Physical and Mechanical Properties of beans

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Abstract: Food properties are needed and play a significant role to predict and define the quality and behavior of seeds. In this study physical (dimension, weight, volume, sphericity, static coefficient of friction) and mechanical (maximal impact deformation, dynamic coefficient of friction) properties of four common beans are reported. As static coefficient of friction is equal to tangent of slip angle, a suitable apparatus was constructed and static coefficient of friction for four genotypes Daneshkadeh and Dehghan (white color) Naz and Sayyad (Red color) on three surfaces (rubber, tarpaulin and steel galvanized) were measured. Also dynamic coefficient of friction was determined at surface moving velocities of 4, 8 and 12 m/min. Mechanical behavior under impact load were determined in terms of average rupture force in pendulum impact, that is design and constructed. Randomize complete block design showed that, static and dynamic coefficient of friction had major difference between beans genotypes, surfaces and velocity. Mean values showed that the lowest static coefficient (0.32) occurred with steel galvanized surface and highest (0.44) on tarpaulin surface. The lowest dynamic coefficient of friction (0.24) occurred with steel galvanized surface and highest (0.385) on tarpaulin surface. It was observed that the magnitudes of physical damage in Sayad beans were higher than Naz, Daneshkadeh and Dehghan respectively. The average loss of germination to beans decreased with increasing impact energy. Naz and Dehghan had minimum mean volume and weight and Daneshkadeh had maximum sphericity and geometric mean.

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INTRODUCTION and LITERATURE REVIEW

In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of bean seeds, it is necessary to determine their physical properties. Recently scientists have made great efforts in evaluating basic physical properties of agricultural materials and have pointed out their practical utility in machine and structural design and in control engineering. Dimensions are important to design the cleaning, sizing and grading machines. Coefficient of friction is important in designing equipment for solid flow and storage structures. The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on walls (Amin et al., 2004).

Several investigators determined the physical properties of seeds such as Shepherd and Bhardwaj (1986) for pigeon pea; Amin et al. (2004) and Carman (1996) for lentil seed; Ogunjimi et al. (2002) for locust bean seed; Yalcin et al. (in press) for pea seed; Konak et al. (2002) for chickpea seeds, Dutta et al. (1988a) and Aviara et al. (1999) for gram and guna seeds respectively.

The coefficient of friction is important parameter in the design of material handling equipment and storage structures. Methods that have been used to study the coefficient of friction of agricultural products include moving a given surface against the material (Lawton, 1980), tilting an inclined plane, (Aviara et al. (1999), Deshpande et al. (1993), Dutta et al. (1988a) and the use of shear box equipment (Osunade and Lasisi, 1994). The structural surfaces usually employed are galvanized steel sheet, wood and plywood. Studies on the angle of repose of grains and seeds have been conducted by various researchers using a specially constructed box with removable front panel (Dutta et al., 1988a; Fraser et al., 1978). The objective of this part of project was to measure the peak static and dynamic coefficient of friction for various bean cultivars against common construction materials with typical surface conditions.

The study of the mechanical characteristics in agricultural products is important in order to design equipments operating with maximum efficiency but not compromising the final product quality. The seed coat layer is thin, making them susceptible to mechanical damage during handling and drying. Generally, mechanical injury occurs during harvesting when the pods are threshed, but injury can also occur any time when the seeds are processed or handled including during planting (Copeland and Saettler, 1982). When grains are submitted to forces that exceed the resistance of the material, grain breakage or cracks are found (Liu et al., 1990). During harvesting, handling and storage operations, the grains go through several static and dynamic pressures such as high speed impacts which cause bruises, crushes and cracks that increase the susceptibility to deterioration during storage (Bargale et al., 1995).

Bergen et al. (1993) in a study on 'Trapper' peas and 'Laird' lentils observed that seeds dropped from a greater height caused more seed damage on all three selected surfaces, namely: steel, plywood, and concrete. Seeds with lower moisture content reportedly incurred more damage. However, they did not observe any significant change in the germination percentage. Perry and Hall (1965) studied the mechanical properties of pea beans using an experimental impact machine and high-speed motion picture camera. They were able to estimate the kinetic energy, maximum total force during impact, average time of impact, and the deformation. Their results showed that pea beans were elastic since temporary deformation averaged 12.7% during impact, while permanent deformation averaged 2.7% only. In a study of damage on soybean seed quality, Paulsen et al. (1981) observed that an increase in impact velocity resulted in increased split beans. Evans et al. (1990) impacted soybean seeds in a seed impacting device at four moistures (7.2, 10.1, 12.9, and 16.2%), four impact velocities (10, 20, 30, and 40 m/s), and five seed orientations. A steel impact surface caused the most damage, while the polyurethane surface caused the least. Seed damage increased with impact velocity and decreased with moisture content. Bartsch et al. (1979) observed that impact damage for soybeans at 5 m/s and 10 m/s were statistically similar. Nevertheless, damage increased as the approach velocities increased from 10 m/s to 15 m/s.

