Removal of Sprouted Kernels from Hard Red Spring Wheat with a Specific Gravity Table[1]

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ABSTRACT

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Commercially grown samples (27) of hard red spring wheat from the 1989 Western Canada harvest that had varying degrees of sprout damage were fractionated on a specific gravity table. Sprouted, shrunken, and broken kernels were highly concentrated in the least dense fractions. The remaining denser fractions exhibited improved appearance, higher test weight, and reduced α-amylase activity. The removal of sprouted, shrunken, and broken kernels in the lightest fractions resulted in improved milling performance for the remaining wheat. When six samples that had been downgraded to Canada Feed wheat because of sprout damage were fractionated, an average of 62% (range, 42–81%) was recovered that met the visual requirements of No. 3 Canada Western Red Spring wheat. The wheat fractions promoted to the No. 3 grade exhibited improved processing quality consistent with the assigned grade. Specific gravity table fractionation of wheat has enormous potential for increasing the market value of low-grade wheat by segregating portions with improved processing quality.

Specific gravity tables, which fractionate samples on the basis of differences in density, are effective in removing light foreign material from seeds (Peske and Boyd 1985). More recent studies (Winter 1987, Hook et al 1988, Munck 1989) indicate that specific gravity tables can be used to recover fractions of improved test weight and reduced α-amylase activity from sprouted European wheat.

Workers at the Grain Research Laboratory have been studying the specific gravity table separation of wheat for about 20 years. Recently, we reported that specific gravity separation of Canada Western Red Spring (CWRS) wheat has enormous potential for increasing market value in that it isolates wheat fractions with improved visual appearance and improved milling quality (Tkachuk et al 1990). Based on a limited number of samples, we concluded that fractions of greatly reduced α-amylase activity could be isolated from sprout-damaged CWRS wheat with a specific gravity table. The purpose of the present study was to establish the broad applicability of specific gravity tables for removing sprouted kernels from CWRS wheats by using a more diverse set of commercially grown samples.

MATERIALS AND METHODS

Wheats

The Grain Inspection Division of the Canadian Grain Commission supplied 27 samples (50 kg each) of hard red spring wheat in November 1989. The samples were predominantly No. 3 CWRS wheat and some that had been downgraded to Canada Feed.

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Some samples were selected from the Division's 1989 new crop survey of individual farmers' deliveries; others were selected from rail carlots sampled during unloading at terminal elevators in Thunder Bay, Ontario, and Vancouver, British Columbia.

Gravity Table Fractionation

The samples were cleaned to export standards with a Carter C-989 dockage tester (Simon-Day Ltd., Winnipeg, MB) and were fractionated in 40-kg lots with a specific gravity separator (SY 300, Spiroll Kipp Kelly, Inc., Winnipeg, MB). This specific gravity table has a capacity of 580 kg/hr and can produce up to five fractions.

The specific gravity table consists of a reciprocating metal screen deck through which air is forced. The deck is oscillated laterally and longitudinally; its action causes the denset wheat kernels to travel farther along the deck before being discharged. The less dense kernels float more from the force of the air current than do the denser kernels and thus are more affected by the force of gravity. They travel across the line of the deck incline and are discharged at a position corresponding to a shorter distance along the deck.

The proportions of the recovered fractions can be changed by adjusting airflow, deck incline, oscillation and distance, and discharge splitter positions. Ideally, settings should be adjusted slightly between samples to optimize separation, but the relatively small size of our samples made that impractical. Instead, we used constant settings that stratified all the wheat samples in a reasonably uniform layer. Settings were as follows: eccentric, 7; air gate, 3; side raise, 1; end raise, 5; speed, 6.5; hopper, 4. The fractions collected in the current study were designated in order of increased density as F1–4 (F4 comprises the two densest fractions).

Wheat Physical Characterization

Unfractionated samples and individual fractions of the specific gravity table were inspected by inspectors from the Canadian Grain Commission. They assigned a grade to each sample and the corresponding fractions and determined the proportion of kernels that were broken, shrunken, or sprouted (lightly, moderately, and severely).

Test weights were determined singly with a Schopper chondrometer using a 1-L container (Dexter and Tipples 1987); kernel weights were determined as described by Dexter et al (1987).

