TECHNICAL NOTE

Physical properties of buckwheat cultivars

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Parde, S.R., Johal, A., Jayas, D.S. and White, N.D.G. 2003. **Physical properties of buckwheat cultivars.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **45**: 3.19 - 3.22. Bulk (standard and compact) densities, emptying and filling angles of repose, and friction coefficients against galvanized steel, plywood, and concrete surfaces were determined for three cultivars of buckwheat (Koto, Koban, and Manisoba) in increasing moisture content (wet mass basis) ranges. Both standard and compacted bulk densities were around 600 kg/m^3 for all three cultivars. With an increase in moisture content, generally, there was a slight decrease in both densities. The friction coefficients against all the surfaces for Koto and Koban were similar but for Manisoba, they were significantly lower. For example, for Manisoba the friction coefficient against galvanized steel was about 0.17 compared to about 0.28 for the other two cultivars. Friction coefficients were significantly affected by the changing moisture contents. The filling and emptying angles either remained constant or increased with increasing moisture content for all cultivars. The maximum emptying angle was 26.7° at 17.9% moisture content for Koto cultivar.

Les densités (normale et compactée), les angles de repos au remplissage et à la vidange, et les coefficients de friction sur des surfaces d'acier galvanisé, de contreplaqué et de béton ont été évalués pour trois cultivars de sarrasin (Koto, Koban, et Manisoba) sur une plage croissante de teneur en eau (base humide). Les densités du matériel normal et compacté étaient d'environ 600 kg/m3 pour les trois cultivars. Généralement une augmentation de la teneur en eau résultait en une faible augmentation des deux valeurs de densité. Les coefficients de friction sur toutes les surfaces pour les cultivars Koto et Koban étaient comparables mais pour le Manisoba, ils étaient significativement plus bas. Par exemple, pour le Manisoba, le coefficient de friction sur l'acier galvanisé était d'environ 0,17 comparativement à environ 0,28 pour les deux autres cultivars. Les coefficients de friction étaient significativement affectés par des changements de teneur en eau. Les valeurs d'angle de repos au remplissage et à la vidange demeuraient constantes ou augmentaient avec une augmentation de la teneur en eau pour tous les cultivars. L'angle de vidange maximal était 26,7° à une teneur en eau de 17,9% pour le cultivar Koto.

INTRODUCTION

The design of storage and handling systems for buckwheat requires data on bulk and handling properties, namely, standard and compacted bulk densities, friction coefficients on commonly used bin wall materials (galvanized steel, plywood, and concrete), and emptying and filling angles of repose. 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 the 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 buckwheat.

The objective of this study was to determine the physical properties of three cultivars of buckwheat at several moisture contents.

MATERIALS and METHODS

Sample preparation

Three different types of buckwheat (*Fagopyrum esculentum* Moench; Polygonaceae), namely, Koto, Koban, and Manisoba with initial moisture contents (moisture contents reported in this paper are on a wet mass basis and are abbreviated as mc) of 13% (for Manisoba) and 14.8% (for Koto and Koban) were obtained from Elie, Manitoba. Moisture contents of the samples of Koto and Koban were raised to the desired levels of 15.8, 16.6, and 17.9%, while those of Manisoba were raised to 14.0, 15.0, 16.0, and 17.0 % by spraying a predetermined amount of distilled water onto the sample while it was tumbling in a concrete mixer. 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 content of the samples was measured by drying triplicate sub-samples in a convection air oven at 130°C for 19 h. ASAE (1997) has adopted this standard for wheat and the same was used for buckwheat.

Measurement of physical properties

The experimental methods for measurement of standard and compacted bulk densities, friction coefficients and emptying and filling angles of repose were the same as used by Rameshbabu et al. (1996). In this study four replicates of each sample of buckwheat cultivar were used for the measurement of all properties.

