

# Bulk and handling properties of hulless barley

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Rameshbabu, M., Jayas, D.S., Muir, W.E., White, N.D.G. and Mills, J.T. 1996. **Bulk and handling properties of hulless barley.** *Can. Agric. Eng.* 38:031-035. Bulk (standard and compact) and particle densities, emptying and filling angles of repose, and friction coefficients against galvanized steel, plywood, and wood-floated and steel-trowelled concrete surfaces were determined for 50 and 95% hulless barley (cultivar 'Condor') in the moisture content (artificially conditioned) ranges of 11.0 to 20.0% and 10.0 to 21.5%, respectively. For 50% hulless barley, densities were higher at 16.0% moisture content (mc) than at other moisture contents. For 95% hulless barley, densities were high both at 10.0 and 14.0% moisture contents compared to other moisture contents studied. For 50% hulless barley, emptying (22.7°) and filling (20.8°) angles were lower at 16.0% mc than at other moisture contents. For 95% hulless barley, emptying (34.5°) and filling (32.8°) angles were higher at 21.5% mc compared to other moisture contents. Within the ranges studied, as moisture content increased, coefficient of friction against all surfaces increased for both 50 and 95% hulless barley. Among the surfaces tested, the friction coefficient was maximum (0.60) at 21.5% mc for 95% hulless barley on wood-floated concrete and was minimum (0.25) at 11.0% mc for 50% hulless barley on galvanized steel.

Les densités particulières et apparentes, les angles de repos lors du remplissage et de la vidange, de même que les coefficients de friction de l'orge nue à 50 et 90% (cultivar Condor) à des taux d'humidité (mouillage artificiel) allant de 11 à 20% et de 10.0 à 21.5%, respectivement, ont été déterminés sur des surfaces d'acier galvanisé, de contre-plaqué, de béton lissé avec une niveleuse en bois et lissé avec une truelle d'acier. Pour l'orge nue à 50%, c'est à un taux d'humidité de 16.0% que les densités étaient les plus élevées. Pour ce qui est de l'orge nue à 95%, les densités étaient les plus élevées à des taux d'humidité de 10.0 et 14.0%. Pour l'orge nue à 50%, on a mesuré les angles de repos en vidange (22.7°) et en remplissage (20.8°) les plus faibles à un taux d'humidité de 16.0%. Pour ce qui est de l'orge nue à 95%, les angles de vidange (34.5°) et de remplissage (32.8°) les plus élevés ont été mesurés à un taux d'humidité de 21.5%. Dans les intervalles étudiés, que ce soit pour l'orge nue à 50 ou à 95%, les coefficients de friction mesurés sur toutes les surfaces ont augmenté avec le taux d'humidité. Le coefficient de friction maximal (0.60) a été obtenu pour de l'orge nue à 95% à un taux d'humidité de 21.5% sur une surface de béton lissé avec la niveleuse en bois. Le coefficient de friction le plus faible (0.25) était celui de l'orge nue à 50% avec un taux d'humidité de 11.0%, sur une surface d'acier galvanisé.

## INTRODUCTION

In the year 1994, about 180 000 t of hulless barley were produced in Western Canada (50, 40, and 10% in Alberta, Saskatchewan, and Manitoba, respectively). This was a 20% increase from the previous year; and similar increases are

expected in the future (Personal communication: M.J. Edney, Head, Applied Barley Research, Canadian Grain Commission, Winnipeg, MB). More than 150 cultivars of hulless barley are available, of which 'Condor', 'CDC Buck', 'CDC Richard', and 'Falcon' are most commonly grown in Canada. Hulless barley is a potential animal feed and can be used as a human food. Farmers and owners of food and feed industries in Canada prefer hulless barley because of its nutritional advantages over hulled barley (Ballestros and Piendl 1977; Classen et al. 1985; Singh and Sosulski 1985; Bhatti 1986; Edney et al. 1992).

