EVALUATION OF A HIGH–SPEED COLOR SORTER FOR SEGREGATION OF RED AND WHITE WHEAT

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ABSTRACT. *A high–speed color sorter has the potential to help wheat breeders purify their white wheat breeding lines and white wheat exporters meet purity requirements of end users. For this reason, a commercial color sorter was evaluated for sorting mixed red and white wheat. Ten wheat blends containing 95% white and 5% red wheat by mass were produced by mixing common cultivars of hard white and hard red winter wheat. The sorter was set to accept white wheat and reject red wheat in single pass when viewed by either a green or red filter. Percentages of red and white wheat in the accept and reject portions were determined by soaking in sodium hydroxide, a definitive method for determining if a wheat kernel is red or white. In order to reject most of the red wheat in a single pass through the sorter, at least 15% of the original wheat mass needed to be rejected. For wheat blends with white wheat of consistent color that contrasted considerably with the red wheat contaminant, this rejection would reduce red wheat mass in the accept portion to <1%. This reduction could be achieved for most other blends when rejecting 20 to 25% of the mass or through re–sorting the accept portion. The red filter resulted in more red kernels rejected than the green filter.*

Keywords. *Hard red winter, Hard white, Color sorting.*

Classifying and sorting wheat according to color class is important because milling, baking, and taste properties of wheat vary according to its color class. Color class can also determine wheat market price, with domestic and foreign buyers sometimes paying a premium for wheat of a preferred color class. For example, hard white wheat (HWH) is preferred in countries where noodles, flat breads, and steamed breads are made from locally produced or Australian hard white wheat (Bequette and Hermann, 1994). When a mixture of two or more contrasting classes occurs, such that a lot is <90% pure, it is classed as mixed, and its price is reduced. Mixing can occur if lots are incorrectly classed at marketing, or if classes are not kept segregated during storage and handling.

Color class identification and sorting is also important to wheat breeders to ensure the purity of their breeding lines. Currently, breeders must manually remove white wheat from hundreds of early generation segregating populations which can contain >98% red kernels. This subjective and laborious process could benefit significantly from a means to automatically purify white wheat samples. Grain inspectors assign wheat class based on visual inspection of kernel size, color, and shape and their knowledge of where the wheat was grown (USDA, 1997). The method can be subjective because kernel color can be influenced by weather conditions, disease, and insect damage. Significant color variations can exist even for a single variety grown over diverse production and environmental conditions (Wu et al., 1999; Peterson et al., 2001). The change in production from hard red winter (HRW) to HWH wheat in traditional HRW wheat growing areas increases the possibility of accidental mixing of red and white wheat. Since mixed lots are of less value than pure lots, a rapid means of purifying red and white lots may benefit the wheat industry

Identifying color class of wheat has been done by soaking in a sodium hydroxide (NaOH) solution, using tristimulus color meters, polyacrylamide gel electrophoresis, reverse–phased liquid chromatography, fluorescence spectrometry, machine vision, and visible–near–infrared (NIR) spectrophotometry (reviewed by Delwiche and Massie, 1996; Dowell, 1998; Wang et al., 1999). Among these techniques, the most promising for an automated color classification system using single kernels is reflectance spectroscopy using visible–NIR wavelengths. Classification models based on reflectance of manually–oriented wheat kernels were developed by Delwiche and Massie (1996) using visible and NIR wavelengths (537 to 993 nm and 1100 to 2498 nm). High classification accuracies were obtained using visible wavelengths (99.0% for hard white vs. hard red winter, 98.9% for soft red winter vs. soft white wheat) because pigmentation between red and white wheat was sufficiently different. Dowell (1997) compared the color classification for difficult–to–classify wheat kernels before and after soaking in NaOH solution, using visible wavelength information (400 to 700 nm). He found that soaking in NaOH solution accentuated the difference between red and white wheat, and the models classified more difficult–to–classify kernels with higher accuracy (98.1%) than the visual method (74.8%).