Standard and compacted bulk densities The equipment to measure the standard bulk density of buckwheat cultivars consisted of a 500 mL capacity metallic container (90 mm diameter and 79 mm height) and a metallic cone (225 mm top diameter, 38 mm bottom diameter, and 160 mm height). The cone was placed on top of the container with its bottom 45 mm above the container. The cone had a flat slide gate at the bottom which was used to allow buckwheat to flow into the container.

Table 1. Mean bulk densities of three buckwheat cultivars (n=4) at various moisture contents.

Cultivar	Moisture content (% wet basis)	Bulk density (kg/m^3)			
		Standard		Compacted	
		Mean*	SD	Mean	SD
Koto	14.8	603.9 xa	3.2	611.5 wa	6.1
	15.8	612.9 wa	6.7	611.0 wa	3.4
	16.6	597.9 xa	3.5	603.4 wa	6.2
	17.9	584.1 ya	4.6	590.4 xa	5.4
Koban	14.8	593.8 xb	1.7	601.0 wa	4.9
	15.8	596.6 xa	4.0	600.9 wa	2.3
	16.6	597.7 xa	2.7	595.5 xa	2.2
	17.9	603.1 wa	1.6	600.8 wb	0.9
Manisoba	13.0	607.9 wa	0.3	606.4 xa	2.5
	14.0	610.7 wa	4.2	610.7 wa	4.2
	15.0	602.2 xa	4.9	601.9 ya	1.9
	16.0	601.1 xa	1.1	602.3 yxa	2.5
	17.0	593.0 ya	2.1	593.9 za	2.0

* Means followed by the same letter between rows (w, x, y, z) and between columns (a, b, c) within each cultivar are not significantly different at 5% level.

Initially, the mass of the empty container was measured. The container was then filled with buckwheat by opening the slide gate at the bottom of the cone. Excess seed was levelled off by smoothening with a wooden rod and the mass of the filled container was then measured. Bulk densities were calculated as the ratio of the masses of samples to the volume of the container and reported in kg/m^3.

Compact bulk densities were determined as the ratio of the compact masses of samples and the known volume of the container. The mass of the empty container was initially measured and then the samples were dropped from a height of 1320 mm from the metallic cone to the metallic container (500 mL capacity) through a 47 mm internal diameter plastic pipe. The compact masses of the sample were then obtained by weighing the masses of the levelled samples.

Friction coefficients Coefficients of sliding friction were determined for galvanized steel, plywood (which had the wood-grain parallel to the motion of the seed), and concrete surfaces. The surfaces were attached to a tilting table, one each during the experiment. A wooden frame (303 mm long and 267 mm wide), made of 20 mm square wood, was placed lengthwise on the tested surface. It was filled with the sample and levelled. The table had an electrically operated switch which allowed the surface to tilt until the sample started to slide. An anglemeter attached to the tilting table measured the angle at which the grain started to slide down the surface. The coefficient of friction was calculated as the tangent of the angle measured.

Emptying and filling angles of repose Emptying angles of repose were measured in a plastic container 449 mm long, 218 mm wide, and 428 mm high. Samples were allowed to flow out through a 56 mm high by 218 mm wide rectangular door provided along the width of the box at the bottom of one end wall into a receiving container. Emptying angles were calculated from measurements of horizontal and vertical scale readings.

Filling angles of repose were measured in a wooden box 1155 mm long, 120 mm wide, and 755 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 the measurements of horizontal and vertical scale readings.

Manisoba cultivar was available in less quantity and therefore filling angles of repose for this cultivar were not determined.

Data were analysed using the Statistical Analysis System, General Linear Model (GLM) Procedure (SAS 2000) and student's *t* test was used to determine the significant differences in the means at the 5% significance level.

RESULTS and DISCUSSION

Bulk densities

The standard bulk density of Koto buckwheat increased significantly from 603.9 to 612.9 kg/m^3 with an increase in moisture content from 14.8 to 15.8%. With a further increase in moisture content, the standard bulk density decreased significantly (Table 1). There were no significant differences in compacted bulk density from 14.8 to 16.6% mc but at 17.9% mc, the compacted density dropped significantly to 590.4 kg/m^3.

