soft wheat flour if the moisture content was raised above 20%. The bridging threshold curves (Fig. 2) for hard and soft wheat flour indicate that increased moisture content had the same effect on flour cohesiveness. The two flour systems reacted to increased moisture content in the same manner. Moisture content is involved in flour cohesiveness, but other phenomena

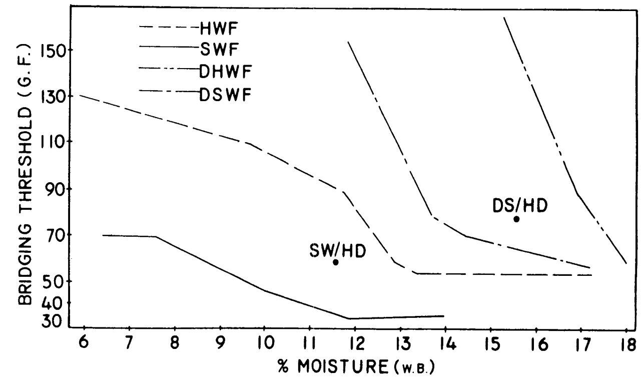

Fig. 2. Bridging threshold (grams of force) versus percent moisture (wet basis) for hard (HWF) and soft (SWF) wheat flours and defatted hard (DHWF) and soft (DSWF) wheat flours; SW/HD = soft wheat with hard wheat particle size distribution, DS/HD = defatted soft with a hard wheat particle size distribution.

TABLE I
Bulking Number and Bridging Threshold Versus Flour Moisture Content

	Percent Moisture	Bridging Threshold (grams of force)	Bulking Number (mm)
Hard wheat	5.9	125	11.9
	9.6	110	13.7
	11.4	90	14.1
	12.8	61	14.0
	13.4	55	14.6
	15.4	55	14.8
	17.2	54	15.7
Soft wheat	6.4	67.5	17.2
	7.5	67.5	19.1
	9.9	47.5	19.5
	11.9	35.0	19.6
	13.9	35.0	19.2

must exist to explain the bridging threshold differences in the two flour systems.

Defatted Hard and Soft Wheat Flour

Both hard and soft wheat flours were defatted to determine the effect of fat on bridging threshold and bulking number. It has often been noted that flour flows almost effortlessly after being defatted. It was thought that defatting might aid in identifying physical characteristics that control flowability. Particle size analysis showed that defatting did not change the particle size distribution of the sample.

Defatted hard wheat flour was very difficult to bridge and did not seem to possess any cohesive properties. The flour was quite free flowing, and the moisture content had to be raised above 14% before the system would bridge. At 15.1% moisture, the defatted hard wheat flour required a 170-g force to cause bridging. As the moisture content was increased further, the bridging threshold values decreased (Fig. 2). The bulking number values increased with increasing moisture content (Table II). The initial bulking number for the lowest-moisture defatted hard wheat flour (8.7%) was 5.7 mm. The highest-moisture defatted hard wheat flour (17.9%) had a bulking number of 12.1 mm.

Defatted soft wheat flour also was difficult to bridge. However, when additional moisture was added, the defatted soft wheat flour responded by bridging (157.5 g of force) at 11.8% moisture. As the moisture content was increased further, the bridging threshold values decreased (Fig. 2). The bulking number values increased with increasing moisture content (Table II). The initial bulking number for the lowest moisture defatted soft wheat flour (11.8%) was 12.5 mm. The highest moisture defatted soft wheat flour (17.1%) had a bulking number of 15.6 mm.

TABLE II
Bulking Number and Bridging Threshold Versus Flour Moisture Content for Defatted Flours

	Percent Moisture	Threshold Bridging (grams of force)	Bulking Number (mm)
Hard wheat	8.7	···	5.7
	13.5	···	9.9
	15.1	170	11.0
	16.8	95	12.3
	17.9	62	12.1
Soft wheat	11.8	157	12.5
	13.7	79	14.0
	14.5	72	15.1
	17.1	57	15.6

Conclusions from Defatted Flours

The results (Fig. 2) show that the presence of fat is a significant contributor to the cohesiveness of flour. Once the flours were defatted, high moisture contents were required to cause either system to bridge. The two defatted flour systems reacted to increased moisture content in the same manner. However, the defatted soft wheat flour required less moisture and less bridging force to establish the bridging threshold curve (Fig. 2). This indicated that defatted soft wheat flour was naturally more cohesive than defatted hard wheat flour. The defatting process removed the free flour lipids and with it much of the flour's natural cohesiveness. Soft wheat flour must contain some physical phenomenon that makes the flour system naturally more cohesive than hard wheat flour.

