The Effect of Frost Damage on the Milling and Baking Quality of Red Spring Wheat

J. E. DEXTER, D. G. MARTIN, K. R. PRESTON, K. H. TIPPLES, and A. W. MacGREGOR[1]

ABSTRACT

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The effect of frost damage on the milling and baking performance of hard red spring wheat was examined in frost-damaged Canada Feed cargoes from the 1982–1983 crop year. As the degree of visual frost damage increased, flour yield decreased, flour ash increased, and flour color darkened. The extreme hardness of badly frost-damaged wheat caused large energy requirements during milling, poor mill balance, excessive flour starch damage, and unsatisfactory physical dough properties. Scanning electron micrographs of kernels and middlings from frost-damaged wheat revealed a structure consistent with very hard wheat. Baking quality deteriorated with increased frost damage. Milling frost-damaged wheat to low starch damage showed that poor gluten quality (rather than excessive starch damage) was the major contributing factor to poor baking performance. To exhibit commercially acceptable milling and baking performance, the frost-damaged wheat had to be blended with at least 70% higher quality wheat.

Frost damage can have very detrimental effects on wheat quality. Geddes et al (1932) and Malloch et al (1937) reported that frost damage reduced flour yields due to the tough and fibrous nature of middlings. However, they found that frost damage has a limited effect on baking quality. Newton and McCalla (1934) demonstrated that the extent of quality deterioration of frost-damaged wheat relates to the degree of frost and the maturity of the wheat at the time of frost. In some instances of severe frost damage, wet gluten yields decline, overall gluten quality deteriorates, and baking quality is adversely affected (McCalla and Newton 1935, Newton and McCalla 1935). They concluded that if grain dry matter exceeds 60% of kernel weight at the time of frost, wheat quality would not be seriously affected.

In late August of 1982, an extensive area of Western Canada experienced heavy frost. An unusually large proportion of the Canada Western red spring wheat (CWRS) crop was graded Canada Feed. However, an attractive price and little evidence of other forms of damage made it inevitable that some Canada Feed would find food-related uses.

The Canadian Grain Commission evaluated the end-use potential of Canada Feed wheat from the 1982 crop to facilitate marketing as a food grain. The ability of the Canadian grading system to predict end-use quality of CWRS wheat by visual assessment of frost damage and the commercial potential of frost-damaged CWRS in blends with other wheats are reported in this article. An effort is made to establish the relative importance of changes induced by frost damage in kernel hardness and gluten properties on CWRS quality.

MATERIALS AND METHODS

Wheat

Loading samples of 15 Canada Feed cargoes shipped during March and April 1983 were supplied by the Grain Inspection Division of the Canadian Grain Commission. Samples were examined individually and composited for further studies. Control samples included a composite of all cargoes of No. 3 CWRS shipped between February 1 and April 30, 1983; a composite of all cargoes of No. 1 CWRS–13.5 (13.5% protein guarantee) shipped between February 1 and April 30, 1983; a sample of No. 1 CWRS–14.5 wheat purchased from Soo Line Mills, Winnipeg, in 1982; and a composite of rail carlots of No. 2 Canada Western amber durum shipped in May 1983.

Wheat Physical Properties

All wheat samples were graded by the Grain Inspection Division. Test weight (standard deviation [SD] = 0.2 kg/hl) was determined in duplicate with a Schopper Chondrometer using a 1-L container. Weight per thousand kernels was determined with an electronic seed counter using 20-g samples from which all broken kernels and foreign material had been removed by hand. Results (SD = 0.2 g) were expressed as the average of four determinations.

Wheat hardness was estimated in duplicate by the particle size index (PSI) test of Symes (1965) using a KT 30 burr mill (SD = 0.2%) as described by Williams and Thompson (1978).

The degree of frost damage in the cargo composites was estimated by handpicking 200 g of each sample. All severely frosted kernels were separated from lightly damaged and undamaged grains and expressed as a percentage by weight.