For the Koban cultivar, moisture content did not show any significant effect on the standard bulk density except when it increased to 603.1 kg/m^3 at 17.9% mc. The compacted bulk density for Koban cultivar remained constant from 14.8 to 15.8% mc (600.9 kg/m^3) but then dropped significantly to 595.9 kg/m^3 at 16.6% mc. At 17.9% mc, it regained its original value.

For the Manisoba cultivar, the standard bulk density dropped significantly at 15% mc and this drop continued at higher moisture contents. A similar significant drop was observed in compacted bulk density with increase in moisture content.

As moisture levels increase, the kernels swell and increase their 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. Increased moisture levels, however, change the elastic properties of kernels and this can increase bulk density at increased overburden pressures (Thompson and Ross 1983).

There were no significant differences between standard and compacted bulk densities at corresponding moisture contents in Koto and Manisoba cultivars. In Koban cultivar, standard and compacted bulk densities differed significantly at 14.8 and 17.9% mc (Table 1).

Usually compacted densities are higher than the standard densities (Muir and Sinha 1988). The similarity in two densities imply that the tetrahedron shape of buckwheat does not result in dense packing when dropped from 1.3 m. It is possible that with further increase in drop height, the compact densities may be higher.

In general, the moisture content of buckwheat had a significant effect on its bulk density. In Koto and Manisoba

Table 2. Mean coefficients of friction of three buckwheat cultivars on galvanized steel (GS), plywood (PW), and concrete (C) (n=4) at various moisture contents.

Cultivar	Moisture content (% wet basis)	Surface					
		GS		PW		C	
		Mean*	SD	Mean	SD	Mean	SD
Koto	14.8	0.25 yb	0.01	0.26 yb	0.01	0.38 ya	0.01
	15.8	0.27 xc	0.01	0.30 wxb	0.01	0.41 xa	0.01
	16.6	0.27 xc	0.01	0.29 xb	0.01	0.42 wxa	0.01
	17.9	0.29 wb	0.01	0.31 wb	0.01	0.43 wa	0.01
Koban	14.8	0.28 xc	0.01	0.32 wb	0.01	0.40 wa	0.01
	15.8	0.29 wb	0.01	0.30 xb	0.00	0.39 wa	0.01
	16.6	0.27 yb	0.01	0.28 zb	0.01	0.39 wa	0.01
	17.9	0.28 xyc	0.01	0.29 yb	0.00	0.40 wa	0.01
Manisoba	13.0	0.18 wc	0.01	0.21 wxb	0.01	0.25 wa	0.01
	14.0	0.17 xc	0.01	0.20 wxb	0.01	0.26 wa	0.00
	15.0	0.16 xb	0.01	0.22 wa	0.04	0.24 xa	0.01
	16.0	0.17 xc	0.01	0.21 wxb	0.00	0.25 wa	0.01
	17.0	0.16 xc	0.01	0.19 xb	0.00	0.26 wa	0.01

* Means followed by the same letter between rows (w, x, y, z) and between columns (a, b, c) within each cultivar are not significantly different at 5% level.

cultivar, increasing moisture content resulted in a decrease in standard and compacted bulk densities. This was particularly observed for higher moisture contents at or above 16%, which is classified "tough" by the Canadian Grain Commission. A similar trend was observed by Muir and Sinha (1988) in the measurement of standard and compacted bulk densities for wheat, oats, barley, and rye.

Table 3. Mean emptying and filling angles of repose for three buckwheat cultivars (n=4) at various moisture contents.

