Groat proportion in oats as measured by different methods: Analysis of oats resistant to dehulling and sources of error in mechanical dehulling

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Doehlert, D. C., McMullen, M. S. et Riveland, N. R. 2010. Groat proportion in oats as measured by different methods: Analysis of oats resistant to dehulling and sources of error in mechanical dehulling. Can. J. Plant Sci. 90: 391–397. Groat proportion is the groat yield from an oat dehulling process. We compared hand, impact and compressed-air dehulling to measure groat proportion, and evaluated sources of error. Hand dehulling was the simplest and most accurate method, because all groats and hulls can be accounted for. Mechanical methods dehulled most, but not all, oat kernels. Failure to account for oats resistant to dehulling in calculations resulted in gross errors. Oats resistant to impact dehulling did not differ in groat proportion from the general population, but differed in many physical properties. Hull structure may account the most for their resistance to dehulling. Mechanically dehulled oats consistently yielded lower groat proportions than those from hand dehulling. Since the difference cannot be attributed to oats resistant to dehulling, groats must be lost during the aspiration process, common to all mechanical methods. Uniform aspiration protocols should provide a uniform error. All groat proportion values obtained here were highly correlated among themselves, except when values were not corrected for oats resistant to dehulling. A theoretical groat proportion calculated from the ratio of the mean groat mass (collected by any means available) and the mean kernel mass yielded a groat proportion value that did not differ significantly from the hand dehulling value.

Key words: Oat milling, groat proportion, oat dehulling

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Abbreviations: B, mass of broken groats; CGP, complete groat proportion; CRGP, crude groat proportion; DHE, dehulling efficiency; GM, groat mass; GP, groat proportion; HGP, groat proportion as determined by hand dehulling; IGP, groat proportion as determined by impact dehulling; KM, kernel (grain) mass; MCF, moisture correction factor; RGP, groat proportion of oats resistant to dehulling; RM, mass of oats resistant to dehulling; TGP, theoretical groat proportion
The oat grain generally consists of the caryopsis or groat and the hull, which includes the lemma and palea that enclose the groat (Fulcher 1986; White 1995). Oats are generally dehulled as part of their processing for human consumption. The yield of groats from a grain sample is referred to as the groat proportion or the groat percentage and represents the economic yield of a given sample of oat grain.

Groat proportion can be measured analytically by hand dehulling (Doehlert et al. 1999; White et al. 2000), or by mechanical dehulling. Analytical mechanisms for mechanical oat dehulling include the compressed-air type dehuller, as described by Kittlitz and Vetterer (1972) or may use an impact dehuller, such as that described in Cleve (1948), Stuke (1955), Deane and Commers (1986) or Ganssmann and Vorwerck (1995). During mechanical dehulling, some type of mechanical stress is applied to the oat kernel, which results in the hull breaking free of the groat. The hulls are then separated from the heavier groats by aspiration (Doehlert and McMullen 2001).

In theory, the groat proportion would be the ratio of the grain mass to the groat mass.

\[
GP = \frac{GM}{KM}
\]  

(1)

Here, GP is groat proportion, GM is the groat mass from a sample and KM is oat kernel mass of that sample (with the hull). Such a relationship holds true if one measures groat proportion by hand dehulling, where the entire oat sample is dehulled. But most analytical operations and all commercial operations use some type of mechanized dehulling, where the entire oat sample is not dehulled. A portion of the oats in any sample will be resistant to mechanical stress and will retain their hulls. However, because the oats resistant to dehulling remain with the groats during aspiration, a groat proportion calculated from the ratio of the crude groat preparation mass to the original oat grain sample mass will over-estimate the true groat proportion, because of the presence of hulls attached to the resistant oats. To avoid this error for analytical purposes, it was recommended to sort the crude groat sample (Doehlert et al. 1999; Doehlert and McMullen 2001), and to remove the oats resistant to dehulling, and then to calculate groat proportion from the mass of cleaned groats based on the mass of oats that were actually dehulled:

\[
GP = \frac{GM}{KM - RM}
\]  

(2)

where RM is the mass of the oats resistant to dehulling. It was suggested that this treatment provides a more accurate estimation of groat proportion (Doehlert et al. 1999) and prevented one from selecting oat lines for high dehulling resistance when one intended to select for high groat proportion.

