

Optimizing Conditions for Experimental Oat Dehulling

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ABSTRACT

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The determination of groat percentage in experimental oat breeding lines requires the dehulling of oats. Here, we report the results of our efforts to optimize dehulling conditions so that the most accurate and reliable result can be obtained. Hand dehulling was always reliable and accurate, however, it was the most time-consuming and tedious of the methods studied. Two mechanical methods of oat dehulling, compressed-air dehulling and impact dehulling, also frequently provided reliable results, however, results were strongly influenced by dehulling conditions. Optimal dehulling conditions represented compromises between unfavorable extremes. Correct aspiration strength was critical to accurate groat percentage determination. We have found that a secondary aspiration is highly desirable after compressed-air dehulling to remove hulls remaining with

the groats after dehulling. Also, increased mechanical stress on oats as exerted either by the number of passes through the impact dehuller, or by the air pressure in the compressed-air dehuller, resulted in higher dehulling efficiency, but increased groat breakage as well. Dehulling efficiency decreased as moisture increased from 7.5 to 15%, but increased as moisture was further increased to 30%. In contrast, groat breakage with impact dehulling decreased as moisture increased from 7.5 to 30%. A new equation for groat percentage calculation has been introduced where the mass of hulled oats remaining after dehulling is subtracted from the mass of the original oat sample, so that poor dehulling efficiency does not influence the groat percentage.

Groat percentage is one of the most important quality characteristics of oats. It is the principal component of milling yield (Ganssmann and Vorwerck 1995) and provides information on the economic value of a sample of oats for milling (Salisbury and Wichser 1971) as well as providing information on the digestibility of oats to be fed to animals (Zavitz 1927). Yet, very little information is available concerning optimal methods to measure groat percentage.

The most direct way to measure groat percentage is by hand dehulling. In hand dehulling, the hulls of individual oat kernels are peeled away by hand. Although this method is reliable and accurate, it is very time-consuming and only small samples can be processed. Three basic mechanical methods for dehulling oats include the impact dehuller, the compressed-air dehuller, and the wringer dehuller. The impact dehuller (Cleve 1948; Stuke 1955; Ganssmann and Vorwerck 1995) feeds grain into a spinning rotor. The impact of the grain with a wall as they are expelled from the rotor releases the groats from the hulls. The hulls are then removed by aspiration. The compressed-air dehuller (Fraser 1944; Kittlitz and Vetterer 1972; Meyer and Zwingelberg 1981) uses a stream of pressurized air to apply mechanical shock to the oat releasing the groats from the hulls. Hulls are removed by aspiration. Compressed-air dehullers have only recently been marketed commercially and are starting to become widely used among oat research laboratories. In wringer-type dehullers (Love and Craig 1944), oat kernels are fed individually by hand into a mechanized roller that pulls in the hulls and deposits the groat in a bin. A wringer dehuller can dehull oats faster than by hand but the requirement of feeding individual kernels into the rollers by hand limits the possible sample size.

Hand dehulling and wringer dehulling provide a ceiling value for groat percentage because no groats are lost in mechanical treatment and aspiration. However, mechanical dehullers, especially impact and compressed-air dehullers, allow dehulling of larger samples that are impractical for hand dehulling. Impact dehullers

are commonly used by commercial millers to dehull oats, although an additional method, known as stone hulling, is also used by some commercial milling operations (Ganssmann and Vorwerck 1995). For experimental oat dehulling, an ideal mechanical method would dehull large samples with yields equivalent to those obtained by hand dehulling. Unfortunately, groat percentages derived from mechanical dehulling can diverge significantly from those obtained by hand dehulling.

A recent study from Doehlert et al (1999) compared groat percentage values obtained by hand dehulling, impact dehulling, and compressed-air dehulling. The results indicated that dehulling conditions could have a profound effect on groat percentage data. In mechanical dehulling, insufficient mechanical stress resulted in incomplete dehulling, whereas excessive mechanical stress resulted in groat breakage. Excessive aspiration, required to remove hulls from the groats, can remove groats as well as hulls. Insufficient aspiration left some hulls with groats, resulting in an overestimation of groat percentage. Groat percentages obtained by various methods were correlated, although absolute values differed. Additional hand-sorting to remove hulls from the groat preparation improved the correlation of mechanical dehulling with hand dehulling.