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Dowell (1998) included the NIR region when using automatically–fed and randomly–oriented wheat kernels. Higher correct classification (>99% of kernels) was obtained using partial least squares (PLS) regression models that used the full spectrum (450 to 1688 nm), than was found with models that used either the visible (450 to 700 nm) or the NIR region (700 to 1688 nm). Wang et al. (1999) obtained similar results using PLS and multiple linear regression classification models covering the 500– to 1700–nm range. They found $\approx$500 nm to be the most important for wheat kernel color classification and observed differences in absorption in 1460– and 1930–nm wavelengths that could be related to tannin, the red pigment in the seed coat. Since NIR could detect differences in the molecular structure of red and white wheat classes, their results suggested that classifying difficult–to–classify kernels could be improved by using both visible and NIR regions.

The cited studies used wheat color classification models based on the spectral information from visible–NIR wavelengths. Systems based on single or two wavelengths, such as those used in commercial color sorters, would provide high–speed sorting of red and white wheat. The first color sorter was invented in 1931 and was first used for sorting Michigan navy beans (Satake–USA, 2001). Design improvements have been introduced into color sorters through the years that have resulted in standard features such as multi–channel slides or chutes, pneumatic ejectors, and monochromatic or bichromatic sensors (Sortex, 1994; Key Technology, 2000; Satake–USA, 2001). Present sorter models have capacities of about 0.3 to 12 t/h and are being used to remove defects and impurities from products such as soybeans, peas, peanuts, and milled rice.

The objective of this study was to evaluate the accuracy of a commercial color sorter for removing red wheat from white wheat.

Materials and Methods

Wheat Varieties

HWH and HRW wheat varieties, commonly planted in Kansas and the Midwest, were blended to obtain 2.5–kg samples with a 95:5 white:red mass ratio (tables 1 and 2). This ratio approximated the possible inadvertent mixing of HWH and HRW wheat. HRW wheat was considered as the contaminant in these experiments, because it is generally the lower value wheat. HWH wheat may have $\approx$0.1% red wheat contamination, and HRW wheat may have the same amount of white wheat contamination. This allowance was considered in blending.

Color Sorter

A ScanMasterII 200 high–volume color sorter (Satake–USA, Houston, Tex.) was used in these experiments (fig. 1). Wheat falling from a vibratory feeder is singulated and accelerated in inclined channels (10 per chute). Front and rear CCD cameras view each kernel once it reaches the viewing area. An air ejector is triggered to divert a kernel from its trajectory when kernel color, as seen by either one of the cameras, exceeds a set sensitivity (or threshold) level. Diverted kernels fall into a “reject” container, while free–falling kernels fall into an “accept” container (hereafter, wheat falling into the containers for accept and reject portions will be referred to as accepts and rejects, respectively). Sensitivity levels can be adjusted from 1 to 999. These numbers correspond to the percent mass rejected. The number defining the sensitivity level can yield different amounts of

Table 1. Hard white and hard red winter wheat varieties that were blended for the sorting experiments.

Wheat Variety/ Code[a]	Location	Crop Year	Description
Hard White Wheat			
Betty 0RL	Riley, Kans.	2000	Mostly amber (vitreous) kernels with occasional chalky, creamy white (non–vitreous) kernels; negligible dark–tipped kernels
Betty 0RP	Republic, Kans.	2000	About half vitreous and half non–vitreous kernels; occasional dark tips and discoloration
Heyne	Riley, Kans.	1999	About 60% bright creamy white kernels, the rest vitreous; occasional dark tips
Lakin	Hays, Kans.	2001	Mostly brownish red vitreous kernels; 40% kernels with dark tips or spots
Trego	Hays, Kans.	2000	Mostly vitreous kernels; negligible dark tips
Hard Red Winter Wheat			
2137	Franklin, Kans.	2001	100% weathered; occasional dark tips
2174 9RL	Riley, Kans.	1999	Mostly non–vitreous kernels (color ranges from weathered to pale red); about 10% dark tips
2172	Riley, Kans.	1997	Distinctly brown red in appearance; mostly vitreous; large kernels
Jagger	Harvey, Kans.	2000	60% weathered; the rest pale to bright brown red
2174 1RL	Riley, Kans.	2001	Mostly distinctly red with negligible weathered kernels

[a]Foundation seeds from Kansas State University Agronomy Farm, Manhattan, Kansas and the Agricultural Research Center at Hays, Kansas.

Table 2. Wheat blends used in the sorting experiments.