Milling

Gravity table fractions derived from Canada Feed samples were individually composited into two fractions: Canada Feed and those graded No. 3 CWRS or better. The unfractionated Canada Feed samples and each corresponding pair of specific gravity table composites were milled into flour in single 1-kg lots collected from the specific gravity table without further cleaning. Samples were prepared for milling as described by Dexter and Tipples (1987) and milled by a five-stand Allis-Chalmers laboratory mill using the Grain Research Laboratory sifter flow (Black et al 1980). Flour yields were expressed as the proportion of wheat to first break on a constant moisture basis.

Wheat and Flour Analytical Tests

All analytical tests were performed in duplicate and adjusted to 14% moisture basis. The moisture contents of ground wheat and flour were determined by a moisture tester (C. W. Brabender Instruments, South Hackensack, NJ) as outlined in the instruction manual.

Wheat and flour protein contents (%N $\times$ 5.7) were determined by the Kjeldahl procedure as modified by Williams (1973). Semolina ash and wet gluten content were determined by AACC methods 08-01 and 38-11, respectively (AACC 1983). Flour grade color was determined with a color grader (Series IV, Henry Simon, Stockport, U.K.) as outlined in the instruction manual. The enzymatic procedure of Farrand (1964) was used to estimate starch damage.

Wheat falling number was determined on 7-g samples from duplicate 300-g grinds (Tipples 1971). A nephelometric procedure (Kruger and Tipples 1981) was used to determine α-amylase activity in flour and wheat falling number grinds. Amylographs were performed on 65 g of flour in 450 ml of deionized water; maximum viscosity was measured by AACC method 22-10 (AACC 1983).

Farinograph

Farinograph properties were determined by AACC method 54-21 (AACC 1983) with minor modifications (Preston et al 1982).

Baking

Flours were baked in duplicate and scored by the remix procedure (Kilborn and Tipples 1981). Baking strength index values, which compare loaf volumes independently of protein content, were determined as described by Tipples and Kilborn (1974).

RESULTS AND DISCUSSION

Wheat Characteristics

Samples representing farmers' deliveries and rail carlots were chosen to ensure that the samples were as heterogeneous as possible. The specific gravity table separated all the wheat samples into fractions with a wide range of test weight and kernel weight. Table I shows the results for six samples downgraded to Canada Feed as representative examples.

The specific gravity table was highly effective in removing sprouted kernels yielding fractions with improved (increased) falling number. Table II summarizes the contents of sprouted kernels determined by Canadian Grain Commission inspectors and the falling numbers for the specific gravity table fractions obtained from all the wheats that exhibited some evidence of sprout damage. The consistent success achieved in removing sprouted kernels from such a diverse set of red spring wheat samples is compelling evidence of the broad applicability of the specific gravity table for that purpose.

The detailed analyses of the Canada Feed samples and the specific gravity table fractions by the inspectors confirmed that sprouted, shrunken, and broken kernels were highly concentrated in the least dense wheat fractions (Table I). As a result, the denser fractions had larger kernels and fewer sprouted kernels than did the corresponding unfractionated controls. For the six fractionated Canada Feed wheats, 42–81% (by weight) of the denser fractions qualified for the No. 3 CWRS grade, corresponding to a 20–40% increase in market value of the total wheat lots. These results corroborate our preliminary conclusion that specific gravity tables have enormous commercial potential for increasing the market value of low-grade red spring wheat (Tkachuk et al 1990).

We recently reported that specific gravity tables could be used to isolate fractions of improved visual quality from low-grade durum wheat (Dexter et al 1991). A negative quality attribute of the improved durum wheat fractions was significantly lower protein content compared with the unfractionated controls because of a strong inverse relationship between durum wheat test weight and protein content (Dexter et al 1987). In the current study, the denser red spring wheat fractions of improved quality were comparable in protein content to those of the unfractionated controls (Table I). This agrees with our preliminary investigations of gravity table fractionation of red spring wheat (Tkachuk et al 1990). Apparently, the relationship between wheat test weight and protein content established for durum wheat does not apply to red spring wheat.