Particle Size Distributions

Hard and soft wheat flours with identical particle size distributions were produced to determine the significance of particle size on bulking number and bridging threshold. The basic objective of hard and soft wheat flour particle size distribution manipulation was to determine whether hard wheat flour would act like soft wheat flour, and soft wheat flour like hard wheat flour, given the same particle size distributions. A soft wheat flour that possessed the same particle size distribution as the hard wheat flour was obtained by gradually reducing soft wheat midds on a smooth roll milling system (Fig. 1). The original hard wheat flour had a median particle size of 73 μm (Fig. 3), and the soft wheat flour with a hard wheat flour particle size distribution had a median particle size of 71 μm.

Likewise, a hard wheat flour with the same particle size distribution as soft wheat was produced. The original soft wheat flour had a median particle size of 44 μm (Fig. 3). The hard wheat flour pin-milled at 7,000 rpm had a median particle size of 42 μm (Fig. 4).

The bridging threshold versus median particle size data for hard wheat flour are depicted in Fig. 5. The bridging threshold values decreased as median particle size was decreased. An increase in cohesiveness in conjunction with a reduction in particulate size is a well-accepted trend for particulate solids. The hard wheat flour pin milled at 7,000 rpm had the same basic particle size distribution as

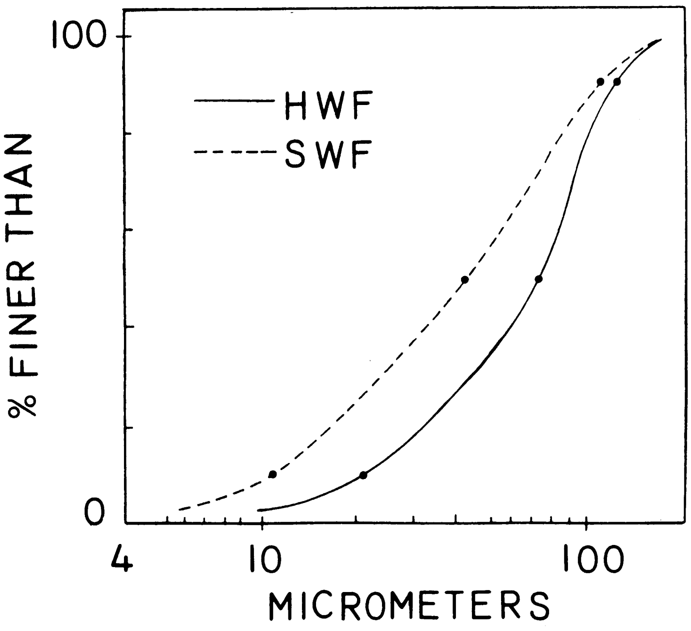

Fig. 3. Particle size distribution for hard (HWF) and soft (SWF) wheat flours.