In recent studies from this laboratory (Doehlert and Wiesenborn 2007; Doehlert et al. 2009a, b) we have studied oat dehulling using an impact dehuller, and compared dehulling characteristics with a variety of physical oat kernel characteristics. One calculation, called “theoretical groat proportion” (TGP), was the ratio of mean groat mass, determined from whole unbroken groats recovered after mechanical dehulling with the mean kernel (grain) mass, with the hull on. It appears that this value should be equivalent to groat proportion (Eq. 1), although it was not calculated by traditional means. We found that TGP values were consistently and statistically significantly higher than groat proportion determined by the impact dehuller (IGP), where IGP was calculated by an equation resembling Eq. 2. We considered the possibility that oats resistant to dehulling may have some unique property so that their subtraction from the starting mass might introduce an unexpected error into the groat proportion calculation. In this study we collected those kernels resistant to dehulling and analyzed their physical characteristics to test the hypothesis that these may contribute to error in the determination of groat proportion.

A second hypothesis to address the difference between TGP and IGP is that aspiration applied to the groat hull mixture sucks some small or broken groat out along with the hulls. Essentially, if the oats resistant to dehulling cannot account for the difference in IGP and TGP, we must conclude that the missing mass is carried out with the hulls, in order for our process to remain consistent with the principle of the conservation of mass.

To test these hypotheses, we have analyzed the oats resistant to impact dehulling as generated in a previous study (Doehlert et al. 2009b) that included 16 genotypes grown at six locations in replicated plots. We have analyzed their size, mass and density. We have also determined the groat proportion of all samples analyzed by hand dehulling, and by a second mechanical mechanism known as the compressed-air dehuller. Our results also contribute to the technology of the measurement of groat proportion.

**MATERIALS AND METHODS**

**Plant Material**

Fourteen oat (*Avena sativa* L.) cultivars (AC Assiniboia, Beach, Brawn, CDC Dancer, HiFi, Killdeer, Leonard, Maida, Morgan, Morton, Otana, AC Pinacle, Ronald, and CDC Weaver) and two breeding lines (ND021612, ND030291) were grown at three locations (Carrington, Fargo, and Williston) in North Dakota in 2005 and 2006. A seeding rate of 247 kernels m$^{-2}$ was used for all experiments. Herbicide treatments consisted of pre-emergence application of 3.93 kg ha$^{-1}$ propchlor and post-emergence application at the three-leaf stage.
with a tank mix of 0.14 kg ha⁻¹ thifensulfuron, 0.07 kg ha⁻¹ tribenuron and 0.14 kg ha⁻¹ clopyralid. Experimental units consisted of four rows spaced 0.3 m apart and 2.4 m long. The two center rows were harvested with a two-row binder and threshed with a plot thresher. The harvested grain was cleaned using a Clipper (Bluffton, IN) Model 400 Office Tester and Cleaner fitted with a 4.75 x 19 mm oblong hole sieve and with aspiration adjusted so that kernels containing groats were not removed. The sieve removed grain under 2 mm in width.

**Hand Dehulling**

Two-gram samples were removed from sample bags and weighed to the precision of one hundredth of a gram. Hulls were then removed from each kernel by hand. An effective technique for rapid hand dehulling involved pinching the kernel just above the abscission scar. The groat will frequently emerge promptly from the top of the hulls. Groats and empty hulls were stored in separate trays, and weighed when dehulling was completed. Groat proportion was calculated according to Eq. 1.

**Impact Dehulling**

Four 50-g samples from each sample were placed in 450-mL glass jars. Grain moisture was determined by measuring the mass loss in a 2-g grain sample after 2 h at 130°C in a convection oven. The moisture of the grain in the jars was then adjusted to 9% by adding water to the grain in the jars, sealing for 24 h, and shaking at irregular intervals.

