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Physical and Mechanical Properties of Alfalfa Grind as Affected by Particle Size and Moisture Content

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ABSTRACT

Physical and mechanical properties of alfalfa (*Medicago sativa, L.*) grind are required for optimum design of equipment used in transporting, processing and storage of the material. This study was conducted to determine the effect of particle size (2.38, 3.36 and 4.76 mm) and moisture content (8, 9.3 and 11% wb) on some physical and mechanical properties of alfalfa grind. These properties include: geometric mean diameter, bulk density, coefficient of static friction (on galvanized iron, Plexiglass, rubber and polished steel surfaces), filling angle of repose, coefficient of internal friction, cohesion, and adhesion to polished steel plate. The bulk density varied from 161.6 to 202.2 kg m^{-3}. The coefficient of static friction changed from 0.26 on polished steel plate to 0.87 on rubber surface. Larger particles with higher moisture content had the highest filling angle of repose (54.5°). The coefficient of internal friction varied from 0.64 to 0.88. The 2.38-mm alfalfa grind at moisture content of 11% (wb), and the 4.76-mm at moisture content of 8% (wb) had the highest and lowest cohesion (7.65 and 4.80 kPa), respectively. The adhesion on polished steel plate varied from 0.19 to 1.54 kPa.

Keywords: Alfalfa grind, Bulk density, Coefficient of static friction, Cohesion.

INTRODUCTION

Alfalfa (*Medicago sativa,* L.) often called "Queen of forages" is the most important forage crop species in the world. Good quality alfalfa hay contains digestible fibers and a range of useful minerals and vitamins. Since 1970, the processing of alfalfa to produce products such as pellets and cubes has been increasing due to ease of transportation and better digestion (Haiqing, 2004).

Physical and mechanical properties of alfalfa grind are required for optimum design of equipment being used in transporting, processing and storage of the material. Geometric mean diameter and particle size distribution of biomass grind are important factors affecting the binding characteristics for densification, and are also useful information in the design of pneumatic conveyors and cyclones (Mani *et al*., 2004a).

Bulk density can be useful in sizing hoppers and storage facilities; it can affect the rate of heat and mass transfer of moisture during aeration and drying process. Moisture content, bulk density, true density and particle size and shape of biomass particles after grinding are important for downstream processing (Manlu *et al.*, 2003). Fathollahzadeh *et al*. (2008) reported that bulk density of barberry increased from 700.01 to 1,224.67 kg m^{-3} with increasing moisture content from 12.64 to 89.23% (wb).

The frictional behavior of biomass grind in all engineering applications is described by two independent parameters: the coefficient of internal friction and the coefficient of static friction. Coefficient of

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internal friction is a very important factor in design of storage structures. The lateral pressure acting on storage bin walls is determined based on the angle of internal friction of the stored materials (Chevanana *et al*., 2008). Coefficient of static friction is used in the design of densification equipment and modeling of compression behavior of powder materials (Mani *et al*., 2004b; Al- Mahasneh and Rababah, 2006). Design of handling systems requires the coefficient of static friction between forage and structural surface in contact with the forage. Aydin (2002) reported that coefficient of static friction of nut increased significantly as moisture content increased. Tabil and Sokhansanj (1997) reported that cohesion decreased with increase in particle size of alfalfa grind from 2.4 to 3.2 mm. For ground marigold petals, Zou and Brusewitz (2001) found that the moisture content and particle size had the most and the least effects on cohesion, respectively. Mani *et al*. (2004) found that adhesion of ground corn stover to galvanized steel plate decreased with an increase in particle size.

Based on our literature review, there is little information on the physical and mechanical properties of alfalfa grinds. Therefore, the objective of this study was to determine the effect of particle size (2.38, 3.36 and 4.76 mm) and moisture content (8, 9.3 and 11% wb) on bulk density, coefficient of static friction (on galvanized, Plexiglass, rubber and polished steel surfaces), angle of repose (filling), coefficient of internal friction, cohesion, adhesion to polished steel surface. This range of the moisture content was selected because most of the processing operations of alfalfa are performed in this range.

MATERIALS AND METHODS

Rectangular bales of alfalfa were obtained from Isfahan University of Technology Research Station Farm. The alfalfa bales were chopped using a chopper equipped with a screen size of 18 mm. The chopped alfalfa was ground using a hammer mill with screen openings of 2.38 ($SS_{2.38mm}$), 3.36 ($SS_{3.36mm}$) and 4.76 mm ($SS_{4.76mm}$). The initial moisture content of grinds was 9.3% (wet basis; wb). A portion of the ground samples was dried by spreading them in thin layer at room conditions to obtain the moisture content of 8% (wb) by controlling the samples mass. Another portion of the grind was further conditioned by spraying a predetermined amount of distilled water over the samples, agitating, and storing for 48 hours at 5ºC to obtain ground sample with moisture content of 11% (w. b.).

Moisture Content Measurement

The moisture content of alfalfa chops was determined according to ASAE standard S358.2 FEB03 for forage (ASAE, 2003a). A sample of 25 g was oven dried for 24 hours at 105±3°C. The moisture content of the grind was determined by the procedure given in ASTM Standard D 3173-87 for coal and coke (ASTM, 1996). One gram of pulverized sample which was passed through a sieve with openings of 0.25 mm (sieve #60) was taken and oven dried for 1 h at 104°C.