In this report, we introduce several innovations in experimental oat dehulling protocols and in the calculation of groat percentage. Our objectives were to determine how variations in certain dehulling conditions such as number of passes through the impact dehuller, grain moisture, and the blast gate aperture and air pressure of the air-pressure dehuller affected oat dehulling characteristics.

MATERIALS AND METHODS

Plant Material

Oats (*Avena sativa* L.) cv. Dumont and Whitestone were used for all experiments. These cultivars were chosen because past experience had suggested that dehulling these cultivars was especially problematic. Dumont was particularly prone to breakage and Whitestone frequently exhibited low dehulling efficiency. Thus, problems typical of oat dehulling were likely to be accentuated in these cultivars. Oats were raised in the 1998 growing season in Fargo, North Dakota, and were stored under refrigeration until used for the experiment.

Dehulling Equipment

The compressed-air oat laboratory dehuller used for this study was manufactured by Codema Inc. (Eden Prairie, MN). The impact dehuller was manufactured by local contract from plans provided by the Quaker Oats Company, and is similar in design to those described previously (Cleve 1948; Stuke 1955; Ganssmann and Vorwerck

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1995). Primary aspiration for the impact dehuller and secondary aspiration for the compressed-air dehuller was provided by a Bates laboratory aspirator (Seedburo Equipment Co., Chicago, IL). The grain flow setting for the Bates aspirator was 2.0, the air flow setting was 3.0, and the variable fan speed setting was 7.5.

Moisture Control

Moisture of most samples was controlled to a constant 9.5% by allowing samples to equilibrate for a week in desiccators containing saturated solutions of potassium carbonate (Wolf et al 1984). To test the effect of grain moisture on dehulling characteristics, grain was first dried overnight in a convection oven at 40°C. Moisture of dried samples was then determined by measuring the change in mass of 2-g samples after incubation in the convection oven at 130°C for 2 hr. Samples (40 g) were placed in glass jars with lids, and water was introduced into each jar to bring the moisture up to the desired level, then the jars were sealed. Jars were allowed to incubate for ≈14 hr at 4°C with occasional shaking to allow the moisture to equilibrate before samples were dehulled.

Dehulling Protocols

Oat samples (2 g) were hand dehulled by picking up individual kernels, one at a time and peeling away the papery hull surrounding the groat using fingernails. The masses of samples were measured before and after dehulling to calculate groat percentage.

Oat samples (40 g) were dehulled with the impact dehuller. The motor was turned on and allowed to reach maximum speed before the oat sample was fed manually into the rotor. Our impact dehuller had no rheostat control of rotor speed, and the rate of rotor revolution was not known. Dehulled groats mixed with hulls were collected at the bottom of the machine. Selected samples of the groat-hull mixture were passed through the dehuller a second time. Hulls were removed from the free groats by passing the sample through the Bates aspirator twice. Samples were stored and hand-sorted later.

Samples (40 g) were also dehulled with the compressed-air dehuller. The vent opening was kept constant at 7 mm for all experiments. Air pressure was 414, 483, 552, 621, or 690 kPa. The blast gate aperture, which is the opening of the blower that expels air, was

0.5, 1.5 or 2.5 cm. Dehulling time was 60 sec for all experiments. After dehulling, groat samples were subjected to a secondary aspiration (secondary to the dehuller's internal aspiration system) with the Bates aspirator. Samples were passed through the secondary aspirator twice to remove remaining hulls. Sample masses were measured before dehulling, after dehulling, and after secondary aspiration. The cleaned groat sample was stored for sorting, as were the hulls collected by the dehuller and by the secondary aspirator. A flow chart indicating the processes to obtain the various fractions is presented in Fig. 1.

Sorting

Groat samples collected from the aspirator after impact dehulling were sorted by hand into whole groats, broken groats, hulled oats (remaining after dehulling), and free hulls. Broken groats were defined as groats with ≥10% of their mass broken away, as determined by visual inspection. Groat samples recovered from the compressed-air dehuller after secondary aspiration were hand-sorted in the same way as those recovered from the impact dehuller. Hulls recovered from the compressed-air dehuller and from the secondary aspirator were also sorted by hand in an attempt to recover all groats that were removed from the groat sample by force of aspiration.