Milling

Samples were tempered overnight to 16.5% moisture before milling with the 254-mm Grain Research Laboratory (GRL) experimental mill (Black et al 1980) in a controlled temperature (21°C) and humidity (60%) environment. For mixed grists the wheats were tempered separately and combined just before milling. Flour yields (SD = 0.4%) were expressed as a proportion of wheat sent to first break on a constant moisture basis.

Except where sample size was limiting, all experimental millings were performed in duplicate on 2-kg samples. For the evaluation of plump undamaged kernels from Canada Feed wheat and a series of admixes of severely frosted kernels to No. 1 CWRS–13.5 wheat, single 1-kg millings were performed.

The milling procedure was altered for the Canada Feed cargo composite to reduce starch damage. A 1-kg sample was milled, using corrugated sizing rolls for all middling passes. A second 1-kg portion was milled using the corrugated rolls for middling passes in conjunction with coarser clothing on the floor sieves (8XX for M1-M4 and 7XX for remaining reductions compared to 10XX normally used for all reductions).

Break release was measured for experimental millings as the proportion of stock tailing over the 24W of the B1 sifter. Milling energy consumption (SD = 0.4 W hr/kg wheat) was measured as described by Kilborn et al (1982).

Analytical Tests

Analytical test results for wheat (13.5% moisture basis) and for flour (14% moisture basis) were performed in duplicate. Where millings were duplicated, flours were composited before analysis.

The standard ICC falling number method (1980) was followed. The precision of the falling number test varies depending on the soundness of the sample and the sample size, but when falling number ranges around 300 sec, as was common for the wheats in this study, standard error would be less than 20 sec (Tipples 1971).

The Kjeldahl procedure as modified by Williams (1973) was used to determine protein content (% N × 5.7, SD = 0.15%). Standard AACC methods (1983) were used to determine ash (SD = 0.1%)

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[1] Canadian Grain Commission, Grain Research Laboratory, Winnipeg, Manitoba, R3C 3G8. Contribution No. 551.

and wet gluten (SD = 0.71%). Flour color (SD = 1.0 units) was determined with a Kent-Jones and Martin color grader as described by Holas and Tipples (1978). The method of Farrand (1964) was used to determine starch damage (SD = 1.5 units).

Physical Dough Properties

Farinograph dough development time (SD = 0.2 min), farinograph absorptions (SD = 0.35%), farinograph mixing tolerance index (SD = 5 Brabender units), extensigraph length (SD = 0.32 cm), extensigraph height (SD = 40 Brabender units), and extensigraph area (SD = 10 cm^2) were obtained by modifications of standard AACC methods (1983) as outlined by Preston et al (1982).

Baking

Flours were baked (SD loaf volume = 10 cc) and scored (SD of each scoring procedure = 0.2 units) in duplicate by the GRL remix baking test and the GRL blend remix baking test (Kilborn and Tipples 1981). Baking strength index values (SD = 1.2%), which are used to compare loaf volumes of Canadian wheats independently of protein, were determined as described by Tipples and Kilborn

Scanning Electron Microscopy

Whole kernels were cracked open longitudinally through the crease and fixed to microscope stubs with double-sided sticky tape. Stock, normally sent to M1 (overs of 10XX from break sifters) during experimental milling, was fixed to microscope stubs with Dotite silver paint. Samples were coated with gold and analyzed on a JEOL 35C scanning electron microscope at an accelerating voltage of 10 kV. Photomicrographs were taken on Plus-X Pan Kodak film.

RESULTS AND DISCUSSION

Wheat and Milling Properties of Frost-Damaged Canada Feed

Canada Feed wheat is a catch-all grade for wheat other than amber durum that does not qualify for any of the numerical grades. Therefore, a wider range in quality occurs among Canada Feed cargoes than for numerical grade cargoes. The Grain Inspection Division examined each Canada Feed cargo, confirmed that they all contained less than 5% of wheat classes other than hard red spring, and categorized them into two groups of varying visual quality (Table I). These are relative rankings—all cargoes were much below the minimum grade standard for No. 3 CWRS. As visual quality declined, the proportion of severely frosted kernels increased, and the degree of damage within the severely frosted fraction became greater. Kernel weight decreased as degree of damage increased, but although lower in test weight than the No. 3 CWRS control, the Canada Feed samples exhibited no relationship between test weight, degree of damage, and kernel weight. As pointed out by Hlynka and Bushuk (1959), other factors such as heterogeneity of kernel size, density, and packing factors strongly influence test weight.