The North Dakota State University Agricultural and Biosystems Engineering Department manufactured the impact dehuller as described earlier (Doehlert and Wiesenberg 2007). It consisted of a 50-cm-diameter, 12-vein rotor and a granite impact ring. Rotor speed was controlled with a variable frequency drive and calibrated with a tachometer. Rotor speeds of 1502, 1661, 1807, and 1949 rpm corresponded to peripheral speeds of 39.3, 43.5, 47.3, and 51.0 m s⁻¹. Fifty-gm samples equilibrated to 9% (db) moisture were poured by hand into the dehuller at a rate of about 200 g min⁻¹. Dehulled samples passed directly from the dehuller into a Kice laboratory aspirator (Kice Metal Products, Wichita, KS) and collected at the bottom of the aspirator, which also served to control dust. Afterwards the samples were passed through a Bates type laboratory aspirator (Seedboro Company, Chicago IL) to remove remaining hulls. Hulls were discarded without examination. Immediately after aspiration, the mass of the crude groat preparation was recorded and samples were stored in paper envelopes until sorting.

Moisture changes in the storage of the grain samples between the time of dehulling and sorting required that the mass of crude groat samples be measured again immediately before sorting. This allowed for the calculation of the “moisture correction factor” (MCF), which was the original sample mass divided by the current sample mass (Doehlert and McMullen 2001). Samples were then sorted by hand into whole groats, broken groats and hulled oats remaining. Groat proportion was corrected for the hulled oats remaining after dehulling as shown in Eq. 3:

\[
IGP = \frac{[GM + B] \times MCF}{[KM - (RM \times MCF)]}
\]  

where KM is the undehulled oat mass, RM is the mass of oats resistant to dehulling, GM is the mass of unbroken groats, and B is the mass of broken groats.

Dehulling efficiency (DHE) was the proportion of oats dehulled with a single pass through the dehuller.

\[
DHE = \frac{100 \times [KM - (RM \times MCF)]}{KM}
\]

Oats resistant to dehulling were collected by hand sorting. Groat percentage of these resistant oats grains (RGP) was determined by hand dehulling, as described earlier. Complete groat proportion (CGP) was calculated in order to estimate the groat proportion if all of the oats resistant to dehulling had been dehulled, and their groat mass contributed to that used in the groat proportion calculation (Eq. 5).

\[
CGP = IGP \left[ \frac{DHE}{100} \right] + \left[ RGP \left( 1 - \left[ \frac{DHE}{100} \right] \right) \right]
\]

The crude groat proportion (CRGP) was calculated as the value that would be obtained for groat proportion if one dehulled oats by a mechanical means, but calculated the groat proportion without removing the oats resistant to dehulling (Eq. 6).

\[
CRGP = \frac{(GM + B + RM)}{KM}
\]

**Compressed-air Dehulling**

The compressed-air groat proportion (AGP) was obtained using a Codema (Eden Prairie, MN) Laboratory Oat Huller, that resembled in design the apparatus describer by Kittlitz and Vetterer (1972). Forty-gram samples were weighed out for each dehulling. Moisture was not controlled, but was estimated to range from 6 to 8% at the time of dehulling. Air pressure of 522 kPa was used for 60 s to dehull the oats. The vent opening was 7 mm, and the blast gate was 1.5 cm. In addition to the aspiration mechanism built into the Codema instrument, crude groat preparations were passed over a Bates type aspirator twice, to remove as much of the free hulls as possible. The air flow rate for the Bates aspirator was 2.0, the air flow setting was 3.0 and the variable fan speed was 7.5. The cleaned crude groat preparations were weighed, placed in paper
envelopes and stored until they could be sorted. Crude groat preparations were sorted exactly as were those derived from the impact dehuller, although the oats resistant to dehulling were not saved. Thus, AGP was calculated according to Eq. 3, where AGP is substituted for IPG.

**Theoretical Groat Proportion**
The theoretical groat proportion was calculated as described in an earlier companion paper (Doehlert et al. 2009a) and as described by Eq. 1 in this report, except GM is the mean groat mass determined from intact groats isolated after mechanical dehulling, and KM is the mean kernel mass.

**Analyses**
Physical characteristics of grain resistant to dehulling, including bulk density, mean kernel mass, mean kernel volume, mean kernel density, mean groat mass, mean groat volume, mean groat density, mean hull mass, mean hull volume, mean hull density, oat kernel length, kernel width, and kernel image area were determined as described in detail earlier (Doehlert and McMullen 2008).