Calculations

The crude groat percentage was calculated as:

$$\text{Crude Groat Percentage} = \left[\frac{\text{Crude Groat Mass}}{\text{Whole Oat Mass}} \right] \times 100 \quad (1)$$

where the whole oat mass is the mass of whole oat fed into the dehuller, and the crude groat mass is either the mass of groats recovered from the compressed-air dehuller before secondary aspiration, or the mass of groats recovered from the impact dehuller after aspiration.

A corrected groat percentage was obtained with samples derived from the compressed-air dehuller by subjecting the crude groat preparation to secondary aspiration, resulting in a cleaned groat sample:

$$\text{Corrected Groat Percentage} = \left[\frac{\text{Cleaned Groat Mass}}{\text{Whole Oat Mass}} \right] \times 100 \quad (2)$$

where the cleaned groat mass is the mass of the groat sample after secondary aspiration.

The cleaned groat preparation from the compressed-air dehuller, or the crude groat preparation from the impact dehuller (after aspiration) were then sorted by hand to separate the whole groats, hulled oats remaining, and broken groats. These preparations were generally devoid of free hulls. Because the groats are usually sorted some time after dehulling, the cleaned groat preparation usually changed mass because of moisture change. Thus, a moisture correction factor (MCF) was calculated as:

$$\text{MCF} = \left[\frac{\text{Original Groat Preparation Mass}}{\text{Current Groat Preparation Mass}} \right] \quad (3)$$

Broken groats were expressed as a proportion of the total groat preparation:

$$\text{Percent Broken Groats} = \left[\frac{\text{Broken Groat Mass}}{\text{Whole Groat Mass} + \text{Broken Groat Mass}} \right] \times 100 \quad (4)$$

Dehulling efficiency (DHE) was calculated from the mass of hulled oats recovered from the groat preparation:

$$\text{DHE} = 100 - \left[\left(\frac{\text{Hulled Oats Remaining} \times \text{MCF}}{\text{Whole Oat Mass}} \right) \times 100 \right] \quad (5)$$

Because the crude and cleaned groat preparations contained hulled oats remaining after dehulling, the groat percentage calculated with them was upwardly biased. This bias is corrected in the final groat percentage. Because in a typical oat mill, hulled oats remaining can be recovered after dehulling (Deane and Commers

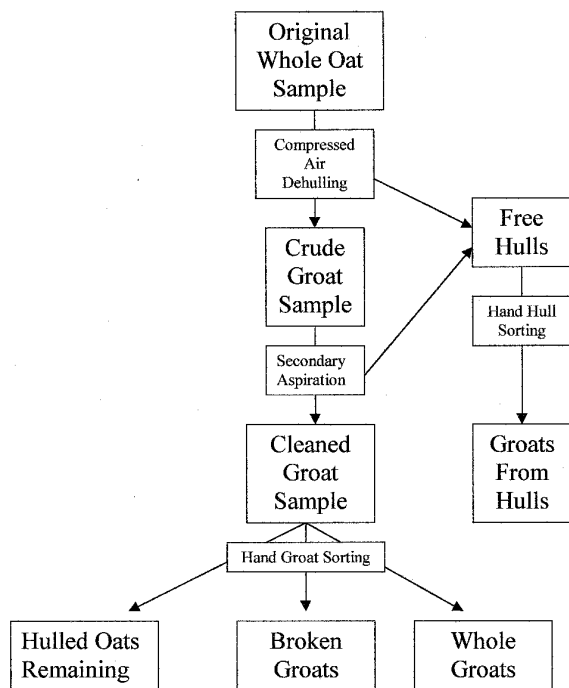


Fig. 1. Processing of oat samples by a compressed-air oat dehuller.

1986) and run through the dehuller again, hulled oats remaining are subtracted from the original oat mass before groat percentage is calculated:

$$\text{Final Groat Percentage} = \left[\frac{([\text{Whole Groat Mass} + \text{Broken Groat Mass}] \times \text{MCF})}{(\text{Whole Oat Mass} - [\text{Hulled Oats Remaining} \times \text{MCF}])} \right] \times 100 \quad (6)$$

A total groat percentage was calculated for samples dehulled by the compressed-air dehuller, where the mass of groats recovered from the hull fractions was added back into the final groat mass:

$$\text{Total Groat Percentage} = \left[\frac{([\text{Whole Groats} + \text{Broken Groats} + \text{Groats from Hulls}] \times \text{MCF})}{(\text{Whole Oat Mass} - [\text{Hulled Oats Remaining} \times \text{MCF}])} \right] \times 100 \quad (7)$$

