

Bulk characteristics of a hulless and two hulled cultivars of oats

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Lepper, S., White, N.D.G. and Jayas, D.S. 1997. **Bulk characteristics of a hulless and two hulled cultivars of oats.** Can. Agric. Eng. 39:085-090. Handling and storage properties of one hulless cultivar (AC Belmont), and two hulled cultivars (Robert and AC Marie) of oats (*Avena sativa* L.) were measured for bulk samples for moisture contents from 10.5% to 19.5%, wet mass basis. The properties were friction coefficients, standard bulk density, pail bulk density, particle density, and filling and emptying angles of repose. Friction coefficients against the four structural materials tested (galvanized steel, plywood, wood-floated concrete, and steel trowelled concrete) ranged from 0.24 at 10.5% moisture content (m.c.) for AC Belmont and Robert oats on galvanized steel, to 0.68 at 19.4% moisture content for AC Belmont on wood-floated concrete. Generally, as the grain moisture content increased, the friction coefficient increased. Standard bulk densities for AC Belmont oats decreased as the moisture content increased. AC Belmont had a mean standard bulk density of 637 kg/m³. The maximum particle density of AC Belmont was 1409 kg/m³ and the lowest value was 1360 kg/m³ at 19.5% m.c. The Robert oats had a mean standard bulk density of 538 kg/m³ which showed a decreasing trend as the moisture content increased. Particle density dropped steadily from 1378 kg/m³ to 1340 kg/m³ as the moisture content increased. The standard bulk density for AC Marie oats was constant at approximately 445 kg/m³, except at 19.5% moisture content where it was lower. The average particle density of AC Marie oats was 1305 kg/m³. AC Belmont had the highest bulk density among the oats at 82% of the bulk density of Columbus wheat, with Robert and AC Marie having densities of 59 and 67% of wheat, respectively. AC Belmont had steadily increasing emptying and filling angles with increasing moisture to a maximum of 35.8° for an emptying angle and 38.6° for a filling angle at 19.5% m.c. Robert oats had a gradual rise in emptying and filling angles with increasing moisture to a maximum of 32.9° for emptying and 29° for filling at the highest moisture content. The emptying and filling angles of AC Marie oats stayed fairly constant until the moisture content increased to 19.5%. The absence of hulls in AC Belmont generally resulted in greater friction coefficients, bulk density, particle density, emptying and filling angles than for the two cultivars with hulls at a given moisture content. The main difference when comparing all the cultivars was a greater particle density for Robert oats. All of the oat cultivars exerted a similar lateral force to galvanized steel walls (4.8 to 5.2 kPa) at 17.0% m.c., which is 6 to 13% less than that for wheat. Key words: oats, hulled, hulless, bulk, physical properties.

Les caractéristiques de manutention et d'entreposage d'un cultivar à grain nu (AC Belmont) et de deux cultivars à grain vêtu (Robert et AC Marie) ont été mesurées chez des échantillons d'avoine en vrac (*Avena sativa* L.). Ces caractéristiques comprenaient divers coefficients de frottement, la masse volumique apparente en vrac normale, la masse volumique réelle en seau, la masse volumique réelle du grain ainsi que l'angle de repos au remplissage et au déchargement.