**Experimental Design and Statistical Analysis**
Field plots were arranged in a randomized complete block design with three replicates. Analysis of variance was applied to data where genotypes were considered fixed and environments were considered random. Analyses of variance were calculated with the Statistix computer package (Analytical Software, Tallahassee, FL), where the environment × replicate mean square was used as an error-term to test the environmental effect. The genotype × environment interaction mean square was used to test the genotypic effect, and the genotype × environment interaction was tested with the residual mean square. Mean separation for genotypes was evaluated by the least significant difference, which was also calculated by the Statistix software program using the genotype × environment mean square as an error term. Homogeneity of variances was determined from the Bartlett’s test for equal variances before data were pooled.

Differences among GP values obtained by different approaches were determined by one-way ANOVA. Where genotypic differences are present, difference among GP approaches were derived from the means for all genotypes. Where rotor speed differences are presented, GP values for each speed were calculated and compared separately. Correlations among different approaches for calculation of GP were generated also by using the Statistix computer package.

**RESULTS**

**Groat Proportion Measurements by Different Methods**
As an initial observation, it is apparent that the CRGP values provide the highest GP values, although significant differences cannot be resolved among genotypes, and genotype ranking differs, in several cases, depending on the method, such as with Leonard, Pinnacle, Morgan, ND021612 and ND030291. A rearrangement of the data to test for significant differences between approaches to groat proportion calculation indicated that CRGP was higher than all other methods. The hand dehulling groat proportion (HGP) did not differ significantly from TGP, and these were all significantly higher than IGP or AGP (Table 1). Although genotypic differences could not be resolved in this study with compressed-air dehulling, genotype ranking was very similar among values of IGP, AGP, HGP, and TGP, except for an inexplicable difference in the ranking of Kildeer by the TGP calculation (Table 1). Values of IGP, AGP, HGP, and TGP from Table 1 were all significantly correlated with each other (P < 0.01), whereas values of CRGP were not significantly correlated with any of the other GP values (P > 0.05).

An analysis of impact rotor speed on mean values of IGP (Table 2) indicated that the value at the slowest speed did not differ significantly from the next two faster rotor speeds, but was significantly lower than the value from the fastest rotor speed.

The DHE increased with rotor speed at all rotor speeds (Table 2), as reported in detail in our earlier paper (Doehlert et al. 2009b). The CRGP also changed with rotor speed, but was highest at the slowest rotor speed, where oats resistant to dehulling would contribute the most to this value. The CRGP value approached the IGP value as rotor speed increased.

The analysis of the oats resistant to dehulling by impact dehulling rotor speed (Table 2) indicated that their groat percentage (RGP) determined by hand dehulling decreased with rotor speed. A rearrangement of data to test differences between RGP and IGP indicated no significant difference between these values at any rotor speed.

The CGP was calculated in an attempt to correct for any difference in the calculated groat percentage from impact dehulling that could be attributed to differences between the mean groat percentage and that of the resistant oats. But the CGP did not differ from IGP at any rotor speed, as would be expected considering that RGP did not differ significantly from IGP at any rotor speed, although CRGP was significantly higher than IGP and CGP at all rotor speeds. Like IGP, CGP also decreased with increasing rotor speed.

**Properties of Oats Resistant to Dehulling**
Physical properties of oats resistant to dehulling were determined in comparison to the original sample
Table 1. Mean groat proportion and ranking (parentheses) of oat genotypes grown in 6 environments as measured by a variety of approaches