Blends	Description
Betty 0RL–Jagger	Weathered red wheat not visually distinguishable from white wheat, except for larger size of red wheat
Betty 0RL–2137	Weathered red wheat not visually distinguishable from white wheat, except for larger size of red wheat and occasional dark tips
Betty 0RL–2172	Distinct color and size contrast between red and white wheat
Betty 0RL–2174 9RL	Generally good color contrast, except for few weathered red wheat
Betty 0RP–2172	Distinct color contrast between red and white wheat
Betty 0RP–2174 9RL	Generally good color contrast, except for few weathered red wheat
Heyne–2137	Poor color contrast between weathered red wheat and vitreous white kernels
Heyne–2174 1RL	Substantial contrast between red wheat and mostly creamy white wheat
Lakin–Jagger	Hard to distinguish weathered red from white wheat, except for a few reddish kernels; dark tips of white wheat makes visual distinction harder
Trego–2137	Substantial contrast between red wheat and mostly vitreous white wheat

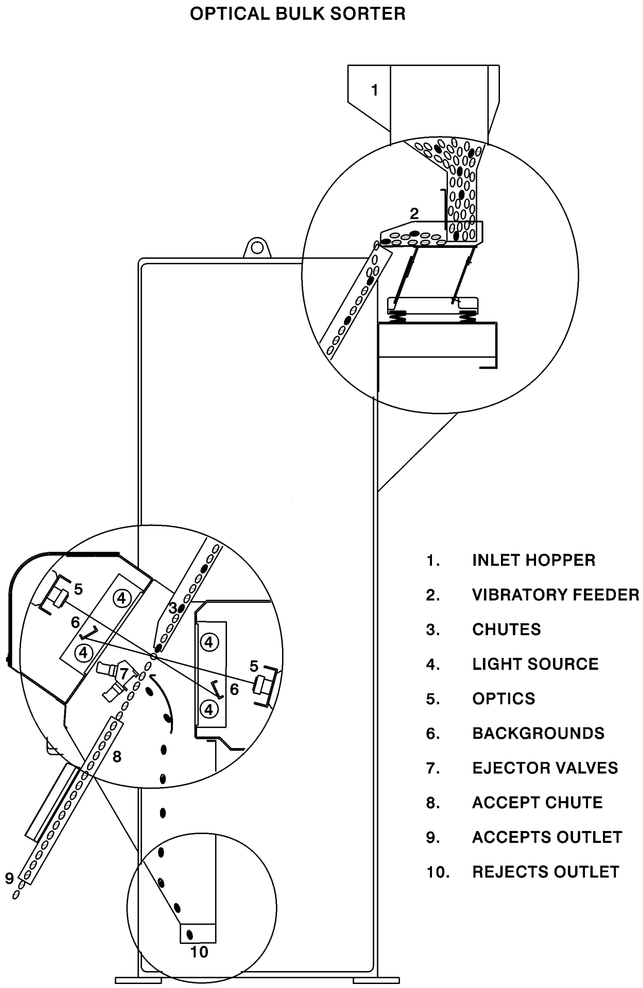

Figure 1. Side view and cut–away sections of the high–volume color sorter.

rejects for different wheat blends because blends vary in optical properties, e.g. some blends have a greater number of dark kernels than others. In order to compare sorting performance between wheat blends, the sensitivity was set to reject the same percent mass for each sample tested. This procedure involved trial–and–error, i.e., the mass of rejects corresponding to a set sensitivity number was measured, then sensitivity was increased or decreased to give a desired percent mass of rejects. Initial tests showed that sensitivity levels that rejected <15% of the wheat mass were not enough to lower the amount of red wheat in the accepts to $\leq$1%. Sensitivity levels were, therefore, set to reject 15, 20, and 25% mass of the input wheat blend. Feed rate was fixed at 200 kg/h (or 2.5 kg in 45 s) in order to handle small (2.5 kg) samples. A single chute was used. Filters (interference–type) used were green (515 nm) and red (675 nm) with full–width half maximum bandwidth of 80 and 30 nm, respectively. The sorter had dual–peak visible–NIR filters. In typical applications where seeds came with a substantial amount of impurities, NIR wavelengths were used to remove either translucent impurities like broken glass or opaque impurities like stems or shells. Wheat samples used did not have these impurities; hence, only visible wavelengths were used for sorting.

