Physical properties of flaxseed, lentils, and fababeans

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Irvine, D.A., Jayas, D.S., White, N.D.G., and Britton., M.G. 1992. **Physical properties of flaxseed, lentils, and fababeans**. Can. Agric. Eng. 34:075-081. Bulk and particle densities, emptying and filling angles of repose, and sliding friction coefficients against galvanized and corrugated steel, parallel to and perpendicular to grain plywood, and steel-trowelled (smooth) and wood-floated (rough) concrete were determined experimentally for McGregor flaxseed, Eston and Laird lentils and Ackerperle fababeans, at various moisture contents. Both bulk and particle densities decreased with an increase in moisture content for all seed types. Filling and emptying angles of repose and friction coefficients did not have similar trends for all seeds. However, friction coefficients against corrugated steel were the highest among all surfaces for all seed types.

Les masses volumiques en vrac et les densités de particules, les angles de déversement de vidage et de remplissage, ainsi que les coefficients de frottement de glissement contre de l'acier galvanisé ou ondulé, parallèlement ou perpendiculairement au fil de contreplaqué et à du béton aplani à la truelle ou au bois, ont été déterminés expérimentalement avec différents taux d'humidité pour la graine de lin McGregor, la lentille d'Eston et de Laird et la féverole d'Ackerperle. Les masses volumiques en vrac et les densités de particules ont diminué avec un accroissement du taux d'humidité pour tous les types de semences. Les angles de déversement de vidage et de remplissage et les coefficients de frottement n'ont pas présenté les mêmes tendances pour toutes les semences; cependant les coefficients de frottement contre l'acier ondulé étaient les plus élevés pour tous les types de semences et de surface.

INTRODUCTION

The production of specialty crops such as lentils and fababeans is gradually increasing in Canada. Physical properties of these materials are required for designing product storage and handling systems (Kukelko et al. 1988; Jayas et al. 1990). Information on physical properties of fababeans, lentils, and flaxseed is lacking in the literature.

The purpose of this study was to determine the physical properties of McGregor flaxseed, Ackerperle fababeans, and two cultivars of lentils (Eston and Laird). The physical properties determined were bulk density, particle density, emptying and filling angles of repose, and coefficients of sliding friction on galvanized steel, corrugated steel, plywood parallel to grain, plywood perpendicular to grain, steel-trowelled (smooth) concrete, and wood-floated (rough) concrete. All seed types were tested at a minimum of four different moisture contents, representing a typical moisture content range encountered during storage and handling of these seeds. Flaxseed was also tested at three levels, by mass, of foreign material. Five replicates were performed for each physical property.

EXPERIMENTAL PROCEDURE

Sample preparation

Registered McGregor flaxseed at 8.0% moisture content wet basis (wb), commercial Eston and Laird lentils at 11.6% and 12.1% moisture content, respectively, and Ackerperle fababeans at 12.7% moisture content were purchased from a local seed supplier. Moisture contents were raised to desired levels by spraying calculated quantities of distilled water on the seed while being tumbled in a concrete mixer. Moisture contents were lowered by holding the seed in a room with a low relative humidity. This method reduced the moisture content of flaxseed, lentils and fababeans to levels as low as 6.5, 11.5 and 12.5%, respectively. Conditioned samples (about 40 kg each) were stored in a sealed container for a minimum of 16 h to allow for moisture equilibrium at 20 to 25°C. Moisture content of the seed was never raised more than 3.0% in a single wetting for any of the seed types. Each batch of seed was tested at two moisture contents (initial and adjusted).

Physical properties of flaxseed were measured at three levels, by mass, of foreign material content. These tests were done at a moisture content of 9 ±0.5%. The foreign material was obtained from a local seed cleaning plant. The foreign material was separated into defined percentages of large and small weed seeds, cereals and other miscellaneous material such as chaff and flaxseed shells. The mixture contained 20% pigweed, 12% canola, 8% lady's thumb, 25% wheat, 12% buckwheat, 3% round leaf mallow and 20% flaxseed shells, stalks and chaff. The foreign material was mixed manually with the flaxseed in pre-determined proportions using a scoop and a large pan.

Moisture measurement

Moisture contents (wet mass basis) of flaxseed samples were determined by drying triplicate samples in an air convection oven set at 103°C for 4 h (ASAE 1990). Lentils and fababeans were considered to be edible beans and moisture content was determined by drying triplicate samples in an air convection oven set at 103°C for 72 h, as recommended in ASAE Standard S352.2 (ASAE 1990).