The design of grain storage and handling systems for hulless barley requires data on bulk and handling properties, namely, bulk and particle densities, friction coefficients of grains on commonly used bin wall materials (galvanized steel, plywood, and wood-floated and steel-trowelled concrete), and emptying and filling angles of repose. Bulk density is used in design of near-ambient drying and aeration systems because it affects the resistance to airflow of a stored bulk (Bern and Charity 1975). Theories used to predict the pressures and loads on storage structures (Janssen 1895; Lvin 1970) require bulk density, angle of repose, and friction coefficients against bin wall materials. Also, the design of grain hoppers for processing machinery requires data on bulk density and angle of repose. An example of use of various bulk and handling properties of grains in the design of storage structures is given by Singh and Moysey (1985). No information is available in the literature about bulk and handling properties of hulless barley.

The objective of this study was to determine the bulk and handling properties of 50 and 95% hulless barley (cv. 'Condor') that was artificially conditioned in the moisture content ranges of 11.0 to 20.0% and 10.0 to 21.5%, respectively.

## MATERIALS AND METHODS

### Sample preparation

Fifty and ninety-five percent 'Condor' hulless barley with initial moisture content (moisture contents reported in this paper are on a wet mass basis and are abbreviated as mc) of 14.5% were purchased from a local farm. Moisture content of samples was increased by spraying the calculated quantity of distilled water on grain samples, while being tumbled in a concrete mixer for 2 h. Moisture content of samples was reduced by drying in a convection air oven at 40°C. Samples

were stored in sealed bags for a minimum of 20 h to allow moisture equilibration at 20 to 25°C (Sokhansanj et al. 1983).

### Moisture measurement

Moisture contents of samples were determined by drying triplicate sub-samples in a convection air oven at 130°C for 20 h (standard method for barley; ASAE 1990).

### Bulk and particle densities

Standard bulk densities of samples were measured using the Canadian Grain Commission Standard (Canadian Grain Commission 1984). 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. Samples were levelled by striking off the excess grain with a rod and the masses of samples in the container were measured. Bulk densities were calculated as the ratio of the masses of samples to the volume of the container and reported in kg/m<sup>3</sup>.

Compact bulk densities were determined as the ratio of the compact masses of samples and the known volume of the container. The compact masses of samples were obtained by dropping samples 1500 mm through a 45 mm internal diameter plastic pipe from a conical container to a metallic container of 500 mL capacity and by weighing the masses of levelled samples.

Particle densities were calculated as the ratio of the masses of samples to the particle volume of samples measured using an air comparison pycnometer (Model 930, Beckman Instruments Inc., Fullerton, CA).

### 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. The box was filled with samples to a depth of 350 mm. 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. Filling angles were calculated from measurements of sample profile depth at two horizontally-spaced points 300 mm apart. The first point was approximately 100 mm away from the impact flattened apex of the cone. Filling angles were measured on both sides of the apex and averaged for individual replicates.

### 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 concrete. 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. The frame was lifted slowly to an approximate height of 2-3 mm so that the frame was not resting on the surface. Using a manually driven screw, the table was tilted slowly until the sample started to slide. The angle of the tilting table was measured using a protractor and a plumb bob. The coefficient of friction was calculated as the tangent of the angle measured (Muir and Sinha 1988). In this study, five replicates were done for the measurement of all properties.

## RESULTS AND DISCUSSION

### Bulk and particle densities

Means, associated standard deviations, and results of Duncan's multiple range tests on standard bulk, compact bulk, and particle densities of 50 and 95% hullless barley are given in Table I. The standard bulk density of 50% hullless barley increased by 8.2% (from 687 to 743 kg/m<sup>3</sup>) when the moisture content increased from 11.0 to 16.0%. With a further

TABLE I: Mean bulk and particle densities and associated standard deviations for 'Condor' hullless barley