This study was undertaken to a) determined some physical properties of bean seeds, Dimensions, volume, sphericity; b) measuring the static and dynamic coefficient of friction against three different materials; c) quantify the physical damage caused to dry beans due to impact caused by pendulum; d) determine the loss in germination to dry beans due to impact and e) compare strain energy and rebound energy for four bean genotypes, Daneshkadeh and Dehghan (white color) Naz and Sayyad (Red color).

MATERIAL and METHOD

Physical attributes

The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds. The initial moisture content of the seeds was determined by oven drying at 105±1º C for 24 h (Suthar and Das, 1996; Yalcin and Ozarslan, 2004). The initial moisture content of the seeds was 8 to 10% d.b. The moisture in the seeds was allowed to equilibrate at room temperature of 27C for at least 72 h. To determine the average size of the seed, 100 seeds were randomly picked and their three linear dimensions namely, length, width and thickness were measured using a micrometer with accuracy of 0.01 mm (Altuntas et al., 2005). The sphericity and volume of seeds was calculated by using Mohsenin (1986) relationships.

Coefficient of friction

The friction device, utilized in this experiment (Figure1) was essentially a refined version of the device used by Mohsenin (1986). The static and dynamic coefficient of friction of bean seeds against three different structural materials, namely rubber, tarpaulin and galvanized iron was determined. A polyvinylchloride cylindrical pipe of 50 mm in diameter and 50 mm in height was placed on an adjustable tilting plate, faced with the test surface and filled with the 30g bean sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt α was read from a graduated scale (Singh and Goswami, 1996; Suthar and Das, 1996). The coefficient of friction was calculated from the tan(α). The maximum value of friction force was obtained when box started moving, and this was used to calculate the static coefficients of friction. While the box continued to slide over the friction surfaces at 4, 8 and 12 m/min velocity, the dynamic friction force was measured. The test table height was adjusted so that the cable between the box and force gage was always in a horizontal position. The horizontal pull (friction force) was measured by the A&D Co. digital force gage with 0.1g accuracy and continually recorded on a computer. The maximum amplitude of the consequent undulating dynamic force line was the peak force. The dynamic friction force calculated by dividing the total area (integrated time base) under the force travel curve by the total travel distance (extension). The sliding friction force divided to sample weight was used to calculate the dynamic coefficients of friction. An analysis of variance evaluation was made for the peak static and dynamic friction data respectively. A Duncan rank test was used to test for significant differences between each treatment.

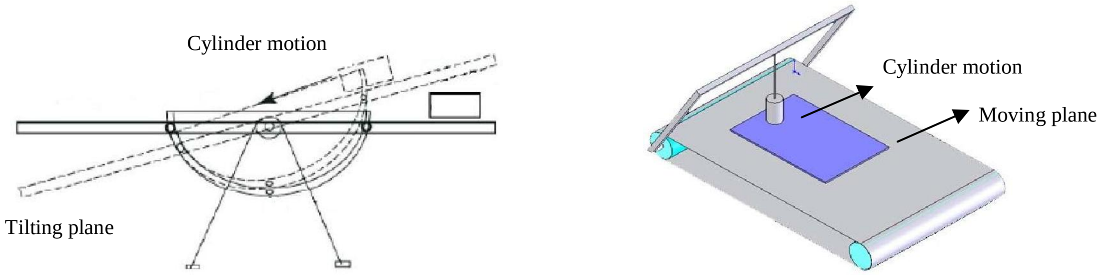

Figure1. Apparatus for measuring (a) static CoF (b) dynamic CoF

Impact damage to beans

Seeds are also subjected to forced pendulum impact that happens in threshers. The tested and untested (control) seeds were graded manually according to the guideline of the Canadian Grain Commission (1993). The seeds were sorted as cracked, split, and undamaged. Splits included broken pieces that were less than three-quarters of the whole seed and halves that were loosely held together. Cracked seeds included seeds with visibly cracked seed coats and seeds with less than one-fourth seed broken off. The percentage of cracked split, and undamaged seeds was adjusted for damage in the untested seeds. Undamaged seeds from each treatment combination were subjected to germination tests to check for internal damage. Germination tests were done by Alberta Wheat Pool at Camrose, Alberta. In each sample tested, seeds were placed evenly on two sheets of a germination paper towel, then covered with a single sheet, rolled and held in upright position. The rolled towel was moistened until its mass was about three times its dry mass (Canadian Food Inspection Agency, 1995).