Le coefficient de frottement a été mesuré au contact de quatre matériaux structuraux: l'acier galvanisé, le contreplaqué, le béton fini à la taloche et le béton fini à la truelle. Ce coefficient allait de 0,24 (teneur en eau de 10,5%, avoines AC Belmont et Robert sur acier galvanisé), à 0,68 (teneur en eau de 19,4%, avoine AC Belmont sur béton lissé à la taloche). En général, plus la teneur en eau du grain était élevée, plus le coefficient de frottement l'était également. La masse volumique apparente en vrac normale de l'avoine AC Belmont diminuait avec l'augmentation de la teneur en eau; elle s'établissait en moyenne à 637 kg/m³. La masse volumique réelle du grain de ce cultivar atteignait un maximum de 1409 kg/m³, mais tombait à 1360 kg/m³ quand la teneur en eau était de 19,5%. La masse volumique apparente en vrac normale de l'avoine Robert diminuait également avec l'augmentation de la teneur en eau; elle était de 538 kg/m³ en moyenne. La masse volumique apparente en vrac normale était constante, s'établissant généralement à environ 445 kg/m³, mais elle était moindre quand la teneur en eau atteignait 19,5%. La masse volumique réelle était de 1305 kg/m³ en moyenne. L'avoine AC Belmont présentait la masse volumique apparente en vrac la plus élevée, équivalant à 82% de celle du blé Columbus. Les masses volumiques apparentes des avoines Robert et AC Marie équivalaient respectivement à 59 et 67% de celle du blé. Les angles de repos au déchargement et au remplissage augmentaient constamment dans le cas de l'avoine AC Belmont, atteignant 35, 8° au déchargement et 38, 6° au remplissage pour une teneur en eau de 19,5%. Ces angles augmentaient graduellement dans le cas de l'avoine Robert, atteignant 32,9° au déchargement et 29° au remplissage pour la teneur en eau la plus élevée. Dans le cas de l'avoine AC Marie, les deux angles de repos variaient peu jusqu'à ce que la teneur en eau atteigne 19,5%. L'absence de balle chez l'avoine AC Belmont entraînait de façon générale des coefficients de frottement, une masse volumique apparente en vrac, une masse volumique réelle ainsi que des angles de repos plus élevés que dans le cas des deux cultivars à grain vêtu, pour une teneur en eau égale. La principale différence observée entre les divers cultivars était la masse volumique réelle plus élevée de l'avoine Robert. Les grains de tous les cultivars exerçaient une pression latérale similaire contre les parois d'acier galvanisé (4,8 à 5,2 kPa), pour une teneur en eau de 17,0%. Cette pression est 6 à 13% moindre que celle exercée par les grains de blé à teneur en eau de 16,4%. Mots clés : avoine, grain vêtu, grain nu, vrac, propriétés physiques.

INTRODUCTION

The physical properties of bulk grain must be known to design grain storage and handling systems (Cenkowski and Zhang 1995). An average of 1.3 Mha of land is seeded annually in Canada for oat production of 3.6 Mt (million tonnes) (Canadian Grains Council 1994). Oats are used either as a feed grain or for human consumption. A number of

different cultivars, with widely varying properties, are grown. In the feed industry, hullless cultivars are preferred because of increased digestibility and therefore increased nutritional value (Ballestros and Piendl 1977).

The aim of this study was to determine the bulk properties of three relatively new oat cultivars, a hullless oat, AC Belmont with about 7% oil [w/w] and two cultivars of hulled oats with differing oil contents, AC Marie with about 7% oil (w/w) and Robert with about 5% oil (w/w) (Unpublished data, N.D.G. White, Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, MB). The properties measured were friction coefficient against structural materials, standard bulk density, pail density, particle density, and the filling and emptying angles of repose. The friction coefficients were measured on four materials used in storage structures: galvanized steel, plywood, wood-floated concrete, and steel-trowelled concrete. These experimentally determined data were used in Janssen's equations to predict the pressures on the bin walls (Manbeck et al. 1995).

EXPERIMENTAL PROCEDURE

Sample preparation

Three different types of oats were purchased from a seed company near Winnipeg, MB. The original moisture contents were 10.5% for AC Belmont and Robert and 11.0% for AC Marie. The moisture contents were measured on a wet mass basis. Moisture contents were raised to desired levels by spraying predetermined amounts of distilled water onto the sample while it was tumbling in a concrete mixer. Sample moisture contents were measured after oats were allowed to equilibrate for approximately a day in sealed bags at 20 (2°C. Moisture contents of the oats were determined by drying triplicate samples in an air convection oven set at 130°C for 16 h (ASAE 1993).

Measurement of bulk properties

The experimental methods for measurement of friction coefficients, standard, pail, and particle densities, and emptying and filling angles of repose were the same as used by Rameshbabu et al. (1995).

Bulk and particle densities

Bulk densities were determined by filling a 500 mL metallic container (90 mm diameter and 79 mm height) with grains using a metallic cone (225 mm top diameter, 38 mm bottom diameter, and 160 mm height), which was used as a grain hopper. The bottom of the cone was 45 mm above the container. When a flat slide gate on the bottom of the cone was opened, the samples flowed freely from the cone and filled the container. Bulk densities were calculated as the ratio of the masses of samples to the volume of the container.

Compact bulk densities (pail densities) were determined as the ratio of the compact masses of samples and the known volume of the container.

Particle densities were calculated as the ratio of the masses of samples to the particle volume of samples measured using an air comparison pycnometer.