Barley	Moisture content <sup>†</sup> (%)	Standard density		Compact density		Particle density	
		Mean* (kg/m <sup>3</sup> )	SD** (kg/m <sup>3</sup> )	Mean* (kg/m <sup>3</sup> )	SD** (kg/m <sup>3</sup> )	Mean* (kg/m <sup>3</sup> )	SD** (kg/m <sup>3</sup> )
50% hullless	11.0	687aw	3.8	715bw	7.6	1396cw	1.3
	14.5	738ax	2.9	742ax	5.6	1398bw	2.2
	16.0	743ay	1.9	777by	6.1	1436cx	2.6
	17.0	733az	4.7	758bz	5.6	1395cw	1.4
	20.0	691aw	3.2	719bw	3.8	1341cy	5.3
95% hullless	10.0	782aw	8.0	811bw	2.0	1390cw	7.0
	14.0	770aw	7.9	802bw	3.1	1416cx	5.7
	15.5	777aw	4.2	808bw	3.0	1378cy	1.3
	18.5	760ax	2.3	772bx	1.3	1382cy	1.3
	21.5	702ay	4.6	733by	2.6	1341cz	5.4

<sup>†</sup>The standard deviation in moisture contents was < 0.2 percentage points.

\* Means followed by the same letter for rows (a, b, c) or columns (w, x, y, z) are not significantly different at 95% confidence interval using Duncan's multiple range test.

\*\*SD = Standard deviation based on N = 5

increase to 20.0% mc, the standard bulk density decreased by 7.0% (from 743 to 691 kg/m<sup>3</sup>). A similar trend of change in compact bulk densities with the change in moisture content was observed. Compact bulk density increased 8.7% (from 715 to 777 kg/m<sup>3</sup>) for an increase in moisture content from 11.0 to 16.0%; and then dropped 7.5% to 719 kg/m<sup>3</sup> when moisture content increased to 20.0%. Using the 16.0% mc as a reference, a change in moisture content by 4.0 to 5.0% in either direction, decreased the standard and compact bulk densities by 7.0 to 8.0%. Particle density also followed a similar pattern with the change in moisture content. The decrease in particle density was only 2.8% when the moisture content dropped from 16.0 to 11.0%; and 6.6% when the moisture content was increased from 16.0 to 20.0%. A similar pattern of variation in densities with moisture content was observed for hulled barley (Lorenz 1957), soybeans (Alam and Shove 1973), and canola meal (Kukelko et al. 1988). This might be due to filling of void spaces within the kernels with the moisture when the moisture content increased from 10.0 or 11.0% to 15.0 or 16.0%. Also, it might be due to swelling of amylopectin inside the kernel, especially when moisture content was raised above 16.0%. The swelling might have increased the volume of each kernel more than the mass of water within the kernel.

For 95% hulless barley, standard bulk densities were in the range of 770-782 kg/m<sup>3</sup> at 10.0 to 15.5% mc. They dropped to 760 kg/m<sup>3</sup> at 18.5% mc and dropped further to 702 kg/m<sup>3</sup> at 21.5% mc. A similar pattern of change in compact bulk density with moisture contents was observed. The drop in standard and compact bulk densities was 9.7 and 9.3%, respectively, when the moisture content increased from 15.5 to 21.5%. The particle density was the highest (1416 kg/m<sup>3</sup>) at 14.0% mc compared to other moisture contents. Using the value at 14% mc as a reference, the particle density decreased by 1.8% (to 1390 kg/m<sup>3</sup>), when the moisture content decreased to 10.0%; and by 5.3% (to 1341 kg/m<sup>3</sup>) when the moisture content increased to 21.5%. Considering both types of barley, the compact bulk density was always greater than the standard bulk density by 12 to 34 kg/m<sup>3</sup>.

Muir and Sinha (1988) reported that standard bulk densities for 'Bedford' and 'Bonanza' hulled barley were 664 and 628 kg/m<sup>3</sup>, respectively, at 12.7% mc, which were reduced to 649 and 609 kg/m<sup>3</sup> at 16.4% mc. The particle densities of both 'Bedford' and 'Bonanza' hulled barley were 1345 kg/m<sup>3</sup> at 12.7% mc, whereas at 16.7% mc they were 1372 and 1359 kg/m<sup>3</sup>, respectively. Both the standard bulk density and particle density of hulled barley were lower than for either of the 50% or 95% hulless barley.