From eq. (1) the impact energy (w_i) is equal to summation of rebound energy (w_R), strain energy (w_P) and energy losses (w_L). In pendulum apparatus, total impact energy and rebound energy with an estimation of friction (losses) is distinct, so strain energy will be determined (Sitkei, 1986). Coefficient of restitution could be determined by eq. (2) (Bueche and Hecht, 1997). In this equation, a and b are primary and secondary angle of pendulum rebound.

$$Wi = w_R + w_P + w_L \qquad (1)$$

$$e = \sin(b/2)/\sin(a/2) \qquad (2)$$

The experiment was set up as a factorial complete design. There were four replicates for the measurements of strain energy and Coefficient of restitution. The Mstat-c software was used to derive the least squares and standard errors for the dependent variables. The Duncan test was used to compare the means.

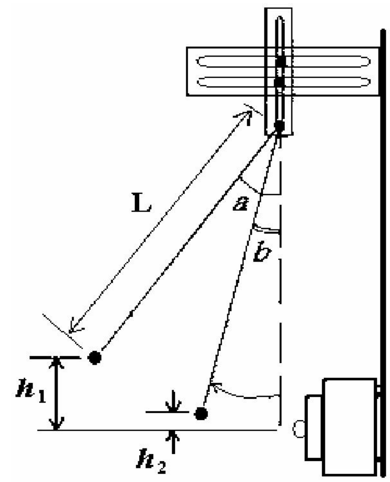

Figure 2. Impact apparatues

RESULTS and DISCUSSION

Seed physical attributes

A summary of the results of the determining physical parameters of 400 seeds is shown in Table (1). The geometric mean diameter ranged from 3.2 to 8.4 mm. The geometric mean of the axial dimensions is useful in the estimation of the projected area of a particle moving in the turbulent or near turbulent region of an air steam. The sphericity was 27.8 to 73.8 Percent which indicated that the shape of the beans makes them difficult to roll on surfaces.

Static and dynamic coefficient of friction

The ANOVA indicated that the variation of peak static coefficients of friction with cultivar and surface was significant ($P<0.05$ and $P<0.01$ respectively). Also cultivar*surface interaction was significant ($P<0.01$). These two factor interactions were further evaluated by plotting and studying interaction patterns. No consistent trends, except for surface effects, were evident. Mean value showed that the lowest static coefficient (0.32) occurred with steel galvanized surface and highest (0.44) on tarpaulin surface. For the dynamic coefficients of friction, the same effects and interactions were found to be significant in the Anova as were found for the peak static coefficients of friction. Mean value showed that the lowest dynamic coefficient (0.24) occurred with steel galvanized surface and highest (0.385) on tarpaulin surface (Table 2).

Table 1. Some physical properties of four beans

Property	Genotype	Mean value	Minimum value	Maximum value
Length, mm	Daneshkadeh	11.39	8.88	13.13
	Dehghan	10.8	9.28	12.46
	Sayyad	11.66	10.02	13.45
	Naz	11.42	9.1	12.79
Width, mm	Daneshkadeh	6.89	5.88	7.57
	Dehghan	6.67	5.48	7.61
	Sayyad	7.19	6.31	8.39
	Naz	6.87	6.04	7.38
Thickness, mm	Daneshkadeh	5.11	3.59	6.22
	Dehghan	4.56	0.49	5.53
	Sayyad	4.44	0.399	5.62
	Naz	4.61	3.86	5.48
Geometric mean, mm	Daneshkadeh	7.37	5.9	8.4
	Dehghan	6.84	3.2	7.8
	Sayyad	7.13	3.04	8.34
	Naz	7.11	6	7.73
Sphericity, %	Daneshkadeh	64.7	60	73.8
	Dehghan	63.4	29.6	70.4
	Sayyad	61.2	27.8	66.3
	Naz	62.4	56.9	67.03
Weight, g	Daneshkadeh	0.296	0.14	0.42
	Dehghan	0.24	0.13	0.35
	Sayyad	0.289	0.2	0.44
	Naz	0.26	0.18	0.32
Volume, cm^3	Daneshkadeh	0.25	0.12	0.35
	Dehghan	0.2	0.11	0.27
	Sayyad	0.25	0.17	0.42
	Naz	0.21	0.13	0.28

Table 2. Static and dynamic coefficients of friction of bean cultivar

Material surface	Bean cultivar	Static CoF	Dynamic CoF			
			Moving velocity, m/s	4	8	12
Galva. steel	Daneshkadeh	0.296		0.23	0.22	0.18
Tarpaulin	Dehghan	0.441		0.44	0.415	0.397
Rubber	Sayyad	0.4		0.35	0.33	0.3
Galva. steel	Naz	0.36		0.34	0.26	0.22
Tarpaulin	Daneshkadeh	0.42		0.407	0.335	0.26
Rubber	Dehghan	0.465		0.439	0.407	0.35
Galva. steel	Sayyad	0.34		0.3	0.28	0.19
Tarpaulin	Naz	0.45		0.44	0.405	0.37
Rubber	Daneshkadeh	0.39		0.39	0.35	0.28
Galva. steel	Dehghan	0.277		0.255	0.23	0.19
Tarpaulin	Sayyad	0.45		0.41	0.39	0.35
Rubber	Naz	0.42		0.425	0.39	0.25