TABLE I

Comparison of Wheat Properties (13.5% moisture) and Milling Performance of No. 3 Canada Western Red Spring (CWRS) Wheat Cargoes and Frost-Damaged Canada Feed Cargoes Exported during March and April 1983

		Canada Feed	
Property	**No. 3 CWRS[a]**	**A[b]**	**B[c]**
Wheat properties			
Severely frozen kernels, %	2	33	55
Test weight, kg/hl	80.1	76.7	77.5
Kernel weight, mg	31.3	29.7	28.1
Protein, % N × 5.7	13.0	13.1	12.9
Ash, %	1.59	1.63	1.71
Falling number, sec	360	307	285
Particle size index, %	15.1	12.9	10.8
Milling performance			
First break release, % through 24W	20.0	15.7	13.4
Energy consumption, W hr/kg	23.7	29.1	33.2
Product distribution			
Bran[d], %	16.7	16.9	17.3
Shorts[d], %	8.6	12.3	13.1
Flour[e], %	73.7	69.3	68.4

[a] Composite sample of all No. 3 CWRS export cargoes.

[b] Mean values for six export cargoes.

[c] Mean values for nine export cargoes.

[d] Proportion of wheat to first break uncorrected for moisture loss.

[e] Proportion of wheat to first break on constant moisture basis.

Wheat protein contents of the frost-damaged Canada Feed cargoes were similar to the No. 3 CWRS sample (Table I). Tipples (1980) showed that wheat protein content is relatively stable once the red spring wheat kernel desiccates to 50% moisture (about two weeks before maturity). The frozen wheat from the 1982 crop would generally have been within two weeks of full maturity at the time of frost. Wheat ash for the frost-damaged Canada Feed cargoes was slightly higher than for the No. 3 CWRS wheat, which agrees with the results of McCalla and Newton (1935).

Falling number values for the Canada Feed cargoes were generally slightly below those for the No. 3 CWRS cargo composites (Table I), although there was no visual evidence of sprout damage. The lower falling numbers may partly reflect a residual effect of the relatively high level of α-amylase present in metabolically active immature wheat kernels (Marchylo et al 1980).

As the degree of damage to the Canada Feed cargoes increased, wheat hardness increased as shown by decreasing particle size index (PSI). Some samples were very hard, exhibiting PSI values comparable to those reported for amber durum wheat (Dexter and Matsuo 1981).

The Canada Feed samples all exhibited milling properties inferior to those of the No. 3 CWRS cargo composite (Table I). As degree of frost damage increased, flour yield decreased. The increased hardness of the frost-damaged wheat caused decreased first break release and increased energy requirements.

Most of the loss in flour yield for the frost-damaged Canada Feed wheats could be attributed to a heavy yield of shorts (Table I). As reported by Geddes et al (1932), frozen wheat middling stocks are difficult to reduce, resulting in an increased flow of stock to the tail end of the mill. For example, all frost-damaged Canada Feed cargoes required seven middlings passes, whereas the No. 3 CWRS cargo composite only required six. The poorest frost-damaged Canada Feed samples produced up to 4% flour (wheat to first break basis) on the sixth middlings pass compared to less than 2% for the No. 3 CWRS wheat, and nearly 2% flour on the seventh middlings pass (results not shown). Under experimental milling conditions, poor mill balance presents few problems, although milling time increases. In continuous commercial milling operations, feed rate would have to be reduced and extensive changes in flow, roll settings, and sifter clothing would be required to prevent excessive build-up of stock on some of the rolls.