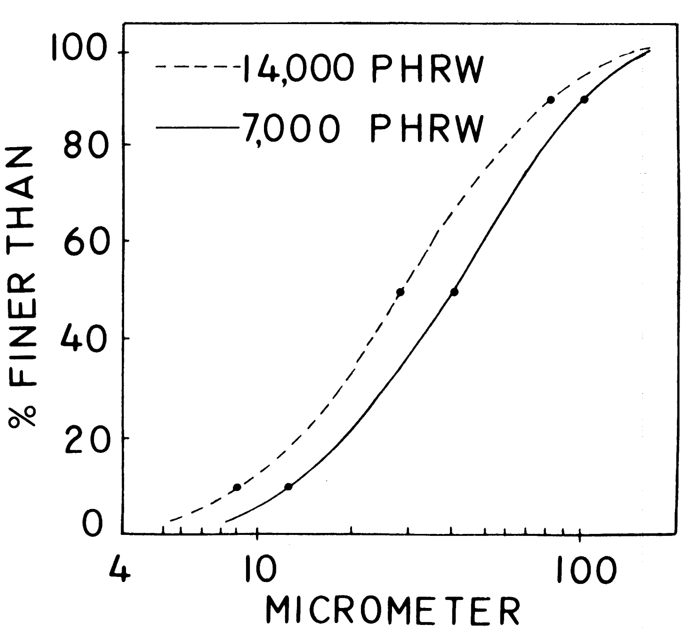

Fig. 4. Particle size distribution for hard wheat flour pin milled at 7,000 and 14,000 rpm; PHRW = pin-milled hard wheat.

the soft wheat flour. Soft wheat flour with a similar moisture content (11.9%) had a bridging threshold of 35 g of force and a bulking number of 19.6 mm (Table I). The bridging threshold for the hard wheat flour with a soft wheat flour particle size distribution (42 μm) was 45 g of force (Fig. 5), and the bulking number was only 17.5 mm (Table III). If particle size distribution were solely responsible for the highly cohesive nature of soft wheat flour, a hard wheat flour with the same particle size distribution should have yielded identical bridging threshold and bulking number values. The fact that the hard wheat flour with a soft wheat flour particle size distribution required an additional 10 g of force to cause bridging indicated that other phenomena were involved in determining bridging threshold.

It is obvious that particle size distribution is an important factor in determining bridging threshold and bulking number because the hard wheat flour particle size can be reduced to a sufficient level to produce soft wheat flour values for these characteristics. The hard wheat flour sample pin-milled at 9,000 rpm had bridging threshold and bulking number values (30 g of force, 17.8 mm) that were very similar to the data obtained for soft wheat flour (35 g of force, 19.6 mm). The hard wheat flour pin-milled at 9,000 rpm had a median particle size of 39 μm, whereas the soft wheat flour had a median particle size of 44 μm. This median particle size difference indicated that the hard wheat flour sample can be made to act like soft wheat flour, but the particle size of hard wheat flour must be reduced below the level of soft wheat flour. This is further evidence for the existence of other physical phenomena responsible for the differences in bulking number and bridging threshold.

The bridging threshold for soft wheat flour with a hard wheat flour particle size distribution is shown in Fig. 2. The moisture content of the soft wheat flour with a hard wheat flour particle size distribution was 11.8%. The bridging threshold was 61 g of force. Soft wheat flour at a similar moisture had a bridging threshold of 38 g of force. Hard wheat flour at a similar moisture content has a bridging threshold of 85 g of force. The difference in bridging threshold of 24 g of force between hard wheat flour and soft wheat flour with a hard wheat flour distribution indicates that particle size distribution is not solely responsible for the difference in bridging threshold between hard and soft wheat flour.

The bulking number values also indicated that some other factor in soft wheat flour is more significant in determining bulking

TABLE III
Bulking Number for Various Hard Wheat Particle Size Distribution Flours

	Moisture Content (12%)	
Sample	**Median Particle Size (μm)**	**Bulking Number (mm)**
Original hard wheat flour	71.2	14.1
7,000 rpm Pin-milled	42.0	17.5
9,000 rpm Pin-milled	39.0	17.8
11,000 rpm Pin-milled	31.6	18.9
14,000 rpm Pin-milled	27.9	19.1
Pin milled twice at 14,000 rpm	22.7	19.8

TABLE IV
Bulking Number and Bridging Threshold for Defatted Hard and Soft Wheat Flour with Various Median Particle Size Distributions

	Median Particle Size	Moisture Content	Bridging Threshold (grams of force)	Bulking Number (mm)
Defatted hard wheat flour	22	19.3	43.5	18.1
	42	19.1	68.5	15.1
	73	19.3	72.0	13.4
Defatted soft wheat flour	20	19.8	45.0	18.6
	45	18.8	64.0	18.1
	71	18.8	66.0	17.2