Color sorters are being used in large–volume, near–continuous mode, whereas small amounts (2.5 kg) were used in these experiments. Therefore, differences in sorting performance between large–volume (where product flow is mostly uniform) and small–volume feeding (where product flow is partly uniform and partly non–uniform), for the same feed rate, were compared. The time it took for the sorter to begin uniform or steady–state feeding and its duration were measured using the transient recorder function of a Digital Storage Oscilloscope (PCS64I model, Velleman, Belgium) connected to a laptop computer (Toshiba, Japan). Steady–state feeding refers to the time when consistent product flow and ejector timing are achieved. Steady–state period was observed to start about 10 s from the onset of feeding (when wheat starts to fall from feeder to chute) and proceed up to 30 s. Therefore, the period from 0 to 9 s and 31 to 45 s is non–steady state.

Experimental Design and Procedure

Single Pass Sorting

Objectives of the single–pass sorting experiment were to identify the filter and sensitivity level that would give the best segregation for the 10 wheat blends, and to check for differences between large–volume (or continuous) and small–volume (or small–sample) feeding. The experimental design used was split–split–plot, with wheat blends (10) as main plot, filters (2) as subplot, and sensitivity levels (3) as sub–subplot. Sorting sequence for wheat blends was randomized for each of two replications. For each wheat blend, six 2.5–kg samples were randomly selected for each replication. Half of these samples were then randomly selected for the green filter and the other half were assigned to the red filter. Sensitivity levels were then randomly assigned to the three samples selected for each filter. All 2.5–kg samples were then labeled accordingly.

Before any sorting run, the filter was attached and the ejector delay and dwell were set. Ejector delay is the time (in ms) required for a product to travel from the viewing point to the rejection point; ejector dwell is the time (in ms) that the ejector is kept on after it is actuated. Then, the signal was balanced for a particular wheat blend. Kernels, as viewed by front and rear cameras, produce either "dark" or "light" signals on an oscilloscope screen. Signal balance was achieved by adjusting the background so that half of the signals are above and half are below the horizontal reference line of an oscilloscope. The sensitivity was then set to reject 15, 20, or 25% mass of the original blend. A wheat blend was then poured into the hopper and two containers each for accepts and for rejects, were positioned (one container for wheat collected during the non–steady state period and another for the steady–state period). A stop watch was used to monitor the feeding time. Accepts and rejects first fell into the containers for the non–steady state period (first 9 s of feeding). Wheat was then diverted to the steady–state containers (next 10–30 s of feeding), and finally switched back to the containers for non–steady flow after 30 s.

The mass of collected accepts and rejects for steady state and non–steady state were recorded. The sorter was cleaned by pressurized air after every sorting run. Representative samples were obtained from the four sorted portions for soaking in NaOH solution. Sampling was done first by using a Boerner divider (Seedburo Co., Chicago, Ill.) until about 160 g had been obtained, then followed by a final sampling using a spinning riffler (Microscal Ltd., London, U.K.) which divided 160 g into 16 test tubes. Two 10–g samples were randomly picked for the NaOH tests. After 10 min soaking in warm (60°C) NaOH solution, red wheat turned pale to bright red, and white wheat turned to straw white (Ram et al., 2002). Soaked samples were washed by water spray and air dried for 24 h before hand sorting of the red and white kernels. Percent red and white kernels for each sorted portion were calculated from the recorded mass. Percent red and white wheat in the accepts and rejects for large–volume feeding were calculated from samples collected during the steady–state period. Percent red and white wheat in the accepts and rejects for small–volume feeding were calculated from samples collected during the total feeding time (non–steady state plus steady–state period).

Two–Pass Sorting

The objective of the two–pass sorting experiment was to learn whether segregation of weathered red wheat could be further improved by a re–sort of the accepts. The experimental design used was a randomized complete block, with three wheat blends and four sorting procedures in a factorial arrangement of treatments. Wheat blends used were Betty0RL–2137, Heyne–2137, and Lakin–Jagger. Sorting procedures used were 15P1–5P2 (rejects 15% mass on the first pass and 5% on the second pass), 15P1–10P2 (rejects 15% on the first pass and 10% on the second pass), and 15P1–15P2 (rejects 15% on the first pass and 15% on the second pass). These sorting procedures were all compared to 25P1 (single–pass, rejects 25% mass of wheat). The red filter and small–volume (2.5–kg samples) feeding at 200 kg/h were used.