The poorest frost-damaged Canada Feed samples exhibited milling energy requirements almost 50% higher than that of the No. 3 CWRS wheat (Table I) for both the break system and the reduction system. The increased flow of stock to the tail end of the mill caused the energy requirements for tail end roll passes to increase drastically. In general, the third break pass required extremely high energy because of a very heavy flow of stock (results not shown).

Flour and Physical Dough Properties of Frost-Damaged Canada Feed Cargoes

The frost-damaged Canada Feed cargoes exhibited much higher flour ash than did the No. 3 CWRS wheat (Table II). Flour color became progressively darker as frost damage increased. The frost-damaged Canada Feed flour ash and color values were unsatisfactory by Canadian standards.

Protein loss on milling was greater in frost-damaged Canada Feed wheat than in the No. 3 CWRS wheat (Tables I, II). This was compounded by a decline in the ratio of wet gluten to flour protein as frost damage became more severe (Table II). This was consistent with the observation of McCalla and Newton (1935) that gluten yields decline when frost damage is severe.

Increasing kernel hardness as frost damage became more severe led to dramatically increased flour starch damage (Table II). The extraordinarily high starch damage probably accounts for the observation by commercial purchasers of frost-damaged Canada Feed wheat that flour maltose values were very high. High maltose values are usually considered to be an indication of sprout damage, but the wheat falling number results (Table I) showed the wheat was fairly sound. Similarly, high starch damage would account for the observation of McCalla and Newton (1935) that frost-damaged wheat flour exhibits high maltose values despite no apparent sprout damage.

The excessive starch damage of the frost-damaged Canada Feed wheat flours resulted in high farinograph absorptions (Table II). The short mixing times and relatively large mixing tolerance indexes may partly result from the high water content of the frost-damaged Canada Feed farinograph doughs, but they also indicate inferior gluten properties. McCalla and Newton (1935) reported that very severe frost can damage gluten properties of red spring wheat, and Tipples (1980) noted that farinograph mixing times are shorter for immature wheat than for fully mature wheat.

As the visual quality of the frost-damaged Canada Feed wheats declined, extensigraph length became undesirably short (Table II), reflecting increased immaturity (Tipples 1980). Extensigraph height exhibited no clear trend with degree of frost damage.

Baking Quality of Frost-Damaged Canada Feed Cargoes

All the frost-damaged Canada Feed samples performed poorly under remix baking conditions (Table III). Overall baking quality decreased as the visual quality of the samples became poorer.

The slightly lower baking absorptions of the Canada Feed samples compared to the No. 3 CWRS control (Table III) confirmed loss of gluten functionality due to frost damage. However, starch damage probably also contributes to the poor Canada Feed baking quality. According to Tipples (1969), the degree of flour starch damage exhibited by the Canada Feed flours (Table II) should result in reduced loaf volume and coarsening of crumb texture.

All Canada Feed samples exhibited very poor crumb color scores (Table III) due to poor flour color (Table II).

The remix baking quality of the Canada Feed samples, when blended with soft wheat flour, improved significantly (Table III). In some cases, loaf volume actually increased under remix blend conditions despite the poor baking quality of the soft wheat flour and the decrease in flour protein, possibly due to reduced flour starch damage.

TABLE II
Comparison of Flour Properties (14% moisture basis) and Physical Dough Properties of No. 3 Canada Western Red Spring (CWRS) Cargoes and Frost-Damaged Canada Feed Cargoes Exported during March and April 1983

Property	No. 3 CWRS[a]	Canada Feed A[b]	Canada Feed B[c]
Flour			
Ash, %	0.53	0.60	0.60
Kent-Jones color, units	2.0	4.7	5.6
Protein, % N × 5.7	12.6	12.1	11.8
Wet gluten/protein	2.99	2.74	2.60
Starch damage, Farrand units	36	52	59
Farinograph			
Absorption, %	66.1	69.4	71.2
Dough development time, min	4.50	2.58	1.78
Mixing tolerance index, Brabender units	30	33	54
Extensigraph			
Length, cm	20.5	17.2	16.3
Maximum height, Brabender units	415	411	462
Area, cm^2	120	98	105

[a] Composite sample of all No. 3 CWRS export cargoes.
[b] Mean values for six export cargoes.
[c] Mean values for nine export cargoes.