Bulk and particle density

Standard bulk density of samples was measured using the Canadian Grain Commission standard (Canadian Grain Commission 1984). The bulk density was also measured by dropping samples 1800 mm through a 76-mm diameter pipe from a conical container having a top diameter of 210 mm, a bottom diameter of 165 mm and a volume of 3785 mL into a 500 mL cup. The sample was then levelled and the mass of the sample was measured. Densities from this test have been designated as pail bulk density. The particle volumes of weighed samples were measured with an air comparison pycnometer (Model 930, Beckman Instruments, Inc., Fullerton, CA) and particle densities were calculated.

Emptying and filling angles of repose

Experimental equipment used to measure the emptying and filling angles of repose were modified from earlier studies (Muir and Sinha 1988; Kukelko et al. 1988). Emptying angles of repose were measured in a box 430 mm long, 200 mm wide and 430 mm high. The box was hand filled with a scoop to an approximate depth of 350 mm for each replication. The sample was then allowed to flow freely through a 50 mm high x 200 mm wide rectangular opening along the bottom of one of the narrow end walls. The emptying angles were recorded with a depth gauge having both vertical and horizontal scales. The locations of the depth measurements for each trial were chosen to best represent the emptying angle.

The filling angle of repose was measured in a box 1220 mm long, 100 mm wide and 760 mm high with one plexiglass side wall. The box was filled from a 53 mm square opening in a wooden hopper which was located midway along the box length and 800 mm above the bottom of the receiving box. Filling slope angle was determined from measurements of the seed profile depth at two points on both sides (left and right) of the cone, the first point being about 100 mm away from the impact flattened apex.

Sliding friction coefficients

Coefficients of sliding friction were determined for clean flaxseed, flaxseed mixed with foreign material, Eston and Laird lentils, and fababeans on six surfaces: galvanized steel, corrugated steel, parallel grain plywood, perpendicular grain plywood, smooth steel-trowelled concrete, and rough wood-floated concrete. The surfaces were attached to a tilting table. A frame constructed of 18 mm square wooden bars, was placed lengthwise on the surface to enclose an area 305 mm long x 255 mm wide. The frame was filled with a grain sample and carefully levelled to frame height. The frame was then raised slightly so that it was not resting on the surface. The table was tilted slowly using a manually driven screw. Angles at which samples started to slide were measured with a plumb bob and a protractor.

RESULTS AND DISCUSSION

Density

Both the Canadian Grain Commission Standard bulk density and pail bulk density, defined earlier, decreased with an increase in moisture content for all grains (Table I). Pail bulk density was always higher than the standard bulk density due to the increased drop height.

The standard bulk density of flaxseed decreased 8.0% from 624 to 574 kg/m^3 when moisture content increased from 7.0 to 15.1%. For the same moisture content change, the pail bulk density decreased 8.7% from 642 to 586 kg/m^3. The maximum difference between the standard and pail bulk density was 32 kg/m^3 at 10.5% moisture content which corresponds to a 5.2% increase in bulk density due to the 1800 mm drop height. Standard bulk densities of flaxseed samples, which included foreign material, were generally lower and pail bulk densities were generally higher than those of clean flaxseed.

The standard bulk density for Eston lentils decreased from 825 kg/m^3 at 11.4% moisture content to 783 kg/m^3 at 18.0% moisture content. The pail densities for Eston lentils decreased 5.6% from 850 kg/m^3 at 11.6% moisture content to 802 kg/m^3 at 18.0% moisture content. The maximum difference between the standard bulk density and pail bulk density was 29 kg/m^3 at 12.3% moisture content.

The standard bulk density for the Laird lentils decreased 4.7% from 804 kg/m^3 at 11.7% moisture content to 767 kg/m^3 at 17.7% moisture content. The pail bulk density for Laird lentils decreased 4.1% from 833 kg/m^3 at 11.7% moisture content to 799 kg/m^3 at 17.7% moisture content. The maximum difference between the standard bulk density and pail bulk density was 46 kg/m^3 at 13.8% moisture content.