### Emptying and filling angles

The mean emptying and filling angles of repose, associated standard deviations, and results of Duncan's multiple range

**TABLE II: Mean emptying and filling angles of repose and associated standard deviations for 'Condor' hulless barley**

Barley	Moisture content <sup>†</sup> (%)	Emptying		Filling	
		Mean* (°)	SD** (°)	Mean* (°)	SD** (°)
50% hulless	11.0	25.0aw	0.5	23.8bw	0.5
	14.5	24.1aw	0.7	22.8bw	0.6
	16.0	22.7ax	0.7	20.8bx	0.7
	17.0	25.2aw	0.4	21.4bx	0.6
	20.0	33.3ay	0.9	28.7by	1.0
95% hulless	10.0	25.7ax	0.7	25.4aw	0.7
	14.0	24.1aw	0.1	23.0ax	1.0
	15.5	24.3aw	0.4	23.1ax	0.6
	18.5	26.4ax	0.3	25.2aw	0.5
	21.5	34.5ay	0.6	32.8by	1.2

<sup>†</sup> The standard deviation in moisture contents was < 0.2 percentage points.

\* Means followed by the same letter for rows (a,b) or columns (w,x,y) are not significantly different based on 95% confidence interval of Duncan's multiple range test.

\*\*SD = standard deviation based on N = 5

tests are presented in Table II. For 50% hulless barley, the emptying angle of repose was the lowest (22.7°) at 16.0% mc compared to the other moisture contents. When moisture content decreased to 11.0%, the emptying angle increased by 10.1% (to 25.0°). When the moisture content increased to 20.0%, the emptying angle increased by 46.7% (to 33.3°).

For 95% hulless barley, the emptying angle was the same and the lowest at both 14.0 and 15.5% mc. When the moisture content decreased to 10.0%, the emptying angle increased by 6.6% (to 25.7°). The increase in emptying angle was 42.0% when the moisture content increased from 15.5 to 21.5%. High emptying angles at high moisture contents may be caused by an increased cohesiveness among grains by the addition of moisture.

A similar trend of change in filling angles with moisture contents was observed for both 50 and 95% hulless barley. In this study, the filling angle (32.8°) was maximum at 21.5% mc for 95% hulless barley and minimum (20.8°) at 16.0% mc for 50% hulless barley. An increase in moisture content by 4.0 percentage points (from 16.0% mc) of 50% hulless barley increased the filling angle by 38.0% and for 95% hulless barley a 6.0 percentage point increase in moisture content (from 15.5% mc) increased the filling angle by 42.0%.

Muir and Sinha (1988) reported that at 12.7% mc, the emptying and filling angles of repose for 'Bedford' hulled barley were 26° and 24°, respectively; and for 'Bonanza' hulled barley both had the same value at 28°. At 16.4% mc, the emptying and filling angles for 'Bedford' hulled barley were 32° and 26° and for 'Bonanza' hulled barley were 37° and 31°, respectively. Both filling and emptying angles of repose for hulled barley were greater than for both types of hulless barley.

### Friction coefficients

The mean friction coefficients and results of Duncan's multiple range tests for 50 and 95% hulless barley against the different structural surfaces tested are presented in Table III. Friction coefficients against all surfaces increased with an increase in moisture content to high levels ( $\geq 20\%$  mc) for both 50 and 95% hulless barley. Hulless barley contains high ( $>80\%$ ) amylopectin, which might swell and become waxy when moisture content is raised above 17% (Bhatty 1986). This may be a reason for an increase in the friction coefficient at or above 17% mc. An increase in moisture content from 17.0 to 20.0% for 50% hulless barley, increased the coefficient of friction by 37.5, 23.5, 24.4, and 24.4% on galvanized steel, plywood, and wood-floated and steel-trowelled concrete, respectively. With an increase in moisture content from 18.5 to 21.5% for 95% hulless barley, the friction coefficient increased by 34.3, 37.1, 33.3, and 27.3%, respectively on galvanized steel, plywood, and wood-floated and steel-trowelled concrete. With an increase in moisture content from 11.0 to 16.0% for 50% hulless barley and an increase in moisture content from 10.0 to 15.5% for 95% hulless barley, the increase in the friction coefficient was either small or non-existent. Friction coefficient of 50% hulless barley on galvanized steel was the lowest (0.25) at 11.0% mc compared to other surfaces and moisture contents. Among the tested surfaces, the maximum friction coefficient (0.60) was on wood-floated concrete at 21.5% mc of 95% hulless barley.