TABLE III
Comparison of Remix Baking Quality of No. 3 Canada Western Red Spring (CWRS) Wheat Cargoes and Frost-Damaged Canada Feed Cargoes Exported During March and April 1983

Property	No. 3 CWRS[a]	Canada Feed A[b]	Canada Feed B[c]
Standard remix			
Baking absorption, %	64	62	61
Loaf volume, cc	845	716	614
Baking strength index, %	102	90	80
Appearance[d]	8.0	5.0 vol	4.1 vol
Crumb structure[e]	7.0 o	6.1	5.4
Crumb color[f]	5.8 d	3.3 g	2.2 g
Remix blend			
Loaf volume, cc	695	652	637
Baking strength index, %	99	95	94
Appearance	6.8 slo	4.7 old	4.7 vol
Crumb structure[e]	7.0	5.7	5.7
Crumb color[f]	7.0	4.2 g	3.6 g

[a] Composite sample of all No. 3 Canada Western red spring export cargoes.
[b] Mean values for six export cargoes.
[c] Mean values for nine export cargoes.
[d] slo = slightly old, vol = very old.
[e] o = open.
[f] d = dull, g = grey.

TABLE IV
Quality Characteristics of Handpicked Plump Kernels from Frost-Damaged Canada Feed Wheat and Effect of Admixes of Severely Frosted Kernels on the Quality of a No. 1 Canada Western Red Spring Wheat (13.5% protein) Sample

Property	Handpicked Plump Canada Feed Kernels	100% No. 1 CWRS	No. 1 CWRS Admixed with Frosted Kernels 15%	No. 1 CWRS Admixed with Frosted Kernels 25%
Wheat[a]				
Grade	No. 3	No. 1	No. 3	Feed
Test weight, kg/hl	79.0	82.1	81.2	80.2
Kernel weight, mg	32.9	32.5	30.8	29.7
Protein, % N × 5.7	12.8	13.5	13.4	13.4
Ash, %	1.54	1.50	1.52	1.55
Falling number, sec	395	470	375	365
Particle size index, %	13.4	15.4	14.7	14.2
Milling energy, W hr/kg	27.0	23.0	24.2	26.3
Flour yield, %	71.8	74.1	73.0	71.9
Flour[b]				
Ash, %	0.53	0.48	0.50	0.52
Kent-Jones color, units	2.0	0.5	1.3	2.2
Protein, % N × 5.7	12.3	13.0	12.9	12.9
Wet gluten/protein	2.80	2.91	2.82	2.81
Starch damage, Farrand units	46	35	40	40
Farinograph				
Absorption, %	67.4	65.1	65.8	66.9
Dough development time, min	4.75	5.00	5.50	5.25
Remix baking				
Absorption, %	65	64	64	65
Loaf volume, cc	820	845	875	840
Baking strength index, %	102	99	103	99
Appearance	7.5	8.2	8.0	7.5
Crumb structure[c]	6.8 o	7.0 o	6.5 o	6.8 o
Crumb color[d]	5.5 d	6.5 d	6.5 d	5.5 d

[a] Analytical results expressed on 13.5% moisture basis.
[b] Analytical results expressed on 14% moisture basis.
[c] o = open.
[d] d = dull.

Relationship Between Visual Estimate of Frost Damage and Wheat Quality

A composite of plump, undamaged, and lightly damaged kernels handpicked from the Canada Feed cargoes showed some discoloration and blistering of the seed coat, characteristic of frost damage. The Grain Inspection Division judged that the extent of frost damage was not great enough to warrant a grade lower than No. 3 CWRS. The quality of the handpicked composite was consistent with the assigned grade (Table IV). Compared to the Canada Feed cargoes, the handpicked composite exhibited increased test weight, reduced hardness, and much improved milling and baking quality.