Cultivar	Moisture content (% wet basis)	Angle of repose (degrees)			
		Emptying		Filling	
		Mean*	SD	Mean	SD
Koto	14.8	23.6 ya	0.27	24.7 wxa	0.92
	15.8	23.3 ya	0.15	21.9 xa	4.93
	16.6	24.8 xa	0.20	24.3 wxa	1.64
	17.9	26.7 wa	0.35	28.4 wa	1.89
Koban	14.8	22.5 zb	0.19	23.5 xa	0.63
	15.8	22.9 yb	0.09	25.3 wa	1.05
	16.6	23.9 xb	0.06	25.6 wa	1.01
	17.9	24.7 wa	0.19	24.8 wxa	0.66
Manisoba	13.0	21.3 x	0.7	-**	-
	14.0	22.9 wx	0.3	-	-
	15.0	25.1 w	3.4	-	-
	16.0	25.1 w	1.3	-	-
	17.0	25.1 w	1.9	-	-

* Means followed by the same letter between rows (w, x, y, z) and between columns (a, b, c) within each cultivar are not significantly different at 5% level.
** - indicates insufficient seed available for the test.

Friction coefficients

The friction coefficient against all the surfaces for the Koto cultivar increased significantly with increase in moisture content except when the difference in two moisture contents was less than 1% (15.8 and 16.6% mc) (Table 2). Because of low values of standard deviations for friction coefficients, small differences were statistically significant (Table 2).

For the Koban cultivar, the friction coefficient on galvanized steel increased to 0.29 at 15.8% mc and thereafter decreased to 0.27 at 16.6% mc. On plywood, the friction coefficient showed a reverse trend, i.e., the coefficient decreased significantly up to 16.6% mc and then increased at 17.9% mc. On concrete, increasing moisture content did not have a significant effect on the coefficient of friction.

For the Manisoba buckwheat, friction coefficients were not affected by increasing moisture content except at 14% mc on galvanized steel and at 15% mc on concrete. The friction coefficients of Manisoba were significantly lower than those for the other two cultivars.

Generally, at low moisture contents, particles of grain tend to be inelastic. As moisture content increases, the grain particles are more elastic and are able to deform requiring increased force to break the bonds between sliding grain and surfaces. Therefore, increased moisture content increases the coefficient of friction (Thompson and Ross 1983, Lawton 1980).

Emptying and filling angles

The emptying angle of Koto cultivar remained constant at about 23.5° from 14.8 to 15.8% mc and then increased significantly with increasing moisture content (Table 3). The filling angle did not differ significantly at 14.8 to 16.6% mc but increased significantly to 28.4° at 17.9% mc.

The emptying angle for the Koban cultivar increased significantly with increasing moisture content. High emptying angles at high moisture contents may be caused by an increased cohesiveness among grains by the addition of moisture. The filling angle increased until the moisture content increased to 15.8% and thereafter it stayed constant.

For the Manisoba cultivar, the emptying angle increased significantly up to 15% mc and remained constant thereafter.

The emptying and filling angles did not differ significantly for the Koto cultivar. For the Koban cultivar, filling angle of repose was significantly greater than the emptying angle at 14.8, 15.8, and 16.6% mc.

The compacted bulk densities of buckwheat cultivars in the above experiments were determined by dropping samples from a height of 1320 mm. Rameshbabu et al. (1996) and Lepper et al. (1997) dropped samples of barley and oats from a height of 1500 mm and found significant differences in the standard and compacted bulk densities. Similar results were obtained by Muir and Sinha (1988) when samples of wheat, rapeseed, mustard, flax, and soybean were dropped from a height of 1620 mm. In our experiments, standard and compacted bulk densities did not differ significantly. The reasons for this could be attributed to the tetrahedronal shape and lightness of buckwheat. Each buckwheat kernel weighed not more than 0.036 ± 0.008 g. An increase in drop height may increase the compacted bulk density further.

CONCLUSIONS

1. The standard and compacted bulk densities of buckwheat cultivars significantly decreased or remained constant at or above 16% moisture content.
2. The friction coefficients of Manisoba were significantly lower than those for the other two cultivars. The highest coefficient of friction (0.43) was at 17.9 % moisture content for the Koto cultivar on the concrete surface.
3. The emptying and filling angles of repose generally increased with an increase in moisture content. The maximum emptying angle of repose was 26.7° at 17.9% moisture content for the Koto cultivar.

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