Experimental Design

All experiments contained three or four replicates and were repeated with two oat cultivars, Dumont and Whitestone. Results were analyzed by analysis of variance and means compared with least significant difference, all calculated with Statistix computer software (Analytical Software, Tallahassee, FL)

RESULTS AND DISCUSSION

In a previous study from this laboratory (Doehlert et al 1999), the importance of hand-sorting mechanically dehulled oat samples was stressed to avoid error in the groat percentage due to hulls remaining in the groat sample. Subsequently, we have found a variety of aspirators that function well to remove free hulls in groat samples without removing groats: the Bates aspirator, the South Dakota seed blower, and various homemade aspirators (data not shown). It is essential that the blowers be set to an aspiration strength that removes hulls completely, while removing few or no groats. "Clipper" type seed cleaners were unsatisfactory for groat percentage determination because of poor reproducibility and excessive groat loss (data not shown).

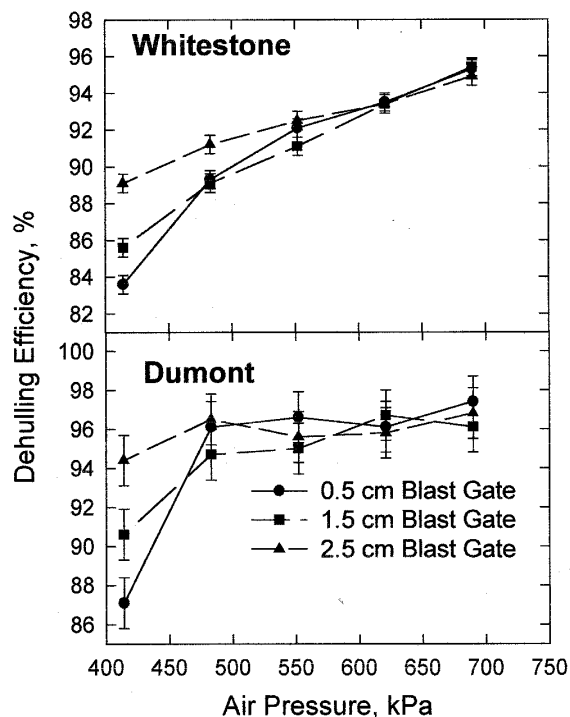


Fig. 2. Effect of air pressure and blast gate aperture on dehulling efficiency of Whitestone and Dumont oat cultivars. Error bars are least significant difference ($P < 0.05$), $n = 3$.

An innovation in the sorting protocol has also been introduced. In the previous study (Doehlert et al 1999), free hulls and hulled oats remaining after dehulling were sorted into the same fraction, and labeled "hulls remaining". In this study, hulled oats remaining were sorted into a different fraction than the free hulls. Also, in this study, free hulls were virtually absent because of the introduction of improved aspiration protocols described above.

Several innovations in the calculation of groat percentage have also been introduced since the previous study. The introduction of the MCF has corrected for minor changes in mass of samples during storage due to moisture loss or gain. Also, the treatment of hulled oats remaining after dehulling has been changed. In the previous work, hulled oats remaining after dehulling were bulked with free hulls and their mass was subtracted from the crude groat mass for the calculation of the final groat mass. Because hulled oats remaining after dehulling can be separated from groats in commercial milling streams and recycled back into the dehullers (Deane and Comers 1986), we decided that the mass of hulled oats remaining should not subtract from a groat percentage calculation. Thus, the mass of hulled oats remaining after dehulling is subtracted from the original whole oat mass when calculating the final groat percentage. This assures that the calculated groat percentage is based on the mass of oats that were actually dehulled. A dehulling efficiency value has also been introduced to quantify the extent of dehulling under any particular treatment.