TABLE V
Effect of Altering Flour Starch Damage on the Milling and Baking Properties of Frost-Damaged Canada Feed Wheat

Property	Corrugated Reduction Rolls	Corrugated Reduction Rolls and Coarser Flour Clothing
Flour yield, %	67.7	69.6
Milling energy consumption, W hr/kg	23.9	22.2
Flour[a]		
Ash, %	0.60	0.62
Kent-Jones color, units	5.1	5.7
Protein, % N × 5.7	11.8	11.9
Wet gluten/protein	2.77	2.68
Starch damage, Farrand units	38	32
Farinograph		
Absorption	65.2	63.8
Dough development time, min	1.75	2.50
Remix baking		
Absorption, %	62	63
Loaf volume, cc	675	670
Baking strength index, %	87	85
Appearance	5.0 old	5.2 old
Crumb structure	5.5	5.8
Crumb color	3.0 grey	2.5 grey

[a] Analytical results expressed on 14% moisture basis.

When 15 and 25% of severely frost-damaged kernels handpicked from the Canada Feed cargoes were admixed to a No. 1 CWRS sample, the Grain Inspection Division assigned grades of No. 3 CWRS and Canada Feed, respectively. The assigned grades were warranted on the basis of reduced milling yield (Table IV). Loaf volume was not influenced despite the apparent effect of frost on gluten properties. The good gluten properties of the No. 1 CWRS wheat would be expected to "carry" inferior gluten. The good baking quality of the admixtures could also reflect absence of the excessive starch damage observed for the Canada Feed cargoes.

Effect of Reduced Starch Damage on Frost-Damaged Wheat Quality

The relative contributions of poor gluten properties and high flour starch damage to the poor baking quality of frost-damaged Canada Feed wheat were examined by milling low starch damage flour by using corrugated reduction rolls (Table V). Milling energy consumption, flour starch damage, and farinograph absorption were greatly reduced compared to the normally milled frost-damaged Canada Feed cargoes. However, the frozen Canada Feed flour produced by corrugated reduction rolls exhibited no improvement in baking quality and still exhibited a very short farinograph mixing time. When coarser flour sieve clothing was used in conjunction with the corrugated reduction rolls, milling energy consumption, flour starch damage, and farinograph absorption were decreased further but baking quality did not improve appreciably. Therefore, it would appear that the major cause of the poor baking performance of the frost-damaged Canada Feed wheat flour is inferior gluten properties.