Emptying and filling angles of repose

Emptying angles of repose of samples were measured in a

wooden box: 430 mm long, 200 mm wide, and 430 mm high. samples were allowed to flow out through a 50 mm high and 200 mm wide rectangular opening provided along the width of the box at the bottom of one end wall. Emptying angles were calculated from measurements of horizontal and vertical scale readings.

Filling angles of repose were measured in a wooden box 1200 mm long, 100 mm wide, and 760 mm high with one side made of plexiglass. Samples were allowed to flow freely through a 53 mm square opening in a wooden hopper, whose centre was 1000 mm above the bottom of the receiving box.

Friction coefficients

Coefficients of sliding friction were determined for various surfaces namely, galvanized steel, plywood (which had wood-grains parallel to the motion of the seed), and steel-trowelled and wood-floated concretes. Surfaces were attached to a tilting table (one surface in an experiment). A wooden frame (305 mm long and 255 mm wide), made of 18 mm square wood, was placed lengthwise on the surface. It was filled with the sample and levelled. Using a manually driven screw, the table was tilted slowly until the sample started to slide. The coefficient of friction was calculated as the tangent of the angle measured.

RESULTS AND DISCUSSION

Friction coefficients

The friction coefficients of AC Belmont oats increased as the moisture content increased (Table I). The friction coefficient against galvanized steel increased from 0.24 to 0.53 with an increase in moisture content from 10.5% to 19.5%. The friction coefficient of plywood stayed constant from 10.5% to 13.5% m.c. (0.31) then increased and stayed constant from 17% to 19.5% m.c. (0.47). Wood-floated concrete had friction coefficients that increased from 0.47 at 10.5% m.c. to 0.68 at 19.5% m.c. The coefficients stayed constant from 17% to 19.5% m.c. They ranged from 0.41 at 10.5% m.c. to 0.62 at 19.5% m.c. Wood-floated concrete had the highest friction coefficients, followed by steel-trowelled concrete and plywood. Galvanized steel had the lowest friction coefficients. At 19.5% m.c., galvanized steel and plywood had the same coefficients and wood-floated concrete and steel-trowelled concrete were the same as well at 19.5% m.c.

The friction coefficients on galvanized steel of Robert oats (Table I) stayed constant at 0.24 from 10.5% to 12.0% m.c., then increased to 0.39 at 17.0% m.c. and stayed constant until 19.5% m.c. Plywood had a range of coefficients between 0.3 and 0.4 for moisture contents between 10.5% and 19.5%. Wood-floated concrete had the highest range of values again, starting at 0.45 at 10.5% m.c. and increasing to 0.60 at 19.5% m.c. Values from 12.0% to 15.0% m.c. stayed constant. The coefficients of friction for steel-trowelled concrete stayed constant from 10.5% to 15.0% m.c. (0.42) then increased to 0.53 at 19.5% m.c.

The friction coefficients of AC Marie oats on galvanized steel (Table I) showed an increase (from 0.3) with an increase in grain moisture. The friction coefficient on plywood stayed fairly constant from 11% to 17% m.c. at about 0.32, then increased to 0.42 at 19.5% m.c. The wood-floated concrete

Table I: Mean friction coefficients and associated standard deviations of three oat cultivars on galvanized steel (GS), plywood (PW), wood-floated concrete (WFC), and steel-trowelled concrete (STC)

Cultivar	Moisture content (%)	Surface							
		GS**	SD*	PW**	SD*	WFC**	SD*	STC**	SD*
AC Belmont (hulless)	10.5	0.24va	0.01	0.31vb	0.01	0.47vc	0.01	0.41vd	0.01
	13.5	0.35wa	0.01	0.32vb	0.01	0.51wc	0.01	0.47wd	0.01
	15.0	0.42xa	0.02	0.38wb	0.01	0.57cx	0.02	0.52xd	0.01
	17.0	0.49ya	0.02	0.45xb	0.02	0.64yc	0.02	0.57yd	0.01
	19.5	0.53za	0.02	0.49xa	0.04	0.68yb	0.04	0.62zb	0.02
Robert	10.5	0.24wa	0.01	0.30wb	0.01	0.45wc	0.01	0.41wd	0.01
	12.0	0.24wa	0.01	0.32xb	0.01	0.49xc	0.02	0.42wd	0.01
	15.0	0.32xa	0.01	0.33xa	0.01	0.50xb	0.01	0.42wyc	0.02
	17.0	0.40ya	0.02	0.37ya	0.01	0.53yb	0.02	0.49yc	0.01
	19.5	0.38ya	0.02	0.40ya	0.03	0.60zb	0.01	0.53zc	0.01
AC Marie	11.0	0.31wa	0.01	0.34wb	0.01	0.49wc	0.01	0.43wd	0.02
	13.0	0.33xa	0.01	0.33wxa	0.01	0.49wb	0.01	0.44wc	0.02
	15.0	0.34xya	0.02	0.32xya	0.01	0.49wb	0.02	0.44wc	0.03
	17.0	0.36ya	0.02	0.31yb	0.01	0.51wc	0.03	0.45wd	0.02
	19.5	0.43za	0.02	0.42za	0.02	0.60zb	0.02	0.54zc	0.02