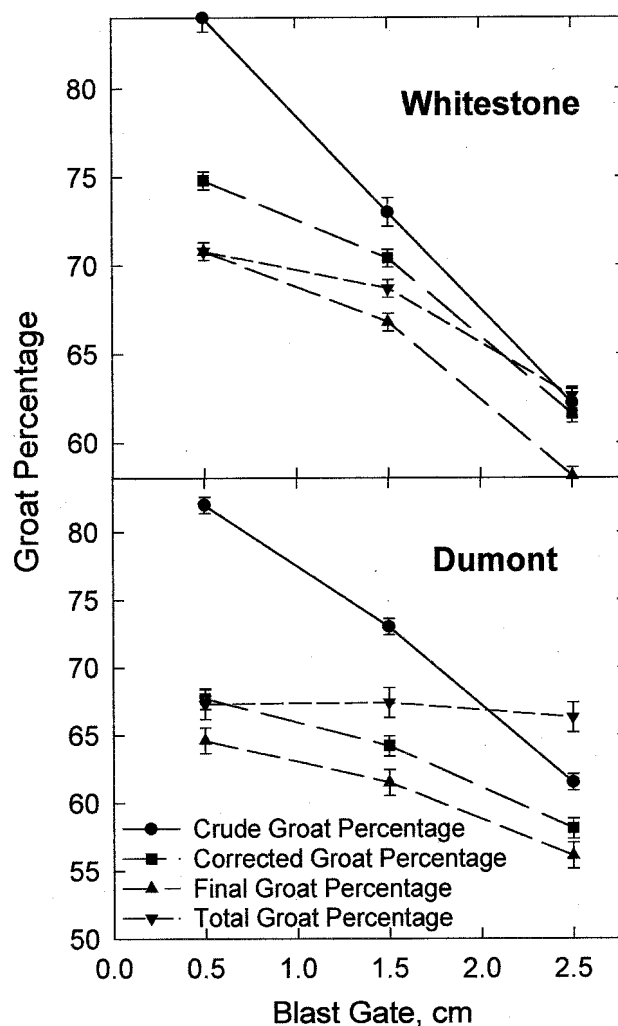


Fig. 3. Effect of blast gate aperture on measuring groat percentage. Groat percentages determined by hand were 72.1 and 71.4% for Whitestone and Dumont oat cultivars, respectively. Error bars are least significant difference ($P < 0.05$), $n = 3$.

The first experiment presented here tested the effect of multiple passes of an oat sample through the impact dehuller. Results (Table I) indicate that the additional pass through the dehuller increased groat breakage and DHE in both cultivars tested. These results are consistent with a previous hypothesis (Doehlert et al 1999) that DHE and groat breakage should increase with mechanical stress applied to the grain. The decrease in the measured groat percentage after two passes through the dehuller is likely due to groat losses from groat breakage that are removed in the aspiration step. The smaller difference between the crude and final groat percentages after two passes is likely due to the nearly complete dehulling achieved with two passes.

In a second experiment, two parameters of the compressed-air dehuller were varied, the blast gate opening and the air pressure. The blast gate affected the aspiration strength of the dehuller. Both the blast gate opening and the air pressure affected the dehulling efficiency (Fig. 2). Dehulling efficiency was best with air pressure >552 kPa and blast gate opening 1.5–2.5 cm.

The various measurements of groat percentage calculated here were not affected by the air pressure (data not shown), but were affected by the blast gate aperture (Fig. 3). At the smallest blast gate opening, the crude groat percentage was much higher than the other groat percentage values because of excessive amounts of hulls remaining in the crude groat preparation that were not removed by low-level aspiration. However, secondary aspiration largely corrected this problem. The corrected, final and total groat percentage values at 0.5 and 1.5 cm blast gate apertures were usually close to, but lower than, the groat percentage as determined by hand dehulling. For Whitestone and Dumont, the hand groat percentage was 72.1 and 71.4%, respectively. However, when blast gate width was 2.5 cm, the measured values of groat percentage dropped drastically. It is particularly evident with the Whitestone sample that much of the decrease in crude, corrected, and final groat percentage at the 2.5-cm

blast gate aperture was due to the loss of groats by excessive aspiration. Groats were recovered in much higher numbers in the hull fraction obtained with the 2.5-cm blast gate aperture than at the smaller blast gate apertures. When these are added back to the groat sample (as in the total groat percentage), groat percentages were still significantly higher at 1.5 cm than at 2.5 cm for the Whitestone sample. However, the total groat percentage for Dumont did not differ for any of the different blast gate apertures (Fig. 3). Overall, it appeared that the most reliable groat percentage values were derived with a blast gate setting of 0.5 or 1.5 cm.