The standard bulk density for the fababeans (Table I) decreased 6.6% from 815 kg/m^3 at 12.6% moisture content to 761 kg/m^3 at 21.9% moisture content. The pail bulk density for fababeans decreased 6.4% from 844 kg/m^3 at 12.6% moisture content to 790 kg/m^3 at 21.9% moisture content. The maximum difference between the standard bulk density and pail bulk density was 29 kg/m^3 at both 12.6% and 21.9% moisture contents.

The standard bulk densities and pail bulk densities decreased with increased moisture content for all seed types. Lorenz (1957) also found a similar trend for bulk density of barley as moisture content increased from 7.9 to 19.6%. Also, Alam and Shove (1973) found a similar trend for soybeans in the moisture content range of 15-30%. In their study, the bulk density dropped from 710 kg/m^3 at 16.0% moisture content to 670 kg/m^3 at 30% moisture contents.

In general, the particle density (Table II) decreased with increasing moisture content for all seed types. Particle density of flaxseed remained relatively constant at approximately 1149 kg/m^3 between 8.2% and 12.6% moisture content. At 15% moisture content the particle density dropped only 0.5% to 1143 kg/m^3. The decreases in particle densities of Eston lentils, Laird lentils and fababeans were 1.3, 2.8 and 1.6%, respectively, when moisture content of these seeds increased between 10 and 18%.

Emptying and filling angles of repose

The emptying angle of repose for flaxseed (Table III) increased with an increase in moisture content from 30.3° at 7% moisture content to 38.0° at 15.1% moisture content. Filling angle of repose (Table III) also tended to increase with an increase in moisture content. This behaviour might be due to increased cohesive properties of the flaxseed at higher moisture contents.

Foreign material, at the levels used in this study, had less effect on the angles of repose than moisture content, although there was a slight increase in both emptying and filling angles of repose with an increase in foreign material (Table III). With 4% foreign material by mass, there was no effect on either emptying or filling angles of repose when compared to zero foreign material at the same approximate moisture content. Emptying angle of repose did, however, increase from 30.9° to

Table I. Bulk densities of flaxseed, lentils, and fababeans at various moisture contents

Sample moisture content	Standard bulk density (kg/m^3)		Pail bulk density (kg/m^3)	
(% wb)	mean	sd*	mean	sd
	Clean Flaxseed			
7.0	623.9 av	1.4	642.4 bv	3.1
10.5	611.3 aw	1.1	643.1 bv	4.2
12.3	587.6 ax	1.5	614.3 bw	2.3
15.1	574.0 ay	1.0	585.7 bx	1.5
	Eston Lentils			
11.4	825.1 av	0.9	844.2 bv	2.6
11.6	824.8 av	2.1	850.2 bw	5.6
12.3	814.2 aw	4.8	843.7 bv	2.8
14.5	800.0 ax	1.6	823.6 bx	2.2
15.8	790.7 ay	1.6	816.1 ax	12.6
18.0	782.8 az	1.8	801.7 by	3.4
	Laird Lentils			
11.7	804.4 av	1.9	833.4 bv	7.6
13.8	789.2 aw	1.2	835.6 bv	10.6
15.9	781.9 ax	2.9	818.0 bw	5.4
17.7	767.3 az	2.3	799.2 bx	7.6
	Fababeans			
12.6	814.8 av	2.7	843.6 bv	5.3
15.0	789.6 aw	1.5	817.8 bw	11.4
18.1	774.1 ax	4.1	796.1 bx	3.8
21.9	761.3 ay	5.8	789.6 bx	8.6
% f.m.				
	Flaxseed at 9% moisture content and foreign material			
4.0	619.6 av	3.8	657.9 bv	2.9
8.0	605.0 aw	3.3	643.6 bw	6.5
12.0	604.7 aw	8.3	655.0 bv	4.1

*sd is standard deviation based on n = 5.

Means followed by the same letter for rows (a,b,c) or columns (v,w,x,y,z) within each crop are not significantly different ($P>0.05$).

Duncan's multiple range test.

33.6° between 4% and 8% foreign material. Filling angle of repose increased from 27.5° at 4% foreign material to 31.8° at 12% foreign material.

Different filling angles of repose on the left side as opposed to the right side of the cone apex were observed. The differences were more evident at some times than others and were related to the behaviour of the seed during the filling process. The seed would slide either to the right or the left depending on the shape of the apex. This behaviour is probably the cause of the large deviations from the mean as compared to those obtained in the emptying angle of repose. For flaxseed, the largest difference between the left and right side filling angle of repose occurred at 15.1% moisture content, with the left side being 29.2° and the right side being 34.6°, on the average. However, this yields very little information because this is an average and the direction of sliding was random, due to the shape of the apex. When estimating the angle of repose from these data, the most conservative average for the desired moisture content should be used.