<table>
<thead>
<tr>
<th>Genotype</th>
<th>CRGP (rank)</th>
<th>IGP (rank)</th>
<th>AGP (rank)</th>
<th>HGP (rank)</th>
<th>TGP (rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Assiniboia</td>
<td>0.828 (6)</td>
<td>0.732 (7)</td>
<td>0.695 (8)</td>
<td>0.763 (5)</td>
<td>0.753 (7)</td>
</tr>
<tr>
<td>Beach</td>
<td>0.808 (12)</td>
<td>0.744 (5)</td>
<td>0.711 (5)</td>
<td>0.749 (8)</td>
<td>0.762 (6)</td>
</tr>
<tr>
<td>Brawn</td>
<td>0.790 (14)</td>
<td>0.699 (11)</td>
<td>0.690 (13)</td>
<td>0.736 (11)</td>
<td>0.722 (13)</td>
</tr>
<tr>
<td>CDC Dancer</td>
<td>0.861 (1)</td>
<td>0.732 (3)</td>
<td>0.704 (7)</td>
<td>0.736 (13)</td>
<td>0.732 (11)</td>
</tr>
<tr>
<td>Killdeer</td>
<td>0.820 (9)</td>
<td>0.723 (9)</td>
<td>0.691 (11)</td>
<td>0.738 (10)</td>
<td>0.768 (4)</td>
</tr>
<tr>
<td>Leonard</td>
<td>0.831 (4)</td>
<td>0.668 (15)</td>
<td>0.684 (12)</td>
<td>0.693 (16)</td>
<td>0.687 (16)</td>
</tr>
<tr>
<td>Maida</td>
<td>0.823 (7)</td>
<td>0.731 (8)</td>
<td>0.707 (6)</td>
<td>0.756 (7)</td>
<td>0.734 (9)</td>
</tr>
<tr>
<td>Morgan</td>
<td>0.822 (8)</td>
<td>0.681 (14)</td>
<td>0.662 (16)</td>
<td>0.703 (14)</td>
<td>0.712 (15)</td>
</tr>
<tr>
<td>Morton</td>
<td>0.812 (11)</td>
<td>0.692 (12)</td>
<td>0.692 (10)</td>
<td>0.724 (12)</td>
<td>0.733 (10)</td>
</tr>
<tr>
<td>ND021612</td>
<td>0.837 (3)</td>
<td>0.705 (10)</td>
<td>0.684 (13)</td>
<td>0.747 (9)</td>
<td>0.729 (12)</td>
</tr>
<tr>
<td>ND100291</td>
<td>0.798 (13)</td>
<td>0.741 (6)</td>
<td>0.704 (7)</td>
<td>0.757 (6)</td>
<td>0.750 (8)</td>
</tr>
<tr>
<td>Otana</td>
<td>0.781 (15)</td>
<td>0.665 (16)</td>
<td>0.676 (15)</td>
<td>0.694 (15)</td>
<td>0.716 (14)</td>
</tr>
<tr>
<td>AC Pinacle</td>
<td>0.813 (10)</td>
<td>0.745 (4)</td>
<td>0.722 (3)</td>
<td>0.779 (3)</td>
<td>0.768 (5)</td>
</tr>
<tr>
<td>Ronald</td>
<td>0.829 (5)</td>
<td>0.753 (3)</td>
<td>0.714 (4)</td>
<td>0.773 (4)</td>
<td>0.794 (1)</td>
</tr>
<tr>
<td>CDC Weaver</td>
<td>0.857 (2)</td>
<td>0.756 (2)</td>
<td>0.749 (1)</td>
<td>0.788 (2)</td>
<td>0.774 (3)</td>
</tr>
<tr>
<td>Means</td>
<td>0.818a</td>
<td>0.719c</td>
<td>0.700d</td>
<td>0.745b</td>
<td>0.745b</td>
</tr>
<tr>
<td>LSD (0.05)b</td>
<td>NS</td>
<td>0.057</td>
<td>NS</td>
<td>0.027</td>
<td>0.051</td>
</tr>
</tbody>
</table>

CRGP, crude groat proportion; IGP, impact dehuller groat proportion; AGP, compressed-air dehuller groat proportion; HGP, hand dehulling groat proportion; TGP, theoretical groat proportion. Values are proportions and have no units.

Table 2. Effect of impact rotor speed on IGP, DHE, CRGP, RGP, and CGP

<table>
<thead>
<tr>
<th>Speed</th>
<th>IGP</th>
<th>DHE</th>
<th>CRGP</th>
<th>RGP</th>
<th>CGP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1502</td>
<td>0.714ab</td>
<td>0.785d</td>
<td>0.777a</td>
<td>0.727a</td>
<td>0.717a</td>
</tr>
<tr>
<td>1661</td>
<td>0.720a</td>
<td>0.858c</td>
<td>0.766b</td>
<td>0.711b</td>
<td>0.718a</td>
</tr>
<tr>
<td>1807</td>
<td>0.704b</td>
<td>0.907b</td>
<td>0.732c</td>
<td>0.696c</td>
<td>0.703c</td>
</tr>
<tr>
<td>1949</td>
<td>0.683c</td>
<td>0.939a</td>
<td>0.702d</td>
<td>0.685d</td>
<td>0.683e</td>
</tr>
</tbody>
</table>

CGP, complete groat proportion; CRGP, crude groat proportion; DHE, dehulling efficiency; IGP, impact groat percentage; RGP, resistant oat groat proportion.