Results and Discussion

Single–Pass Sorting

Small–Volume Feeding

For the sensitivity levels used, a very small percentage of red wheat was left in the accepts while most of the red wheat was rejected. Therefore, one measure of effectiveness of the settings or sorting procedures is percent red wheat in the accepts, i.e., the smaller it is the more effective are the settings. Mean percent red wheat in the accepts for small–volume feeding (R_{ASV}) was significantly influenced by wheat blends, filters, blend–filter interaction, and sensitivity levels ($p < 0.0001$). Across blends and filters, R_{ASV} was 1.35, 0.99, and 0.78% for sensitivity levels 15, 20, and 25%, respectively (standard error, SE = 0.05). Relative to 15% sensitivity, reduction in R_{ASV} for sensitivity levels 20% and 25% were 27 and 42%, respectively. For wheat blends sorted by using the red filter, R_{ASV} values were significantly less than those for blends sorted by using the green filter (table 3). Overall, about 38% reduction in R_{ASV} was obtained for the red filter relative to the green filter.

For most wheat blends sorted using the red filter, R_{ASV} was reduced to < 1% (table 3). For eight wheat blends, R_{ASV} was reduced to <1%, starting at 20% sensitivity; at 25% sensitivity, only Heyne–2137 had an R_{ASV} > 1% (fig. 2).

Wheat blends that did not reach R_{ASV} of <1% at $\geq$20% sensitivity were those that had weathered HRW wheat. However, both Trego–2137 and Heyne–2137 had weathered red wheat, but Trego–2137 had less R_{ASV} than Heyne–2137

Table 3. Mean percent red wheat in the accepts (R_{ASV}) and rejects (R_{RSV}), small–volume feeding for 10 wheat blends, and two filters averaged over sensitivity levels.

	R_{ASV} (%)[a]		R_{RSV} (%)	
Wheat Blends	Green Filter	Red Filter	Green Filter	Red Filter
Betty 0RL–Jagger	0.60a	0.32a	22.75d	23.91a
Betty 0RL–2137	2.31e	1.23d	15.87a	19.99d
Betty 0RL–2172	0.15a	0.14a	25.76e	25.17a
Betty 0RL–2174 9RL	0.79a	0.26a	22.55d	25.22a
Betty 0RP–2172	0.27a	0.63a	25.81e	22.84a
Betty 0RP–2174 9RL	1.32b	0.61a	20.34c	23.4a
Heyne–2137	2.64f	2.16e	14.93a	16.41e
Heyne–2174 1RL	0.76a	1.08c	22.63d	22.02c
Lakin–Jagger	2.12d	0.96b	16.55b	21.85b
Trego–2137	1.87c	0.57b	17.66b	23.43b

[a] In a column means followed by the same letters are not significantly different ($p < 0.01$). For R_{ASV}, SE = 0.18. For R_{RSV}, SE = 1.02. Mean percent white wheat in the accepts for small–volume feeding (W_{ASV}) is 100 – R_{ASV}. Mean percent white wheat in the rejects for small–volume feeding (W_{RSV}) is 100 – R_{RSV}.

(table 3). Also, both Betty0RL–Jagger and Lakin–Jagger had partially weathered red wheat, but Betty0RL had less R_{ASV} than Lakin–Jagger. These results indicated that a favorable color contrast between white and red wheat was necessary for good segregation. A favorable color contrast could be achieved even with weathered HRW wheat contaminant, as long as HWH wheat was substantially distinct in color.

Another measure of effectiveness of the settings or sorting procedures is percent red wheat in the rejects, i.e., the bigger it is, the more effective are the settings. Mean percent red wheat in the rejects for small–volume feeding (R_{RSV}) was significantly influenced by wheat blends, filters, blend–filter interaction, sensitivity levels, and filter–sensitivity interaction ($p < 0.0001$). On average, the red filter gave 9.5% higher values of R_{RSV} than the green filter (table 3) which means more red wheat was detected, and thus rejected, using the red filter. Wheat blends having distinctly red wheat (those with HRW wheat variety 2172 and 2174 9RL) had higher R_{RSV} than those blends with less distinct or weathered red wheat. This result confirmed further the importance of color contrast between HWH and HRW wheat kernels for good segregation. Across wheat blends, R_{RSV} decreased with increased sensitivity (table 4), about 20 and 33% decrease for sensitivity