The emptying angle of repose for Eston lentils (Table III)

Table II. Particle densities of flaxseed, lentils and fababeans at various moisture contents

Sample moisture content (%wb)	Particle density (kg/m^3) mean	sd*
	Clean Flaxseed	
8.2	1148.4 a	2.3
10.4	1150.6 a	3.4
12.6	1148.0 a	0.7
15.0	1143.0 b	1.7
	Eston Lentils	
11.6	1409.9 a	2.2
13.3	1406.2 a	5.0
15.2	1395.1 b	1.5
18.2	1392.0 b	2.7
	Laird Lentils	
11.4	1430.5a	2.2
13.1	1433.2 a	4.1
15.2	1408.7 b	3.3
18.0	1393.3 c	5.8
	Fababeans	
10.3	1392.8 a	5.2
13.5	1395.0 a	2.6
15.2	1382.7 b	4.8
18.0	1373.3 c	2.7

* sd is standard deviation based on n = 5.

Means followed by the same letter within the crop are not significantly different (P>0.05). Duncan's multiple range test.

increased slightly from approximately 25.9° at 11.6% moisture content to 28.6° at 14.5% moisture content. Between 14.5% and 18% moisture content the emptying angle remained relatively unchanged. The filling angle of repose (Table III) remained relatively constant. Deviations from the mean were much smaller for the Eston lentils than for flaxseed.

The emptying angle of repose for the Laird lentils (Table III) increased from 21.6° to 23.9° when moisture content increased from 11.7 to 13.8% but stayed relatively constant at higher moisture contents. The filling angle of repose (Table III) for the Laird lentils remained relatively constant at all moisture contents.

Moisture content effects were negligible on emptying and filling angles of repose of fababeans.

Coefficients of sliding friction

Friction coefficients for flaxseed (Table IV) increased with increases in moisture content on all surfaces. On galvanized steel the coefficient of friction increased from 0.27 to 0.66 with increase in moisture content from 7.0 to 15.1%. The coefficient of friction of flaxseed was usually higher on plywood with the grain perpendicular to the slope of the tilting table than with the grain parallel. On parallel grain plywood the coefficient of friction increased from 0.33 at 7% moisture content to 0.56 at 15.1% moisture content. On perpendicular grain plywood the coefficient of friction increased from 0.43 at 7% moisture content to 0.60 at 15.1% moisture content. The coefficient of friction of flaxseed was slightly higher on rough concrete than smooth concrete at 7.0% moisture content and was the same at other moisture contents. On smooth concrete the coefficient of friction increased from 0.42 at 7.0% moisture content to 0.62 at 15.1% moisture content. On rough concrete the coefficient increased from 0.44 at 7.0% moisture content to 0.63 at 15.1% moisture content.

The galvanized steel had the lowest coefficient of friction at low moisture contents but increased to the highest coefficient of friction at 15.1% moisture content with the exception of corrugated steel. This occurred because the flaxseed was somewhat sticky at 15.1% moisture content and the smooth galvanized steel offered the best surface for adhesion.

In summary the coefficients of sliding friction were lower at low moisture contents on galvanized steel and parallel grain plywood, but as moisture content was increased to approximately 12% there was little difference in the coefficient of friction among any of the flat surfaces.

The addition of the foreign material to the flaxseed did not yield consistent trends relative to the coefficient of sliding friction but it caused the coefficient to fluctuate. In all but one case (12% foreign material on plywood), however, the coefficient of friction did remain lowest on galvanized steel and parallel plywood with the other three flat surfaces being relatively equal. Corrugated steel continued to yield the highest coefficients of friction.

Eston lentils had slightly higher coefficient of friction (Table IV) than the Laird lentils. Friction coefficient increased on all surfaces up to 14.5% moisture content and then either increased or remained the same when moisture content was increased to 18%. Friction coefficients were higher on perpendicular grain plywood than on parallel grain plywood and were higher on steel trowelled concrete than on wood floated concrete. Friction coefficients on corrugated steel were the highest.