* Standard deviations on n=5.

**Means followed by the same letter for rows (a, b, c) and columns (v, w, x, y, z) within each cultivar are not significantly different based on 95% confidence interval of *t*-test.

friction coefficient stayed constant from 11% to 17% m.c. At 19.5% m.c., the friction coefficient increased to 0.60. Much the same trend was noted for steel-trowelled concrete for which friction coefficients stayed constant from 11% to 17% m.c. At 19.5% m.c. the friction coefficient increased to 0.54. The maximum friction coefficient was against wood-floated concrete (0.60) at 19.5% m.c. while the minimum friction coefficient was against galvanized steel (0.31) at 11.0% m.c. The friction coefficients of the hulless cultivar (AC Belmont) were usually greater than the two hulled cultivars (AC Marie, Robert).

Muir and Sinha (1988) found that hulled Fidler oats at 16.4% m.c. on galvanized steel had a friction coefficient of 0.43. Hulled Hudson oats at the same moisture content had a friction coefficient of 0.33. At a lower moisture content of 12.7%, Hudson oats had a coefficient of 0.28 and Fidler oats had a coefficient of 0.30. Similar trends, increasing moisture leading to increasing coefficients, were shown for steel-trowelled concrete and wood-floated concrete. These trends were also seen for friction coefficients for hard red spring wheat reported by Muir and Sinha (1988) (12.7% m.c.: 0.31 on galvanized steel, 0.40 on steel-trowelled concrete, 0.43 on wood-floated concrete; and at 16.4% m.c.: 0.43 on galvanized steel, 0.47 on steel-trowelled concrete and 0.50 on wood-floated concrete).

In general, at low moisture contents around 12% or lower, particles of grain tend to be inelastic. As moisture content increases the grain particles are more elastic and are able to deform requiring increased forces to break the bonds between sliding grain and surfaces. Therefore, increased moisture content increases the coefficient of friction (Thompson and Ross 1983; Lawton 1980).

Density

The mean, standard deviations, and results of *t*-test for standard bulk, pail bulk, and particle densities of AC Belmont, Robert, and AC Marie oats are given in Table II.

The standard bulk density for AC Belmont oats decreased from a density of 671 kg/m³ at 10.5% m.c. to 598 kg/m³ at 19.5% m.c. The pail density of AC Belmont decreased in general from 688 kg/m³ at 13.5% m.c. to 639 kg/m³ at 19.5% m.c. At 10.5% m.c., the pail density was 671 kg/m³. The particle density of AC Belmont was 1410 kg/m³ at 10.5% m.c. and then dropped to and stayed constant at approximately 1368 kg/m³ from 13.5% to 19.5% m.c.

The standard bulk density of Robert oats stayed constant from a moisture content of 10.5% to 15.0%, then dropped to 512 kg/m³ as the moisture content increased to 19.5%. The pail density of Robert oats stayed fairly constant from 10.5% to 15% m.c., then dropped to 557 kg/m³ at 19.5% m.c. The particle density of Robert oats decreased as the moisture content increased. The particle density at 10.5% m.c. was 1378 kg/m³, while the particle density at 19.5% was 1340 kg/m³.

The standard bulk density of AC Marie oats was constant at about 446 kg/m³ for moisture contents from 11% to 17%, but decreased to 435 kg/m³ at 19.5% m.c. The pail density remained fairly constant at about 492 kg/m³ over the range of moisture contents from 11% to 17%, but dropped to 467 kg/m³ at 19.5% m.c. The particle density remained constant over the whole moisture content range tested. Pail densities were always greater than standard bulk densities for the same moisture contents and cultivar.