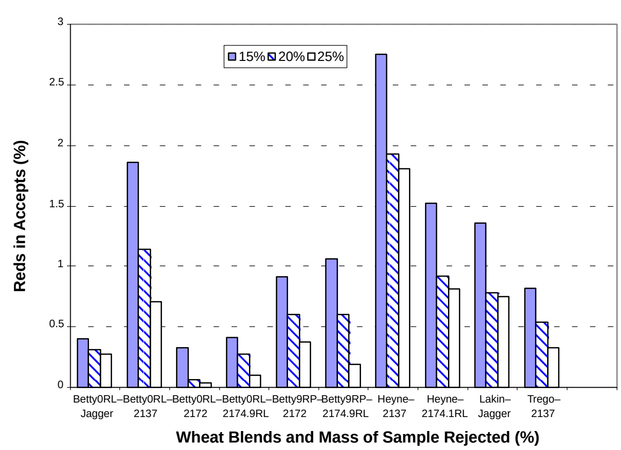

Figure 2. Red wheat in accepts (%) for single–pass sorting of 10 blends at three sensitivity levels using a red filter. Sensitivity expressed as mass (%) of original sample rejected. All samples had 5% red in white wheat before sorting.

Table 4. Mean percent red wheat in the rejects, small–volume feeding (R_{RSV}), for three sensitivity levels and two filters averaged over wheat blends.

Sensitivity Levels (%)	R_{RSV} (%)[a]	
	Green Filter	Red Filter
15	24.60a	27.56a
20	20.04b	21.75b
25	16.82c	17.96c

[a] In a column means followed by the same letters are not significantly different ($p < 0.0001$). SE = 0.35.

levels 20 and 25%, relative to 15% sensitivity level. This result means, in the attempt to segregate more red wheat using higher sensitivities, white wheat with detectable color properties very close to those of red wheat was also rejected. Also, the color of each kernel varied depending on orientation. Because kernels were randomly oriented when presented to the cameras, some kernels might have been unfavorably oriented and thus falsely detected. In addition, an ejector burst intended for a red kernel will often reject other kernels immediately before and after the target kernel.

Results for the large–volume feeding were consistent with those of accepts and rejects for small–volume feeding (data not shown). Differences between small and large–volume feeding for accepts and rejects were not significant ($p > 0.32$ and $p > 0.61$, respectively).

Two–Pass Sorting

Percent weathered red wheat in the accepts and rejects was significantly influenced by sorting procedures and wheat blends ($p < 0.029$). Sorting procedures 15P1–10P2 and 15P1–15P2 yielded less red wheat in the accepts than 25P1 (table 5). Sorting procedure 15P1–5P2 yielded a statistically similar percentage of red wheat in accepts as 25P1, but 15P1–5P2 rejected less total amount of wheat (about 19 vs. 25%). In commercial large–volume sorting, there would be no advantage to using 15P1–5P2 over 25P1, because 15P1–5P2 would require re–sorting the accepts as well as the total rejects from first and second pass, whereas 25P1 would re–sort only the rejects.

Reduction of red wheat in the accepts to < 1% was achieved by procedures 15P1–10 P2 and 15P1–15 P2 (table 5). Relative to 25P1, the reduction of red wheat in the accepts for 15P1–10 P2 and 15P1–15 P2 was 29 and 41%, respectively. Procedure 15P1–10P2 rejected less wheat than 25P1 (about 23 vs. 25%), whereas 15P1–15P2 rejected more wheat than 25P1 (about 28 vs. 25%). In reducing the amount of red wheat in the accepts, procedure 15P1–15P2 had a statistically similar percentage of red wheat in the rejects as 25P1 (table 5). This result meant that, because of higher sensitivity, more white wheat was rejected with the red wheat compared to procedures 15P1–5P2 and 15P1–10P2. For blends having weathered red wheat, results for 15P1–10P1 and 15P1–15P2 showed the potential of further reducing red wheat in the accepts by re–sorting the accepts. The disadvantage of re–sorting both accepts and total rejects might be offset by the advantage of less red wheat in the second–pass accepts. For a mix of white and red wheat, where color contrast is not distinct, it appeared that better segregation of red and white wheat could be obtained by rejecting the same amount of the product in two passes using lower sensitivities for each pass, than a single pass with very high sensitivity.