The concentration of sprouted kernels (severely sprouted kernels, in particular) in the lightest fractions recovered from the Canada Feed samples resulted in greatly improved falling numbers for the denser fractions (Table I). When combined, the recovered fractions that met the visual standards for No. 3 CWRS exhibited drastically reduced α-amylase activity compared with the corresponding unfractionated wheats (Table III). Wheat with a falling

TABLE I
Canada Feed Wheats: Properties and Gravity Table Fractions

Sample	Yield (%)	Grade	Protein Content[a] (%)	Test Weight (kg/hl)	Kernel Weight (mg)	Shrunken and Broken Kernels (%)	Sprouted Kernels[b] S (%)	M (%)	L (%)	Total (%)	Falling Number (sec)
Wheat 1											
UF	100	Feed	15.0	74.8	29.9	2.1	2.5	2.0	1.2	5.7	65
F1	9	Feed	15.9	69.0	20.6	14.5	14.5	7.2	2.4	24.1	60
F2	20	Feed	15.5	74.3	25.5	2.8	4.0	4.0	2.4	10.4	60
F3	29	Feed	15.0	75.6	27.9	0.7	2.4	4.0	1.0	7.4	125
F4	42	3 CWRS	14.8	77.1	30.7	0.2	0.4	1.0	1.2	2.6	220
Wheat 2											
UF	100	Feed	10.3	71.3	33.3	1.6	6.0	1.6	0.8	8.4	60
F1	9	Feed	10.3	64.7	25.1	17.8	36.0	4.1	2.2	42.3	60
F2	18	Feed	10.4	71.7	29.4	2.5	4.8	8.0	2.0	14.8	60
F3	29	Feed	10.3	73.4	33.3	0.5	1.2	2.4	2.0	5.6	110
F4	44	3 CWRS	10.4	74.4	34.4	0.2	0.1	1.2	0.7	2.0	225
Wheat 3											
UF	100	Feed	10.8	74.0	25.4	2.2	2.4	3.6	1.6	7.6	70
F1	5	Feed	11.3	68.5	18.6	23.4	11.5	3.3	4.1	22.9	60
F2	14	Feed	10.8	73.3	22.4	2.6	2.4	3.6	2.8	8.8	65
F3	27	3 CWRS	10.6	74.4	25.0	0.7	1.3	1.4	0.3	3.0	110
F4	54	3 CWRS	10.7	75.3	27.7	0.2	0.2	0.6	1.0	1.8	225
Wheat 4											
UF	100	Feed	13.0	74.6	30.2	1.5	3.2	2.0	1.8	7.0	60
F1	9	Feed	13.0	69.4	22.4	12.5	16.8	6.8	4.0	27.6	60
F2	19	Feed	12.9	74.3	28.4	2.4	4.5	2.8	3.0	10.3	60
F3	26	Feed	13.0	75.7	30.3	1.2	1.6	2.0	1.0	5.6	100
F4	46	3 CWRS	13.3	76.6	33.3	0.1	0.4	0.5	1.4	2.3	175
Wheat 5											
UF	100	Feed	12.1	75.8	30.9	3.5	1.2	2.0	2.2	5.4	105
F1	7	Feed	13.7	69.4	20.0	36.0	8.4	4.4	1.0	13.8	60
F2	16	Feed	12.8	74.6	25.2	7.6	4.4	2.0	0.8	7.2	75
F3	29	3 CWRS	12.0	76.2	30.2	0.5	0.3	0.6	0.7	1.6	180
F4	48	3 CWRS	11.8	77.1	34.9	0.1	0.4	0.4	0.5	1.3	315
Wheat 6											
UF	100	Feed	13.8	76.6	28.8	1.5	1.6	1.8	2.0	5.4	65
F1	5	Sample[c]	14.6	67.4	18.7	19.2	9.0	8.4	1.0	18.4	60
F2	15	Feed	14.4	74.2	23.7	3.2	4.0	4.4	1.2	4.2	60
F3	27	3 CWRS	13.9	76.4	27.5	0.1	1.0	1.6	1.6	4.2	105
F4	53	3 CWRS	13.7	78.1	32.4	0.2	trace	0.2	0.4	0.6	190

[a]Protein content, kernel weight, and falling number are expressed on 14% moisture basis.
[b]S = severe, M = moderate, L = light, UF = unfractionated, F = fraction, CWRS = Canada Western Red Spring.
[c]Sample grade because of heated kernels.