Effect of Frost on Wheat Microstructure

Comparison, by scanning electron microscopy, of the severely

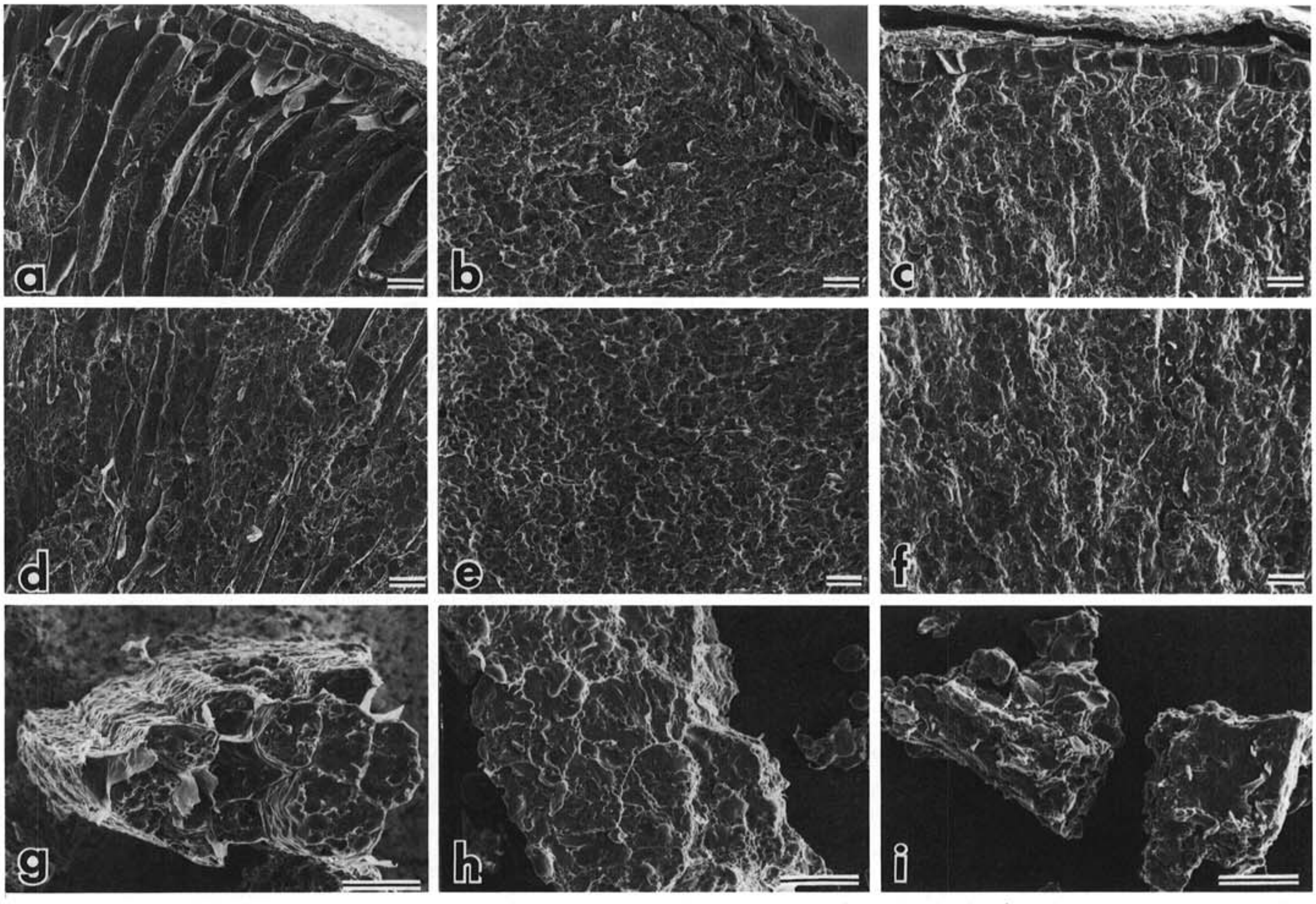

Fig. 1. Scanning electron micrographs of distal half-seeds of unfrozen hard red spring wheat (**a,d**), frozen hard red spring wheat (**b,e**), amber durum wheat (**c,f**) and of coarse middlings stock of unfrozen hard red spring wheat (**g**), frozen hard red spring wheat (**h**), and amber durum wheat (**i**). Scale bars = 50 μm.

frozen kernels from the current study with the microstructure of undamaged CWRS wheat kernels revealed marked structural differences (Fig. 1). The undamaged CWRS kernels exhibited a more ordered aleurone and subaleurone cell structure and a thinner seed coat (Fig. 1 a and b). The latter observation was consistent with the lower flour yield of the severely frozen kernels. Within the endosperm, cellular structure was more clearly defined in plump undamaged kernels than in severely frozen kernels (Fig. 1 d and e). The severely frozen kernels exhibited a very compact endosperm structure. Starch granules were less visible than in the endosperm of undamaged kernels and tended to be fully embedded in and covered by an amorphous protein matrix.