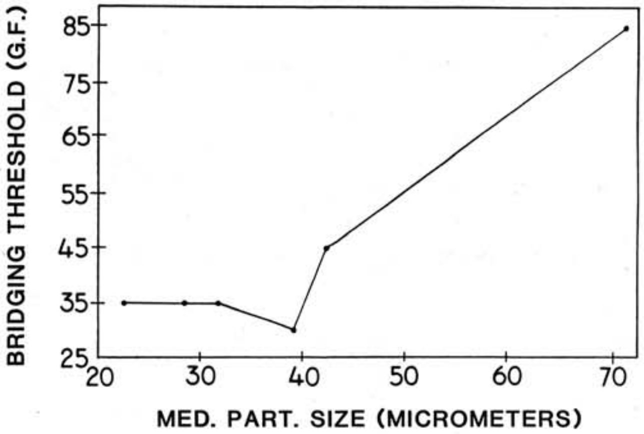

Fig. 5. Bridging threshold (grams of force) versus hard wheat flour particle size.

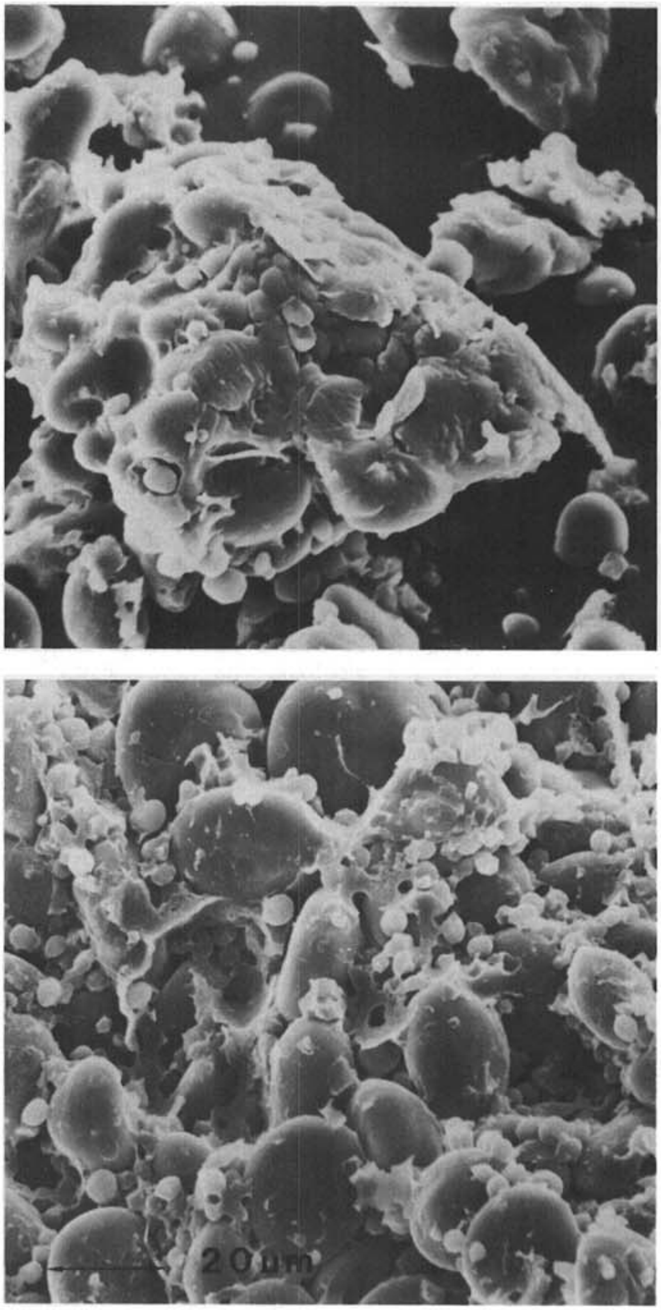

Fig. 6. Scanning electron micrograph of hard wheat flour (**top**) and soft wheat flour (**bottom**).

number than particle size distribution. The bulking number for soft wheat flour with a hard wheat flour particle size distribution was 17.2 mm a value between that for hard wheat (14.0) mm and soft wheat flours (19.5 mm).

Scanning Electron Micrographs of Hard and Soft Wheat Flour

Scanning electron microscopy was used to determine the particulate shape, surface topography, and texture of hard and soft wheat flours (Fig. 6). The hard wheat flour particles appear to have rough and smooth faces, and their shape is irregular. The soft wheat flour particles had a very rough surface or texture and an irregular shape. The basic difference in the two systems seems to be that the hard wheat flour particles have smoother faces than rough soft wheat flour. This is not surprising because hard and soft wheats differ so markedly in the ease and manner with which they break down on impact or crushing (Simmonds 1974).