TABLE II
Properties of Specific Gravity Table Fractions Derived from Canada Western Red Spring Wheat Samples with Variable Sprout Damage

Wheat Sample	Yield (%) Mean	Yield (%) Range	Sprouted Kernels (%) Mean	Sprouted Kernels (%) Range	Falling Number[a] (sec) Mean	Falling Number[a] (sec) Range
Very sprouted (9 samples)						
UF[b]	100.0	···	5.4	2.7–8.4	67	60–75
F1	5.5	1.6–9.5	30.8	13.8–46.0	60	60–60
F2	15.5	10.5–25.9	9.9	7.0–14.8	61	60–65
F3	27.4	25.9–41.5	4.0	1.1–7.4	129	80–200
F4	51.9	41.5–61.0	1.5	0.6–2.6	244	175–335
Badly sprouted (7 samples)						
UF	100.0	···	3.7	2.5–5.4	109	95–125
F1	8.7	4.4–13.9	11.8	6.4–17.2	61	60–65
F2	17.5	13.9–20.9	5.7	0.9–8.6	122	70–325
F3	29.5	27.8–30.8	2.1	0.2–3.3	231	180–405
F4	44.3	35.7–51.6	0.9	0.4–1.5	319	275–420
Moderately sprouted (9 samples)						
UF	100.0	···	1.6	0.6–2.7	229	160–270
F1	9.3	4.7–17.2	5.6	2.0–12.6	80	60–110
F2	17.9	13.7–23.4	1.6	0.7–3.8	241	125–415
F3	27.5	23.3–28.8	0.8	0.2–2.1	319	215–430
F4	45.3	28.8–54.3	0.3	0.0–1.2	370	290–430

[a]Expressed on 14% moisture basis.
[b]UF = unfractionated, F = fraction.

number below 150 sec has poor marketability, because flour from wheat with a low falling number has sticky bread crumb, soft dough properties, and reduced baking absorption (Tipples et al 1966, Ibrahim and D'Appolonia 1979, Buchanan and Nicholas 1980, Moot and Every 1990). Composites of fractions recovered from the Canada Feed samples that graded No. 3 CWRS would meet the minimum falling number requirements for satisfactory baking performance.

The effectiveness of the specific gravity table in removing sprouted kernels from red spring wheat was further verified by fractionating admixtures of a sound No. 1 CWRS wheat and the most severely sprouted Canada Feed sample (Table IV). When 5 and 10% of the Canada Feed sample was blended into the No. 1 CWRS sample, the resulting admixtures were downgraded to No. 3 CWRS, and falling number dropped from 445 to 225 sec and 95 sec, respectively. Removing the least dense fraction from the 5% admixture, 16% by weight, restored the remaining wheat to a visual appearance and falling number comparable to those of the original No. 1 CWRS sample. Removing the least dense fraction from the 10% admixture, 13% by weight, restored the falling number in the remaining wheat to a value near that of the original No. 1 CWRS wheat. However, the denser fractions were downgraded to No. 2 or 3 CWRS because of kernels remaining from the Canada Feed sample that were weathered and damaged by mildew.

Milling Properties

Removing shrunken and broken kernels with the least dense fractions isolated from the Canada Feed samples (Table I) improved the milling performance of composites of the denser fractions and reduced the milling performance of composites of the lighter fractions, compared with the unfractionated Canada Feed controls (Table III). In all cases, flour yields of the denser composites were greater than those of the corresponding unfractionated wheat, without sacrificing flour ash content. Flour colors of the denser composites were brighter (lower grade color) than those of the unfractionated controls, presumably because the shrunken kernels and those damaged by mildew were removed (Dexter and Matsuo 1981, 1982). Flour protein content, wet gluten content, and starch damage were relatively constant for all fractions within a given wheat sample. Flour amylograph peak viscosity was greatest for the denser composites and lowest for the lighter composites, in agreement with α-amylase trends (Table III). Milling yields, flour ash contents, and flour grade colors of the denser composites from the Canada Feed wheats were within the long-term range expected of No. 3 CWRS (Preston et al 1988), justifying their promotion to that grade.