For beans, the dynamic coefficient of friction was less in value than static coefficient of friction, however for high moisture content, chopped forage or plant tissue, the dynamic coefficient of friction does exceed the peak static coefficient of friction (ASAE, 1990; Mekvanich and bagnall, 1978). The static and dynamic coefficient of friction of bean seeds on three surfaces are presented in Table (1) and it was observed that the static coefficient of friction is higher than dynamic coefficients of friction. Both the static and dynamic coefficients of friction were highest in rubber, followed tarpaulin and galvanized steel. This may be due to smoother and more polished surface of galvanized metal than other test surfaces. These results was agree with the behavior of dry engineering materials as noted by Mohsenin (1986), who observed that the friction force decreases as the sliding velocity increases.

The analysis of variance showed a significant effect of moving velocity on dynamic coefficient of friction. Generally, the dynamic coefficients of friction for bean cultivars decreased as the velocity increased. The lowest dynamic coefficient occurred at 12 m/s for galvanized steel and highest occurred at 4 m/s for tarpaulin (Table 2).

Impact force

The means of split and cracked damage in beans and the percentage of seed germination at various impact energy levels are shown in Table 3. It was observed that the magnitudes of physical damage in Sayad beans (Table 2) were higher than Naz, Daneshkadeh and Dehghan respectively. The average loss of germination to beans decreased with increasing impact energy. All two independent variables namely, impact energy and variety had significant effect ($P<0.01$) on the measured values. Figure 3, 4 shows the value of strain energy and Coefficient of restitution of four beans. Bean damage increased as the impact energy increased which was also the case for soybeans (Evans, et al. 1990; Paulsen et al. 1981). A decrease in percent germination was observed as the impact energy increased.

Germination in Naz and Sayyad (Red color) was low in high level impact energy (1.035 j).

CONCLUSIONS

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

. The value of dynamic CoF was less than static CoF and both of them were highest in rubber, tarpaulin and galvanized steel respectively.

Table 3. The means of damage in beans at various impact energy levels

		Impact energy levels, J			
Bean Genotypes		1.035	0.990	0.955	Control
Daneshkadeh	Split	30%	0	0	0
	Cracked	0	10%	0	0
	Germination	40%	60%	70%	90%
Naz	Split	40%	10%	0	0
	Cracked	0	10%	0	0
	Germination	30%	60%	80%	86%
Sayad	Split	50%	0	0	0
	Cracked	0	20%	0	0
	Germination	30%	60%	90%	90%
Dehghan	Split	20%	0	0	0
	Cracked	0	0	0	0
	Germination	50%	70%	90%	100%

. The relationship between loss of germination resulting from the impact tests using different variables were well defined. A decrease in percent germination was observed as the impact energy increased.

. To avoid bean seed damage and thereby to avoid decreased germination capacity during preparation of seeds for sowing, the impact energy level of seed should not exceed 1 J.

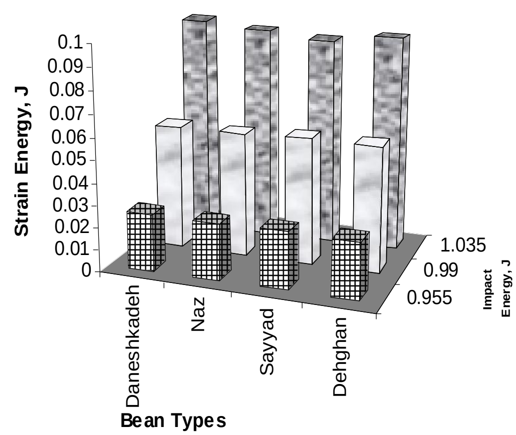

Figure3. Strain energy for four beans

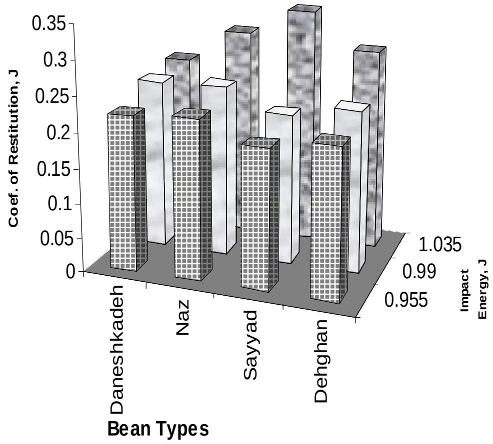

Figure 4. Coefficient of restitution for four beans

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