Table 5. Red wheat (%) in accepts and rejects for four sorting procedures averaged over three wheat blends.

	25P1[a][b]	15P1–5P2[c]	15P1–10P2[d]	15P1–15P2[e]
Accepts (%)[f]	1.24a	1.18ab	0.88bc	0.73c
Rejects (%)[g]	16.63a	18.77b	18.73b	15.72a

[a] In a row, means followed by the same letters are not significantly different at $p = 0.10$.
[b] Single–pass, rejects 25% mass of wheat; reference for comparison.
[c] Two–pass, rejects 15% mass of wheat on the first pass and 5% on the second pass.
[d] Two–pass, rejects 15% mass of wheat on the first pass and 10% on the second pass.
[e] Two–pass, rejects 15% mass of wheat on the first pass and 15% on the second pass.
[f] SE = 0.13.
[g] Reds in rejects for two–pass sorting procedure was based on total rejects from first and second pass. SE = 0.64.

Among the three wheat blends with weathered red wheat, Heyne–2137 had the most red wheat in the accepts and least red wheat in the rejects (table 6). Heyne had more variation in kernel color, whereas the color of Betty 0RL and Lakin were more consistent (tables 1 and 2). This result pointed again to the need for a substantial color contrast between red and white wheat and that re–sort of accepts might not give any advantage if this contrast is not present. The single–pass and two–pass sorting results indicated that the same settings and sorting procedures might not work well for all wheat blends.

Therefore, sorting procedures should be developed and settings decided for a specific wheat blend after evaluating the color contrast between white and red wheat. This procedure would give operators control over sorting results. In these experiments, using higher sensitivity than that which rejected 25% of wheat in a single pass was not tested because of excessive rejected product. This procedure might be promising, provided that the re–sorting of rejects would be able to recover white wheat and bring down the amount of red wheat to the level of the original product. The final choice of procedure and settings would be dictated by the value of the segregated white and red wheat. Overall, the sorting experiments showed the feasibility of segregating red and white wheat for most blends, including those with weathered red wheat, by using proper settings and procedures. However, because of small sample size and low feed rates used, the amount of red wheat in the accepts and rejects obtained in these experiments should be considered as potential values. At 200 kg/h/chute, the product stream was about 23% full (space occupied by the product/total space). Better results should be obtained when the stream is 50 to 70% full, or at about 437 to 612 kg/h/chute, because when kernels flow close together, lighting and shadows are less variable and kernel velocity is more consistent (Gray, 2002).

Table 6. Red wheat (%) in accepts and rejects for three wheat blends averaged over all sorting procedures.

	Betty0RL–2137[a]	Lakin–Jagger	Heyne–2137
Accepts (%)[b]	0.91a	0.90a	1.22b
Rejects (%)[c]	18.12a	18.50a	15.77b

[a] In a row, means followed by the same letters are not significantly different at $p = 0.10$.
[b] SE = 0.11.
[c] SE = 0.56.

CONCLUSIONS

A high–speed commercial color sorter was evaluated for the segregation of red and white wheat, using single–pass and two–pass procedures. Obviously red wheat was segregated better than weathered red wheat because of its distinct color contrast with white wheat. However, blends with weathered red wheat were also segregated well when a substantial contrast was provided by the white wheat. For wheat blends where there was a considerable color contrast between white and red wheat, red wheat in the accepts could be reduced to <1% when 15% of the wheat mass was rejected. For most wheat blends with less distinct color contrast, reduction of red wheat to this level required the rejection of 20 to 25% wheat mass. Red filters detected more red wheat than green filters, thus yielding about 38% less red wheat in the accepts and 9.5% more red wheat in the rejects. Red wheat in the accepts decreased with increased sensitivity. When compared to rejecting 15% of the mass, reductions of red wheat in accepts were 27 and 42% better when rejecting 20 and 25% of the mass, respectively. For the 200 kg/h feed rate used in the experiments, there was no significant difference in segregation between large–volume (continuous) feeding that simulates sorting of large lots and small–volume feeding that simulates sorting small samples. For wheat blends containing weathered red wheat, red wheat in the accepts could be reduced 29 to 41% by using a red filter and a re–sort of accepts rejecting an additional 10 to 15% of wheat.

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