As observed previously (Doehlert et al 1999), increased air pressure in the compressed-air dehuller resulted in more groat breakage (Fig. 4), although the amount of breakage in Whitestone was negligible when compared with Dumont. This is also consistent with the hypothesis that increased mechanical stress results in more groat breakage. The blast gate aperture did not affect groat breakage with either Whitestone or Dumont.

As in our earlier study (Doehlert et al 1999), we found that optimal dehulling conditions with the compressed-air dehuller represent compromises between unfavorable extremes. There we found that a 1-min dehulling time, with a 7-mm vent aperture was optimum. In this study, we found that a 1.5-cm blast gate aperture was optimum. In our opinion, air pressure of 621 kPa was optimal because accurate groat percentage evaluations can be made without excessive groat breakage. Some oat improvement programs may prefer to dehull at a higher air pressure (such as 690 kPa) to get improved dehulling efficiency as well as to select for groat durability.

The effect of grain moisture content on dehulling characteristics of oats with the impact dehuller was tested with Whitestone and Dumont oats (Fig. 5). Groat breakage decreased for both Whitestone and Dumont when moisture was increased from 7.5 to 30%. Dehulling efficiency decreased at 7.5–15% moisture but increased at

TABLE I
Effect of the Number of Passes Through an Impact Dehuller on Measured Groat Percentage, Groat Breakage, and Dehulling Efficiency

Passes	Crude % Groat	Final % Groat	% Broken Groats	Dehulling Efficiency (%)
Dumont				
1	71.3	69.1	8.5	94.1
2	65.9	65.6	31.2	99.5
LSD ^a	1.6	1.5	3.1	0.6
Whitestone				
1	73.5	71.4	3.6	93.0
2	68.0	67.7	24.8	99.6
LSD	1.9	1.9	1.7	0.6

^a Least significant difference ($P < 0.05$), ($n = 4$).

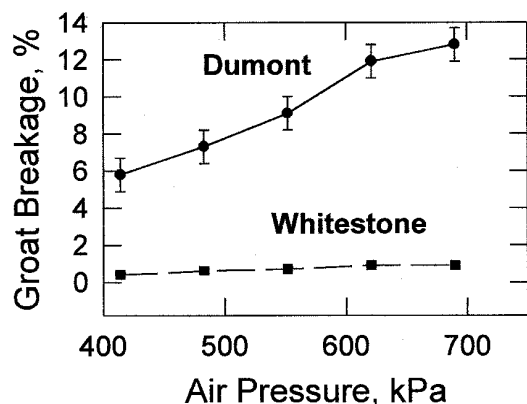


Fig. 4. Effect of air pressure and blast gate aperture on groat breakage by compressed-air dehulling of Whitestone and Dumont oat cultivars. Error bars are least significant difference ($P < 0.05$), $n = 3$.

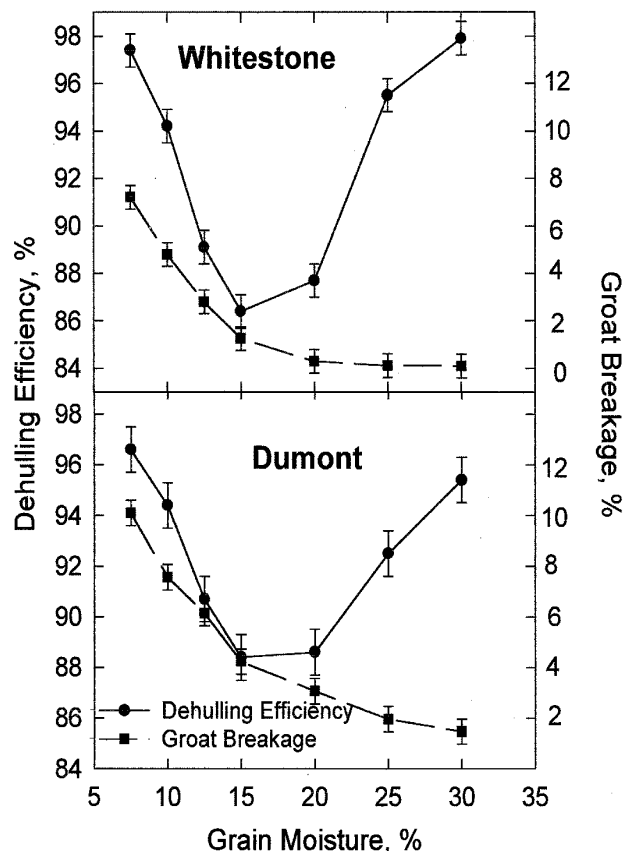


Fig. 5. Effect of grain moisture on dehulling efficiency and groat breakage after impact dehulling of Whitestone and Dumont oat cultivars. Error bars are least significant difference ($P < 0.05$), $n = 3$.