Friction coefficients for Laird lentils (Table IV) did not always increase with increased moisture content. The usual trend was an increase in the friction coefficient with increase in moisture content from 11.7 to 13.8%, then a decrease in the friction coefficient between 13.8 and 15.9% moisture content followed by another increase at 17.7% moisture content. The most evident example of this was on wood-floated concrete on which the friction coefficient was 0.26 at 11.7% moisture content, increased to 0.31 at 13.8% moisture content, and decreased to 0.28 at 15.9% moisture content followed by another increase to 0.33 at 17.7% moisture content.

The friction coefficients for Laird lentils are higher on perpendicular grain plywood than parallel grain plywood, but on concrete the friction coefficients, unlike the flaxseed, are higher on steel trowelled concrete than the wood floated concrete. This may be because for small and flat flaxseed, rough

Table III. Angles of repose (degrees) of flaxseed, lentils, and fababeans at various moisture contents

Sample moisture content	Emptying angle (°)		Filling angle (left) (°)		Filling angle (right) (°)	
(% wb)	mean	sd*	mean	sd	mean	sd
			Clean Flaxseed			
7.0	30.3 av	0.4	28.3 bv	1.2	25.7 bv	3.6
10.5	31.1 aw	0.4	29.4 av	3.8	30.6 avw	3.6
12.3	37.8 ax	0.4	33.4 bw	2.1	34.9 bw	2.8
15.1	38.0 ax	0.4	29.2 cv	1.8	34.6 bw	1.7
			Eston Lentils			
11.4	25.7 av	0.5	27.3 bvw	0.4	28.5 cx	0.4
11.6	25.9 av	0.2	26.8 bv	0.5	27.2 bv	0.3
12.3	27.8 aw	0.3	27.8 avw	0.6	28.6 awx	0.6
14.5	28.6 ax	0.2	27.9 aw	1.0	28.3 awx	0.7
15.8	27.8 aw	0.3	28.0 aw	0.5	28.7 bx	0.3
18.0	28.5 ax	0.3	26.9 cv	0.5	27.9 bw	0.4
			Laird Lentils			
11.7	21.6 av	0.4	23.1 bv	0.2	24.5 cv	0.4
13.8	23.9 aw	0.2	23.3 bv	0.3	24.1 av	0.8
15.9	23.7 aw	0.6	22.4 bv	0.5	24.9 cv	0.4
17.7	23.8 aw	0.4	22.8 bv	0.5	24.2 av	1.3
			Fababeans			
12.6	28.1 av	0.2	29.6 bv	1.0	29.0 bv	0.6
15.0	29.1 aw	0.2	28.9 av	1.1	29.2 av	1.1
18.1	29.1 bw	0.2	29.7 av	0.6	28.3 cv	0.4
21.9	29.3 aw	0.3	29.3 av	1.2	29.3 av	1.1
% f.m.			Flaxseed at 9% moisture content and three levels of foreign material			
4.0	30.9 av	0.4	27.8 bv	2.4	27.5 bv	1.7
8.0	33.6 aw	0.5	30.0 bv	1.0	29.8 bvw	2.2
12.0	33.3 aw	0.3	30.4 bv	2.7	31.8 bw	1.2

*sd is standard deviation based on n = 5.

Means followed by the same letter for rows (a,b,c) or columns (v,w,x,y,z) within each crop are not significantly different (P>0.05). Duncan's multiple range test.

concrete caused obstacles whereas for Laird lentils the rough concrete simply resulted in less contact area. Corrugated steel caused the highest coefficients of friction of all surfaces at all moisture contents.

Friction coefficients for fababeans (Table IV) generally increased with an increase in moisture content. The coefficients of friction were higher for fababeans than for Eston or Laird lentils. Friction coefficients were normally higher on perpendicular grain plywood than on parallel grain plywood, were similar on rough and smooth concretes, and were the highest on corrugated steel at all moisture contents for the fababeans.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn.