The effect of frost on CWRS milling properties could be readily observed by comparing the microstructure of coarse middling particles from the No. 3 CWRS cargo composite to the microstructure of coarse middling particles from a very poor Canada Feed sample. The middling particles of the undamaged wheat appeared to be formed largely by fracture along cell walls (Fig. 1g). Cellular packets were clearly visible. In contrast, Canada Feed wheat middlings contained a large proportion of particles exhibiting random fracturing within cells giving greater evidence of starch granule damage (Fig. 1h). The Canada Feed wheat middling particles also tended to have a more amorphous appearance—starch granules were less conspicuous and more tightly held within the protein matrix.

Amber durum wheat kernels are similar in hardness to the frozen Canada Feed samples (Kilborn et al 1982). Comparison of amber durum wheat kernel structure (Fig. 1 c and f) and middlings structure (Fig. 1i) to severely frozen CWRS kernel structure (Fig. 1 b and e) and frost-damaged Canada Feed middlings structure (Fig. 1h) revealed close structural similarities consistent with current concepts of wheat hardness based on kernel structure (Hoseney and Seib 1973, Moss et al 1980, Simmonds 1974, Simmonds et al 1973). Nevertheless, the apparent hardness of frost-damaged Canada Feed samples must be partially distinct from the concept of wheat hardness based on wheat class and vitreosity. Durum wheat middlings reduce to flour much more readily than do frost-damaged Canada Feed wheat middlings, and durum wheat does not exhibit mill balance problems.

Mixed Gristing Frost-Damaged Canada Feed Wheat

The frost-damaged Canada Feed wheat was comprised of licensed varieties of good intrinsic quality. The remix blend baking results demonstrated the ability of the frost-damaged Canada Feed flours to carry the baking quality of weak low protein flours (Table III). The high milling energy requirement and poor mill balance of the frost-damaged Canada Feed wheat could be avoided by milling mixed grists with other wheats. The maximum proportion of frost-damaged Canada Feed wheat that could be tolerated in a grist would vary depending on the quality requirements of individual markets.

TABLE VI

Effect on Milling and Baking Properties of Mixed Gristing Frost-Damaged Canada Feed Wheat with a No. 1 Canada Western Red Spring (14.5% protein) Wheat

Property	100% Canada Feed	30% Canada Feed	15% Canada Feed	100% No. 1 CWRS
Flour yield, %	69.7	73.9	73.6	74.8
Milling energy consumption, W hr/kg	30.6	26.6	24.1	24.2
Flour[a]				
Ash, %	0.56	0.52	0.48	0.48
Kent-Jones color, units	4.5	2.5	1.7	1.0
Protein, %	12.0	13.2	13.5	13.7
Wet gluten/protein	2.76	2.84	2.83	2.92
Starch damage, Farrand units	50	35	32	31
Farinograph				
Absorption, %	67.7	65.2	64.5	64.0
Dough development time, min	2.00	6.50	6.25	6.25
Remix baking				
Absorption, %	63	64	64	64
Loaf volume, cc	705	920	940	950
Baking strength index, %	90	105	105	104
Appearance	5.1 old	8.1	8.3	8.5
Crumb structure[b]	6.2	6.7 o	7.2	6.9 o
Crumb color[c]	3.2 g	6.5 d	7.3	7.5

[a] Analytical results expressed on 14% moisture basis.

[b] o = open.

[c] g = grey, d = dull.

As shown in Table VI, addition of 15% frost-damaged Canada Feed to No. 1 CWRS-14.5 wheat did not greatly alter flour properties. However, flour yield was reduced by more than 1%. Addition of 30% frozen Canada Feed to the grist did not cause any further loss in flour yield but resulted in increased flour ash values and darker flour color.

The mixed grists exhibited much improved mill balance compared to 100% frost-damaged Canada Feed wheat (results not shown). Milling energy consumption of the mixed grists was only slightly greater than the No. 1 CWRS-14.5 wheat, resulting in only a marginal increase in flour starch damage. Farinograph properties of the mixed grists and the 100% No. 1 CWRS-14.5 flour were comparable. Baking strength indexes were equal to the 100% No. 1 CWRS-14.5 flour, although for the 30% frost-damaged Canada Feed wheat, flour bread crumb structure and crumb color deteriorated.

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