Farinograph Properties

In general, the denser composites from the Canada Feed samples exhibited higher farinograph absorption than did the corresponding unfractionated wheats and the lighter composites (Table V),

TABLE III
Canada Feed Wheats: Milling Properties and Gravity Table Fractions[a]

Sample[b]	α-Amylase Activity (units/g) Wheat	Flour	Flour Yield[c] (%)	Ash[d] (%)	Grade Color (units)	Protein Content[d] (%)	Wet Gluten[d] (%)	Starch Damage[d] (units)	Amylograph Peak Viscosity[d] (BU)
Wheat 1									
UF	807	274	73.5	0.49	1.2	14.1	43.0	27	25
F1–3	1,060	406	72.4	0.48	1.4	14.5	42.8	27	15
F4	78	19	74.8	0.49	0.8	13.9	41.0	27	90
Wheat 2									
UF	1,680	1,066	73.8	0.48	2.0	9.8	27.4	27	10
F1–3	2,132	1,076	73.0	0.47	1.8	9.5	27.0	27	10
F4	81	30	75.0	0.48	0.7	9.8	27.1	25	115
Wheat 3									
UF	706	278	73.6	0.46	−0.1	9.9	26.8	23	30
F1,2	1,410	761	72.1	0.45	1.1	10.1	26.7	22	15
F3,4	167	61	73.8	0.43	−1.3	9.8	26.0	22	65
Wheat 4									
UF	1,317	494	72.6	0.50	1.7	12.3	35.8	32	20
F1–3	1,778	791	72.1	0.50	1.8	12.1	35.0	32	15
F4	119	42	73.6	0.48	1.1	12.4	35.8	29	65
Wheat 5									
UF	330	112	73.1	0.49	1.0	11.2	30.4	30	40
F1,2	986	548	72.5	0.52	2.5	12.2	33.1	31	20
F3,4	49	21	75.0	0.48	0.4	11.1	30.0	30	110
Wheat 6									
UF	772	327	73.3	0.50	1.2	13.1	38.3	33	20
F1,2	2,259	1,121	70.8	0.51	3.3	13.5	38.4	32	10
F3,4	153	52	74.5	0.48	0.2	12.8	37.2	32	55

[a]Gravity table fractions were composited by grade to yield a Canada feed and a no. 3 Canada western red spring component.
[b]UF = unfractionated, F = fraction.
[c]Expressed as proportion of wheat to first break on constant moisture basis.
[d]

TABLE IV
Properties of Gravity Table Fractions from a No. 1 Canada Western Red Spring (CWRS) Wheat Admixed with a Canada Feed Wheat[a]

Sample	Yield (%)	Grade	Protein Content (%)	Test Weight (kg/hl)	Kernel Weight (mg)	Shrunken and Broken Kernels (%)	Sprouted Kernels[b] S (%)	M (%)	L (%)	Total (%)	Falling Number (sec)
Wheat 7											
UF	100	1 CWRS	14.9	78.9	26.9	2.7	0	0	0	0	445
Admixture 1 (90% wheat 7 and 10% wheat 2)											
UF	100	3 CWRS	14.6	77.7	27.8	2.2	0.7	0.8	1.0	2.5	95
F1	13	Feed	14.6	73.2	22.6	11.5	2.8	1.6	2.0	6.4	65
F2	21	3 CWRS	14.6	76.7	25.8	1.4	0.2	0.1	0.6	0.9	325
F3	30	3 CWRS	14.5	78.1	28.1	0.5	0	trace	0.2	0.2	405
F4	36	2 CWRS	14.4	80.5	31.7	0.2	0	trace	0.4	0.4	420
Admixture 2 (95% wheat 7 and 5% wheat 2)											
UF	100	3 CWRS	14.8	77.9	27.3	1.9	0.6	0.4	0.7	1.7	225
F1	16	Feed	15.1	74.3	21.6	10.2	2.8	2.0	1.2	6.0	75
F2	23	2 CWRS	14.7	77.7	26.5	1.2	trace	0.2	0.8	1.0	415
F3	32	1 CWRS	14.5	79.5	29.5	0.3	0	0	0.2	0.2	430
F4	29	1 CWRS	14.6	80.4	32.2	0.1	trace	0	trace	trace	430

[a]Kernel weight, protein content, and falling number are expressed on 14% moisture basis. Properties of the Canada Feed wheat (wheat 2) are given in Table I.
[b]S = severe, M = moderate, L = light, UF = unfractionated, F = fraction.