Muir and Sinha (1988) reported that for 'Bedford' hulled barley, the friction coefficient on galvanized steel surface was 0.29 at 12.7% mc and increased to 0.34 at 16.4% mc. For 'Bonanza' hulled barley, when the moisture content increased from 12.7 to 16.4%, the friction coefficient increased by 20% (from 0.30 to 0.36). Among the concrete surfaces (wood-floated and steel-trowelled), the maximum friction coefficient (0.51) was reported for wood-floated concrete at 16.4% mc, and minimum (0.38) for 'Bedford' hulled barley on steel-trowelled concrete at 12.7% mc. The friction coefficients of hulled barley were greater than that for the 50% or 95% hulless barley

### CONCLUSIONS

1. For 50% hulless barley, the standard, compact, and particle densities were the highest at 16.0% mc. A change in moisture content in either direction reduced the standard, compact, and particle densities.
2. For 95% hulless barley, the standard and compact bulk densities were constant for moisture contents between 10.0 to 15.5%. An increase in moisture content by 6.0 percentage points from 15.5% mc, decreased the standard and compact bulk densities by 9 to 10%. The particle density was maximum ( $1416 \text{ kg/m}^3$ ) at 14.0%

**TABLE III: Mean\* coefficients of friction of 'Condor' hulless barley against galvanized steel (GS), parallel grain plywood (PW), wood-floated concrete (WFC), and steel-trowelled concrete (STC).**

Barley	Moisture content <sup>†</sup> (%)	Surface			
		GS**	PW**	WFC**	STC**
50% hulless	11.0	0.25aw	0.31bw	0.39cw	0.38cw
	14.5	0.29ax	0.31aw	0.40bw	0.39bw
	16.0	0.29ax	0.32bw	0.41cx	0.42cx
	17.0	0.32ay	0.34bx	0.41cx	0.41cx
	20.0	0.44az	0.42ay	0.51by	0.51by
95% hulless	10.0	0.31aw	0.32aw	0.43bw	0.38cw
	14.0	0.32aw	0.32aw	0.41bw	0.40bw
	15.5	0.32aw	0.32aw	0.41bw	0.40bw
	18.5	0.35ax	0.35ax	0.45bx	0.44bx
	21.5	0.47ay	0.48ay	0.60by	0.56cy

<sup>†</sup> The standard deviation in moisture contents was 0.2 percentage points.

\* Standard Deviation  $<0.02$  based on  $N = 5$

\*\*Means followed by the same letter for rows (a,b,c) and columns (w,x,y) are not significantly different based on 95% confidence interval of Duncan's multiple range test.

mc and an increase in moisture content by 7.5 percentage points (from 14.0% mc) decreased the particle density by 5.3%.

3. For both 50 and 95% hulless barley, the emptying and filling angles of repose were the lowest at the middle levels of moisture contents. Either an increase or a decrease in the moisture content increased the emptying and filling angles of repose by up to 47%.
4. As the moisture content increased, the coefficient of friction for both 50 and 95% hulless barley increased on all surfaces.
5. The highest friction coefficient (0.60) was at 21.5% mc for 95% hulless barley on the wood-floated concrete surface and it was the lowest (0.25) at 11.0% mc for 50% hulless barley on the galvanized steel surface.

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