DISCUSSION

Evidence presented here appears to strongly support the hypothesis that errors introduced during the mechanical dehulling of oats are derived from the loss of groats during the aspiration of oat/hull mixtures. We need to assume that the hand dehulling generates the most accurate estimation of groat percentage, although errors can be introduced during hand dehulling. Groats or sample, although the kernel volume of resistant oats isolated at 1502 rpm did not differ significantly from the original sample. Surprisingly, the density of kernels resistant to dehulling increased with rotor speed. The original sample was significantly more dense than only the resistant oats isolated at the slowest rotor speed. Packing efficiency of the original sample was greater than that of all of the kernels resistant to dehulling.

Packing efficiency decreased with all rotor speeds in kernels resistant to dehulling.

Analysis of linear dimensions of oats resistant to dehulling (Table 4) indicated that resistant oats tended to be smaller in size than the original sample. Oats resistant to dehulling at 1661, 1807, and 1949 rpm were shorter in length than grains from the original sample, and mean length of resistant oats decreased with increasing rotor speed. Oats resistant to dehulling at 1807 and 1949 rpm were more narrow in width than the original sample, and width of oats resistant to dehulling decreased with increasing rotor speed. The oat image area was also smaller in oats resistant to dehulling isolated at 1949 rpm than those in the original sample.
Table 3. Physical characteristics of original oat samples and oats resistant to dehulling at four rotor speeds

<table>
<thead>
<tr>
<th>Speed</th>
<th>Bulk density (g L⁻¹)</th>
<th>Mean kernel mass (mg kernel⁻¹)</th>
<th>Mean kernel volume (mm³ kernel⁻¹)</th>
<th>Mean kernel density (mg mm⁻³)</th>
<th>Packing efficiency (g L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original</td>
<td>519</td>
<td>34.1</td>
<td>37.3</td>
<td>0.916</td>
<td>565</td>
</tr>
<tr>
<td>1502</td>
<td>413</td>
<td>32.9</td>
<td>37.0</td>
<td>0.893</td>
<td>499</td>
</tr>
<tr>
<td>1661</td>
<td>419</td>
<td>31.6</td>
<td>35.5</td>
<td>0.898</td>
<td>471</td>
</tr>
<tr>
<td>1807</td>
<td>396</td>
<td>30.9</td>
<td>34.5</td>
<td>0.906</td>
<td>442</td>
</tr>
<tr>
<td>1949</td>
<td>381</td>
<td>30.5</td>
<td>34.5</td>
<td>0.916</td>
<td>429</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>8</td>
<td>0.9</td>
<td>1.2</td>
<td>0.018</td>
<td>10</td>
</tr>
</tbody>
</table>

It is interesting that the value referred to as the theoretical groat proportion in this and an earlier paper (Doehlert et al. 2009a) did not differ significantly from the HGP. In TGP calculations, whole groats are isolated from mechanically prepared groats, discarding the broken groats, usually for purposes of measuring mean groat size or determining rates of groat breakage. We have made no attempts in the past to determine if different groat sizes are more susceptible to groat breakage, as such a property could introduce error into TGP. But the components for the TGP calculation also fit directly into Eq. 1, and the observation that this value did not differ significantly from HGP provides good evidence that this calculation also provides an excellent estimation of groat proportion, better than any of those obtained more directly through mechanical means.