In soft wheat, there is little adhesion either between starch and protein or between cell walls and cell contents. Soft wheat cell contents are readily crushed and released through rupture of the cell walls. It is primarily the release of individual starch granules from the protein matrix of the inner cell that creates the unusually rough surface texture of soft wheat flour. Cell walls tend to form separate sheets of material in soft wheat flour.

In hard wheat, cell contents and walls are coherent (Simmonds 1974). The breakage of hard wheat occurs at the weakest point, which is either along the cell wall or through starch granules and protein. In either case, the result is that hard wheat flour particles consist of smooth, sheared faces. Hard wheat flour particles are occasionally rough, but when they are compared to soft wheat flour particles, they appear smoother. Cell walls remain attached to the small granular flour particles produced during the milling process. If an individual flour particle has cell wall material as one of its facets, that side or facet of the particle will be relatively smooth.

Bridging Threshold and Bulking Number for Defatted Flours with Different Particle Sizes

It was determined above that moisture content, presence of fat, and particle size distribution had a significant influence on the bridging thresholds and bulking numbers of hard and soft wheat flours. Scanning electron micrographs of hard and soft wheat flours showed that soft wheat flour had a very rough surface or texture as compared to hard wheat flour. To study the influence of flour particle surface texture or roughness on bridging threshold and bulking number, all other flour particle attributes known to contribute to these characteristics had to be controlled. A series of defatted hard and soft wheat flours with various particle size distributions were tempered in a humidity cabinet until their moisture contents were similar (Table IV). The various particle size distributions for both hard and soft wheat flour were prepared by either smooth roll reduction or Alpine pin-mill impaction. A smooth roll reduction system was used to produce the soft wheat flours with the two highest median particle sizes (45 and 71 μm). The soft wheat flour with the lowest median particle size (20 μm) was pin-milled twice at 14,000 rpm. A smooth roll reduction system was used to produce the hard wheat flour with the highest median particle size (73 μm). All other hard wheat flour particle-size distributions were produced through the use of an Alpine impaction mill.

The bridging threshold for defatted hard and soft wheat flour was reduced as the median flour particle size was reduced. Both defatted flours exhibited this relationship. Once the median particle size distribution was reduced to the 20-μm level, the defatted soft and hard wheat flours produced essentially the same bridging threshold values (Table IV). The reduction of defatted soft wheat flour median particle size to the 20-μm level eliminated soft wheat flours surface roughness as a contributor to bridging threshold.

The bulking number values are listed in Table IV. Defatted hard and soft wheat flour did not have similar bulking number values until the median particle size of both flour systems was reduced to the 20-μm level.

CONCLUSIONS

A summary for the physical and chemical factors of hard and soft wheat flour that affect bridging threshold and bulking number is a consideration of those characteristics that control flour cohesion. The cohesiveness of a flour system is dependent upon three factors common to both flour systems and one factor found only in soft wheat flour. Moisture content, presence or absence of fat, and particle size distribution all have the same basic effect on hard and soft wheat flour bridging threshold. The shapes of the curves for bridging threshold versus flour moisture content (Fig. 2), and absence of fat (Fig. 2) and particle size distribution (Table IV) are the same for hard and soft wheat flour. In all cases, however, soft wheat flour exhibits more cohesiveness than does hard wheat flour. In all three cases, soft wheat flour's additional sensitivity can be attributed partially to its rough surface characteristics and partially to its reduced particle size distribution.

The presence of fat had the greatest effect on flour cohesion for both hard and soft wheat flours. Fat provides the necessary sites on individual flour particle surfaces for the formation of liquid bridges between particles. Excess moisture also forms liquid bridges. Small particle size provides additional surface area for the formation of liquid bridges, which are strong interparticle forces. Particle surface roughness controls interparticle interaction by Van der Waals forces and by mechanical linkages. When the particle size was reduced to a level (20 μm) where surface characteristics were eliminated, the hard and soft wheat flours had similar bridging threshold and bulking number values.

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