Muir and Sinha (1988) found the standard bulk density, compacted (pail) density, and particle density for Fidler and Hudson oats. At 12.7% m.c., they found the standard bulk

Table II: Mean standard bulk densities, pail densities and particle densities of three oat cultivars

Oats	Moisture content (%)	Bulk density (kg/m ³)		Pail density (kg/m ³)		Particle density (kg/m ³)	
		Mean*	SD**	Mean*	SD**	Mean*	SD**
AC Belmont (hulless)	10.5	506xa	2	671wb	1	1410wc	7
	13.5	651xa	3	688xb	3	1377xc	12
	15.0	646xa	2	681yb	3	1375xc	12
	17.0	617za	2	661zb	3	1360xc	18
	19.5	598za	1	639vb	2	1360xc	26
Robert	10.5	552wa	1	585wb	1	1378wc	1
	12.0	550wa	3	581xb	2	1373wxc	14
	15.0	551wa	3	586wxb	3	1368xc	6
	17.0	525xa	3	570yb	2	1351xc	10
	19.5	512ya	2	557zb	3	1340yc	8
AC Marie	11.0	447wa	2	490wb	2	1294wc	7
	13.0	446wa	1	495xb	1	1301wc	2
	15.0	445wa	3	495wxb	3	1229wc	10
	17.0	447wa	2	492wxb	2	1296wc	9
	19.5	435xa	4	467zb	3	1317wc	15

* Means followed by the same letter for rows (a, b, c) and columns (v, w, x, y, z) within each cultivar are not significantly different based on 95% confidence interval of *t*-test.

**Standard deviations on n=5.

densities of 555 kg/m³ and 488 kg/m³, pail densities of 631 kg/m³ and 555 kg/m³, and particle densities of 1315 kg/m³ and 1302 kg/m³ for Fidler and Hudson oats, respectively. The values for Fidler are similar to the results found in this study for Robert oats. The values for Hudson are between those for AC Marie and Robert oats. In comparison, standard bulk density for hard red spring wheat is about 768 kg/m³ (Muir and Sinha 1988).

As moisture levels of the kernels increase, they swell with water and increase in volume. Dry matter in the test apparatus is replaced by imbibed moisture which has a lower bulk density. Therefore, bulk density decreases as moisture content increases. However, increased moisture levels change the elastic properties of kernels and this can increase bulk density at increased overburden pressures (Thompson and Ross 1983).

Emptying and filling angles

The mean values for filling and emptying angles of repose, standard deviations for the mean, and the *t*-tests results are shown in Table III. The filling angle of AC Belmont started with an angle of 24.2° at 10.5% m.c. and increased to an angle of 38.6° at 19.5% m.c. The emptying angle stayed constant at 24° from 10.5% m.c. until 13.5% m.c. and then increased to 35.8° at 19.5% m.c. The filling angle for Robert oats stayed constant from 10.5% to 15.0% m.c. (23°) and then increased to 29° at 19.5% m.c. The emptying angle stayed constant from 10.5% until 15.0% m.c. (25°) and then increased to 32.9° at 19.5% m.c. The filling angle of AC Marie oats stayed constant over the range of moisture contents from 11.0% to 17.0% m.c. (22°) and at 19.5% m.c. the filling angle increased to 27.4°. The emptying angle for AC Marie stayed constant as the moisture content increased from 11.0% to

17.0% and then increased to 32.5° at 19.5% m.c.

The filling angle was greater than the emptying angle for the hulless cultivar AC Belmont, but the emptying angle was greater for the hulled cultivars Robert and AC Marie at corresponding moisture contents.

The rise in filling and emptying angles of repose that were seen at ≥ 19% m.c. was also seen in tests for hulless barley (Rameshbabu et al. 1995). Muir and Sinha (1988) found filling angles of repose for Fidler and Hudson oats at 16.4% m.c. to be 36° and 30°, respectively. The emptying angles of repose were 32° and 30°, respectively. Comparative values for hard red spring wheat are about 26° (filling), and 23° (emptying) at 12.7% m.c., and 31° (filling), and 34° (emptying) at 16.4% m.c. (Muir and Sinha 1988). Considering the results of filling and emptying angles of Muir and Sinha (1988) for two hulled cultivars of oats, it appears that these properties and their trends are cultivar dependant.