Two mechanisms of mechanical dehulling were used in this study: that of compressed-air dehulling and that of impact dehulling. Both of these procedures apply mechanical stress to the oat kernels to break the groat free of the hull, and apply aspiration to remove free hulls. Although both stress applied to kernels and aspiration applied after dehulling can be varied, both of these methods result in incompletely dehulled oats and usually include some broken groats. In order to obtain a more accurate estimation of groat percentage, it is usually assumed that removal of oats resistant to dehulling by hand sorting is necessary. Values presented in Table 1 tend to support such a hypothesis, where equations resembling Eq. 2 are used to calculate groat proportion. The CRGP were uniformly larger than the IGP, and did not correlate with any other GP value. This difference is entirely due to the presence of oats resistant to dehulling. Although the CRGP may be closer to the HGP and the TGP at many rotor speeds used in this study, this spurious result could lead to the selection of oat lines with poorer GP and DHE, since greater amounts of groats with hulls would create an illusion of a greater groat proportion.

It has never been clear why groat proportion values derived from mechanical means have been lower than those from hand dehulling (Doehlert et al. 2009a). Two possibilities considered involved either the oats resistant to dehulling, or aspiration. In this study, we collected and dehulled (by hand) those kernels that would not dehull mechanically. The CGP derived from this treatment did not differ from the IGP, thus we concluded that the resistant oats themselves do not contribute to the observed difference. According to the law of conserved mass, we must conclude that these differences are due to groat losses during aspiration. No other alternative can be envisioned.

Although the strength of aspiration can be easily controlled in most systems, insufficient aspiration will lead to excess free hulls in the groat preparation, that can only be removed by stronger aspiration or by hand sorting. Hand examination of any hull preparation associated with a dehulling procedure will reveal the presence of groats, but are virtually impossible to quantify. Industry generally recognizes this and can install mechanisms to recover groats lost in aspiration. We would expect that the smallest groats are removed at the slowest rotor speeds, and as rotor speeds increase and groat breakage increases, and more small fragments become available for removal by aspiration. Thus, we suggest that both the difference in groat proportion between mechanical methods and the decrease in observed groat proportion with increasing rotor speed (or increased mechanical stress) are due to groat removal by aspiration.

Oats Resistant to Dehulling

We are not aware of any previous studies on the physical properties of oat kernels resistant to dehulling. This
information may provide insight into properties of oats that will allow them to dehull more easily.

Distinct physical differences are apparent in oats resistant to dehulling. Resistant oats have lower bulk densities, less mass per kernel, and less volume per kernel (Table 2). The linear dimensions of oats resistant to dehulling were generally smaller than those in the general population, and resistant oats isolated at higher rotor speeds were smaller than those isolated at slower speeds (Table 3).

Density analyses of kernels resistant to dehulling do not tell a clear story. Whereas oats resistant to dehulling at the slowest speed were significantly less dense than those of the original sample, the density of the resistant oats increased with rotor speed and those isolated at the fastest rotor speed did not differ significantly in density from the original (Table 2). The trend for kernel density in resistant oats with increasing rotor speed was the opposite of that of the bulk density. The changes in bulk density must be attributed to differences in packing efficiency of the oats resistant to dehulling, since bulk density is defined as the product of kernel density and packing efficiency (Doehlert and McMullen 2008; Doehlert et al. 2009a). Packing efficiency was much lower in all fractions of resistant oats, and their values decreased as rotor speed was increased. Packing efficiency may be related to hull structure (Doehlert et al. 2009a), thus structural aspects of hulls that cause kernels to pack poorly may also make them more resistant to dehulling. We have not yet identified exactly what these hull characteristics are, or how to recognize them.

CONCLUSIONS

All mechanical methods for groat proportion determination appear to underestimate groat proportion because of groats removed by the aspiration necessary for the separation of the free hulls and the groats. Oats resistant to dehulling have about the same groat proportion as that calculated from impact dehulling at a constant rotor speed, but appear to have a variation in hull structure that makes them pack less efficiently. Failure to remove oats resistant to dehulling before calculation of groat proportion will tend to cause one to select for oats with poorer groat proportions with kernels more resistant to dehulling, which are negative quality traits. The most accurate groat proportion values are obtained from hand dehulling. If mechanical means are required for groat proportion determination, consistent aspiration conditions should be used for all samples to be compared, and oats resistant to dehulling should be removed and quantified as DHE. It appears that DHE should be considered to be an important quality characteristic. As long as these precautions were taken, GP values obtained were highly correlated with HGP values, although empirically lower. If values for mean unbroken groat mass and mean kernel (with hull) mass are available, their ratio does not differ significantly from the HGP value.