15–30% moisture. The dehulling efficiencies of both Whitestone and Dumont were nearly as high at 30% moisture as they were at 7.5%, even though they were much lower at 15%. These results are consistent with Bruckner (1953). Dry kernels dehull more easily because the hulls are more brittle. Possibly, the oat dehulls more easily at very high moisture because the coats absorb more water and groat masses become much greater than the hull. Although it seems unlikely that high-moisture dehulling could be adopted by industry, situations may arise when it may be desirable to dehull a particularly brittle sample at high moisture to avoid breakage.

Dumont and Whitestone cultivars are frequently problematic to dehull. Our experience with most other cultivars suggests that they can provide more favorable groat percentage values over a wider range of dehulling conditions. However, all of the trends shown here, such as increased DHE and breakage at greater levels of mechanical stress, are consistent among all cultivars.

CONCLUSIONS

New protocols for experimental mechanical oat dehulling have been proposed. Secondary aspiration after compressed-air dehulling and use of appropriate aspirators after impact dehulling resulted in better groat recovery and the virtual elimination of free hulls in the groat preparations without hand sorting. New equations that subtract the hulled oats remaining after dehulling from the original oat mass are introduced for the correction of groat percentage when dehulling efficiency is less than perfect. Positive relationships between increased mechanical stress on oats during dehulling and dehulling efficiency as well as groat breakage have been documented. Values of groat percentage decreased at higher levels of mechanical stress, probably because of excessive groat breakage. Grain moisture also has a strong effect on dehulling efficiency. Optimal

dehulling efficiency was observed at very low and at very high moisture. Groat breakage decreased with increasing moisture.

LITERATURE CITED

- Bruckner, G. 1953. Der Einfluss der Korneigenschaften auf die Schalung des Hafers. *Die Muhle und Mischfuttertechnik* 90:434-436.
- Cleve, H. 1948. Das Hamringverfahren bei der Haferschabung. *Getreide Mehl Brot* 2:32-36.
- Deane, D., and Commers, E. 1986. Oat cleaning and processing. Pages 371-412 in *Oats: Chemistry and Technology*. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Doehlert, D. C., McMullen, M. S., and Baumann, R. R. 1999. Factors affecting groat percentage in oat. *Crop Sci.* 39:1858-1865.
- Fraser, C. R. 1944. The air jet method of dehulling seeds. *Can. J. Res. F* 22:157-162.
- Ganssmann, W., and Vorwerk, K. 1995. Oat milling, processing and storage. Pages 369-408 in: *The Oat Crop: Production and Utilization*. R. W. Welch, ed. Chapman & Hall: London.
- Kittlitz, E. V., and Vetterer, H. 1972. Untersuchungen zur maschinellen Entspelzung von Hafer mit einem Druckluftspelzer. *Dtsch. Mullerzeitung* 70:245-246.
- Love, H. H., and Craig, W. T. 1944. A machine for dehulling oats. *J. Am. Soc. Agron.* 36:264-266.
- Meyer, D., and Zwingelberg, H. 1981. Untersuchungen zur Verwendung von ländischem Hafer in der Schälmuellerei. *Getreide Mehl Brot* 35:230-234.
- Salisbury, D. K. and Wichser, W. R. 1971. Oat milling: Systems and products. *Bull. Assoc. Oper. Mill.* 1971:3242-3247.
- Stuke, H. 1955. Eine Schnellmethode zur Bestimmung des Spelzengehaltes beim Hafer. *Der Zuchter* 25:90-92.
- Wolf, W., Spiess, W. E. L., Jung, G., Weisser, H., Bizot, H., and Duckworth, R. B. 1984. Standardization of isotherm measurements. *J. Food Eng.* 3:51-73.
- Zavitz, C. A. 1927. Forty years' experiments with grain crops. *Bull. Ont. Dept. Agric.* 332.

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