1. Both bulk and particle densities decreased with an increase in moisture content for all seed types.

Table IV. Friction coefficients against six structural materials of flaxseed, lentils, and fababeans at various moisture contents

Sample moisture content	Galvanized steel		Plywood (Parallel to grain)		Plywood (Perpendicular to grain)		Steel-trowelled concrete		Wood-floated concrete		Corrugated steel	
(% wb)	mean	sd*	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
						Clean Flaxseed						
7.0	0.27 aw	0.005	0.33 bw	0.011	0.43 dw	0.004	0.42 cw	0.004	0.44 dw	0.008	0.56 ew	0.010
10.5	0.41 ax	0.022	0.42 bx	0.014	0.52 cx	0.014	0.49 bx	0.013	0.50 bcx	0.026	0.62 dx	0.049
12.3	0.57 ay	0.006	0.56 ay	0.016	0.58 ay	0.018	0.57 ay	0.028	0.58 ay	0.021	0.75 by	0.049
15.1	0.66 cz	0.023	0.56 ay	0.027	0.60 by	0.019	0.62 bz	0.021	0.63 bcy	0.032	0.76 dy	0.029
						Eston Lentils						
11.4	0.24 bv	0.012	0.17 av	0.003	0.25 bv	0.007	0.32 cw	0.007	0.31 cw	0.016	0.45 dvw	0.009
11.6	0.25 bv	0.004	0.19 aw	0.007	0.25 bv	0.006	0.29 cv	0.011	0.29 cv	0.009	0.46 dvw	0.014
12.3	0.26 bw	0.004	0.23 ax	0.006	0.27 bw	0.010	0.36 dx	0.008	0.34 cx	0.005	0.47 ewx	0.010
14.5	0.29 bx	0.005	0.26 ay	0.017	0.31 cx	0.005	0.37 dx	0.007	0.36 dy	0.006	0.49 ex	0.010
15.8	0.31 cy	0.007	0.24 axy	0.008	0.29 bw	0.011	0.37 ex	0.010	0.34 dx	0.002	0.47 fw	0.005
18.0	0.33 cz	0.008	0.24 axy	0.012	0.31 bwx	0.010	0.41 ey	0.010	0.38 dz	0.007	0.47 fw	0.008
						Laird Lentils						
11.7	0.20 av	0.012	0.15 bv	0.006	0.21 av	0.008	0.27 cv	0.008	0.26 cv	0.006	0.37 dv	0.004
13.8	0.25 aw	0.010	0.24 ax	0.010	0.29 bx	0.010	0.34 dw	0.014	0.31 cx	0.007	0.41 ew	0.020
15.9	0.25 bw	0.010	0.19 aw	0.010	0.26 bcw	0.012	0.32 dw	0.015	0.28 cw	0.010	0.38 evw	0.016
17.7	0.30 cx	0.008	0.22 awx	0.021	0.27 bw	0.003	0.34 dw	0.018	0.33 dy	0.010	0.39 ew	0.005
						Fababeans						
12.6	0.29 av	0.013	0.28 av	0.011	0.32 bv	0.005	0.31 bv	0.005	0.29 av	0.006	0.52 cv	0.042
15.0	0.30 av	0.018	0.33 bw	0.009	0.34 bcw	0.017	0.35 cw	0.009	0.35 cw	0.008	0.56 dv	0.025
18.1	0.34 aw	0.015	0.36 bx	0.012	0.38 bcx	0.018	0.38 bcx	0.019	0.41 cx	0.018	0.64 dx	0.011
21.9	0.36 aw	0.023	0.37 ax	0.013	0.41 cy	0.004	0.39 bx	0.013	0.40 bcx	0.008	0.61 dw	0.009
% f.m.						Flaxseed at 9% moisture content and three levels of foreign material						
0.0	0.36 av	0.014	0.39 aw	0.025	0.50 cv	0.029	0.45 bv	0.020	0.46 bcv	0.017	no data	no data
4.0	0.40 bx	0.004	0.36 av	0.002	0.47 cv	0.017	0.46 cv	0.019	0.50 dw	0.010	0.55 ev	0.012
8.0	0.39 awx	0.008	0.42 aw	0.023	0.50 cv	0.019	0.46 bv	0.010	0.49 cw	0.012	0.62 dw	0.026
12.0	0.37 avw	0.018	0.39 aw	0.016	0.47 bv	0.020	0.46 bv	0.007	0.47 bvw	0.026	0.61 cw	0.009

*sd is standard deviation based on n = 5.

Means followed by the same letter for rows (a, b, c, d, e, f) or columns (v, w, x, y, z) within each crop are not significantly different (P>0.05). Duncan's multiple range test.

2. The drop height of 1.8 m increased the bulk densities by approximately 2 to 5%.
3. Filling and emptying angles of repose and friction coefficients against various structural materials did not show similar trends for all seed types.
4. Friction coefficients against corrugated steel were the highest among all surfaces for all seed types.

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