TABLE V
Canada Feed Wheats: Farinograph and Remix Baking Properties and Gravity Table Fractions[a]

	Farinogram				Remix Bread			
Sample	Abs[b,c] (%)	DDT (min)	MTI (BU)	Stb (min)	Abs[c] (%)	LV (cc)	BSI (%)	Crumb (units)
Wheat 1								
UF	61.7	3.0	70	5.5	62	995	107	6.8-d
F1-3	61.1	3.75	60	5.5	61	970	101	6.5-d
F4	63.3	4.5	40	7.0	63	940	103	6.8-d
Wheat 2								
UF	56.7	1.0	130	1.0	56	700	112	5.8-g
F1-3	56.6	1.0	135	1.5	56	690	114	5.8-g
F4	58.6	1.5	70	3.0	57	690	110	6.5-g
Wheat 3								
UF	56.1	1.25	110	2.0	57	735	117	6.8-d
F1,2	54.1	1.25	110	2.0	55	750	116	6.5-d
F3,4	56.4	1.5	90	2.5	57	690	110	7.0
Wheat 4								
UF	61.5	1.75	75	3.0	62	855	106	5.8-d
F1-3	59.8	1.75	60	4.0	60	850	108	5.5-d
F4	63.3	3.0	45	6.0	63	865	107	6.2-d
Wheat 5								
UF	60.6	2.0	80	3.0	60	700	96	5.8-d
F1,2	59.2	1.75	70	3.0	60	745	94	5.2-d
F3,4	61.7	2.0	55	4.0	60	670	93	5.5-d
Wheat 6								
UF	61.6	3.0	35	5.0	62	895	104	6.0-d
F1,2	60.0	2.75	50	5.5	60	850	96	5.5-d
F3,4	62.5	3.75	50	6.0	63	890	106	6.0-d

[a] Gravity table fractions were composited by grade to yield a Canada Feed and a No. 3 Canada Western Red Spring component.
[b] Abs = absorption, DDT = dough development time, MTI = mixing tolerance index, Stb = stability, LV = loaf volume, BSI = baking strength index, UF = unfractionated, F = fraction, d = dull, g = gray.
[c] Expressed on 14% moisture basis.

although flour starch damages were comparable (Table III). The lower absorption of the lighter composites probably reflects the degradation of damaged starch by α-amylase, resulting in impaired water-binding capacity (Meredith and Pomeranz 1985).

The denser composites also exhibited longer dough development times, longer stability, and lower mixing tolerance indexes, indicating stronger mixing characteristics (Table V). The trend toward weaker dough characteristics for the lighter composites is attributable to high α-amylase activity (Meredith and Pomeranz 1985).

Remix Baking Properties

The well-established detrimental effects of high α-amylase activity on baking absorption and crumb color (Tipples et al 1966, Ibrahim and D'Appolonia 1979) are apparent on comparison of the baking results of the severely sprouted lighter composites and those of the much sounder, denser composites (Table V). Baking strength index, a measure of loaf volume independent of flour protein content, showed no consistent trends with α-amylase activity as shown by Ibrahim and D'Appolonia (1979).

There was no obvious indication of sticky dough or crumb properties often associated with high α-amylase activity (Buchanan and Nicholas 1980, Moot and Every 1990) for any of the samples. These properties are most apparent with long baking processes (Chamberlain et al 1983) and might have been more apparent in the current study had a more rigorous baking process been used.

CONCLUSIONS

This study verifies our preliminary conclusion (Tkachuk et al 1990) that specific gravity tables can effectively remove sprouted kernels from severely sprouted red spring wheat. Not only are the residual fractions lower in α-amylase activity and therefore more suitable for baking, but they also exhibit improved milling performance.

Reports of the successful removal of sprouted kernels from European common wheats (Winter 1987, Hook et al 1988, Munck 1989) and, more recently, durum wheat (Dexter et al 1991) establish the broad suitability of specific gravity table separation for enhancement of wheat quality. The least dense fractions recovered are always inferior in appearance and poorer in processing quality compared with the unfractionated sample. As a result, specific gravity table fractionation of milling-grade wheat would not be economically attractive, since the benefit of producing some wheat of improved quality would be offset by the production of some poorer quality wheat of lower value. However, specific gravity tables undoubtedly have enormous potential for increasing the commercial value of low-grade wheat by recovering portions as milling-grade wheat.

In the current study, fractionations were performed with a single pass over a specific gravity table without optimizing settings between samples. If the gravity table settings were optimized for each sample, and if two or more gravity tables were used in series, more efficient separations could probably be achieved.

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