BIN WALL PRESSURE

As discussed by Kukulko et al. (1988), a widely used method of predicting bin wall pressures is Janssen's theory. It is based on the static equilibrium of a slice of granular material stored in a circular bin.

$$Ph = wR [1 - \exp(-u' Kh/R)]/u' \quad (1)$$

where:

- Ph = lateral bin wall pressure at depth h (kN/m²),
- w = specific weight of stored material (kN/m³),
- R = hydraulic radius of storage structure, defined as the ratio of the cross-sectional area of the bin to the perimeter of the bin (m),

Table III: Mean emptying and filling angles of repose and standard deviations of three oat cultivars

Oats	Moisture content (%)	Emptying angle (degrees)		Filling angle (degrees)	
		Mean*	SD**	Mean*	SD**
AC Belmont (hulless)	10.5	23.8wa	0.8	24.2wa	0.5
	13.5	24.7wa	0.6	28.5xb	0.5
	15.0	28.5xa	0.4	30.0xb	0.7
	17.0	33.6ya	1.2	35.2yb	0.3
	19.5	35.8za	0.9	38.6zb	0.2
Robert	10.5	24.9wa	0.1	22.6wb	0.5
	12.0	25.2wa	0.3	23.4wb	0.7
	15.0	25.8wa	0.5	24.5wa	1.1
	17.0	28.9ya	0.6	27.1xb	0.5
	19.5	32.9za	1.1	29.0yb	0.6
AC Marie	11.0	26.5wa	3.0	22.1wb	0.8
	13.0	26.1wa	0.2	22.6wb	0.4
	15.0	25.9wa	1.3	21.5wb	1.3
	17.0	23.8wa	1.8	22.9wa	1.0
	19.5	32.5xa	1.4	27.4xb	1.1

* Means followed by the same letter for rows (a, b, c) and columns (v, w, x, y, z) within each cultivar are not significantly different based on 95% confidence interval of *t*-test.

**Standard deviations on n=5.

K = the ratio of lateral to vertical pressure (Ph/Pv , dimensionless),

u' = coefficient of friction of storage material on the bin wall material (dimensionless), and

h = depth from the surface of material (m).

The ratio K is the most difficult factor to estimate (Singh and Moysey 1985). The K_{active} can be estimated as:

$$K_{active} = (1 - \sin \Phi \cos 2e) / (1 + \sin \Phi \cos 2e)$$

$$2e = \sin^{-1} (\sin \Phi' / \sin \Phi) - \Phi' \quad (2)$$

where:

Φ = angle of internal friction (Table III) (emptying or filling angle), and

Φ' = angle of friction of stored product on bin wall material (Table I).

When the bin wall is moved away from the stored grain, this would correspond to K_{active} whereas if the bin wall was moved toward the grain this would correspond to $K_{passive}$ (Gaylord and Gaylord 1984; Manbeck et al. 1995).

Using Janssen's theory, the lateral bin wall pressure for a 4-m diameter galvanized steel bin at 3 m depth is 4.83 kPa (17.0% m.c.) and 4.28 kPa (19.5% m.c.), for AC Belmont; 5.19 kPa (17% m.c.) and 3.53 kPa (19.5% m.c.) for AC Marie; and 4.94 kPa (17.0% m.c.) and 4.08 kPa (19.5% m.c.) for Robert oats. This compares to lateral bin wall pressure of 5.54 kPa for Neepawa wheat at 16.4% m.c. on galvanized steel using data from Muir and Sinha (1988).

CONCLUSIONS

1. The hulless cultivar AC Belmont generally had greater friction coefficients than the two hulled cultivars.
2. The friction coefficient increased as the moisture content increased. For all materials the friction coefficient was the highest at 19.5% m.c.
3. The hulless cultivar AC Belmont generally had greater bulk density, pail density, and particle density than the hulled cultivars.
4. Pail density and particle density for Robert oats were somewhat greater than for AC Marie oats.
5. The hulless cultivar AC Belmont generally had greater emptying and filling angles than the hulled cultivars.
6. The lateral forces exerted on a granary wall by oats were less than for wheat because of the lower bulk density of oats. Hulless oats were appreciably more dense than hulled oats and therefore exerted greater lateral pressure on granary walls.

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