Particle Size Analysis

The particle size of the grinds was determined according to ASAE Standard S319.3 FEB03 (ASAE, 2003b). One 100-g sample of grinds was placed on the top of a stack of sieves arranged from the largest to smallest opening. The sieve series selected were based on the range of particles in the sample. For the grinds from $SS_{4.76mm}$, the sieve numbers of 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, 200 and 270 (nominal opening of 2.4, 1.2, 0.85, 0.59, 0.42, 0.30, 0.21, 0.15, 0.01, 0.074 and 0.053 mm, respectively) were used. For grinds from $SS_{3.36mm}$, the sieve numbers of 12, 16, 20, 30, 40, 50, 70, 100, 140, 200 and 270 (nominal opening of 1.2, 0.85, 0.59, 0.42, 0.30, 0.21, 0.15, 0.01,

0.074 and 0.053 mm, respectively) were used. For grinds from $SS_{2.38mm}$, the sieve numbers of 16, 20, 30, 40, 50, 70, 100, 140, 200 and 270 (nominal opening of 0.85, 0.59, 0.42, 0.30, 0.21, 0.15, 0.01, 0.074 and 0.053 mm, respectively) were utilized. Finally, for the fine grinds from $SS_{1.68mm}$, the sieve numbers of 20, 30, 40, 50, 70, 100, 140, 200 and 270 (nominal opening of 0.59, 0.42, 0.30, 0.21, 0.15, 0.01, 0.074 and 0.053 mm, respectively) were used. The duration of sieving was 10 min, which was previously determined through trials to be optimal for alfalfa grind because of its fluffy and dusty nature. After sieving, the mass retained on each sieve was weighed. The geometric mean (d_{gw}) and standard deviation (S_{gw}) of particle diameters for the sample were calculated according to the aforementioned standard.

Bulk Density

Bulk density of ground samples was measured using the grain bulk density apparatus (Canadian Grain Commission, 1984). The grinds were placed on the funnel and dropped at the center of a 0.5 l capacity steel cup continuously. Since the grind was fluffy and did not flow down readily through the funnel, it was stirred using a wire in order to maintain a continuous flow of the material. The cup was leveled gently by a rubber coated steel rod and weighed. The weight per unit volume gave the bulk density of the grind in kg m^{-3}.

Coefficient of Static Friction

Coefficient of static friction for alfalfa grind on different structural surfaces including: Plexiglass, rubber and galvanized iron was measured by applying the inclined plane method which involved using a 150×100×40 mm bottomless wooden box. Test was conducted at three different moisture contents (8, 9.3 and 11% wb). The wooden box was filled with alfalfa grind then placed on an adjustable tilting plate without allowing the wooden box to touch the inclined surface. The tilting surface was then raised slowly and gradually until the wooden box started to slide down. The coefficient of friction was calculated as the tangent of the measured tilt angle (Baryeh, 2001).

Angle of Repose (Filling)

The filling or static angle of repose is the angle with the horizon at which the alfalfa will stand when piled. This was determined using a 1250×750×110 mm topless Plexiglass box. The box was filled using a funnel located at the center of the top of the box (Konak *et al.*, 2002).

Coefficients o Internal Friction, Adhesion, and Cohesion

In this research, the internal (cohesion and coefficient of internal friction) and external (adhesion and coefficient of external friction) properties of alfalfa grind were determined using a shear box apparatus (Equipment Laboratory Engineering, ELE, England). The shear box had a diameter and height of 63.5 of 20 mm, respectively. The bottom half of the box was pulled at a constant speed of 0.3 mm min^{-1} in the horizontal direction. The shear force and vertical displacement were recorded using two horizontal and vertical gages, respectively.

The cohesion and coefficient of internal friction (strength parameters) of alfalfa grind with screen sizes of 2.38 and 3.36 mm were determined at moisture content of 9.3% for two different ranges of normal loads. The first normal load range was 4.7, 39.5, 158.3 and 316.6 N and the second was 728.3, 1,146.4, 1,684.8 and 2,425.8 N. The shear box was filled with the sample. The same bulk density was used for all tests.

To measure the external property of alfalfa grind, a polished steel plate was placed inside the bottom half of the box, the top half was

filled with the sample, and the shear force was measured at four different normal loads (39.5, 126.6, 633.2 and 1,266.4 N).

The shear tests were replicated three times for each normal load range. The maximum shear stresses were plotted versus the normal pressures for each grind size. The slope of the best fitted line to the data was considered as the coefficient of friction, and the intercept of the line was used as the adhesion (or cohesion) of the sample based on Mohr-Coulomb's model. Mohr-Coulomb's model expresses shear strength as a function of normal stress as follows (Chancellor, 1994; Puchalski and Brusewitz, 1996, Lawton and Marchant, 1980):

$$\tau = \mu_s \sigma + C \quad (1)$$

where τ is shear stress, (kPa); μs is coefficient of static friction; σ is normal stress in kPa and C is cohesion in kPa.

Statistical Analysis

Factorial analysis (ANOVA) was used to determine the significance of particle size and moisture content effects on the physical and mechanical properties of alfalfa grind. Fischer's Least Significant Difference (LSD) was used for multiple mean comparisons. Statistical software (SAS Institute, Cary, N.C.) was used to analyze the data.

RESULTS AND DISCUSSION

Size Distribution and Bulk Density

The particle size distribution of alfalfa grind from three hammer mill screen sizes is shown in Figure 1. The particle size distribution depicts a skewness of the distribution, which was similarly reported for alfalfa grind (Yang *et al*., 1996) and corn stover grind (Mani *et al*., 2004b). The grinds from screen size of 4.76 mm ($SS_{4.76mm}$) had a large size distribution with a geometric mean diameter (d_{gw}) of 0.422 mm. The d_{gw} from screen sizes of 3.36 ($SS_{3.36mm}$) and 2.38 mm ($SS_{2.38mm}$) were 0.400 and 0.336 mm, respectively. Information on particle size distribution requirement for various conversion processes is not available. An ideal particle size distribution remains to be determined for each bioconversion process.

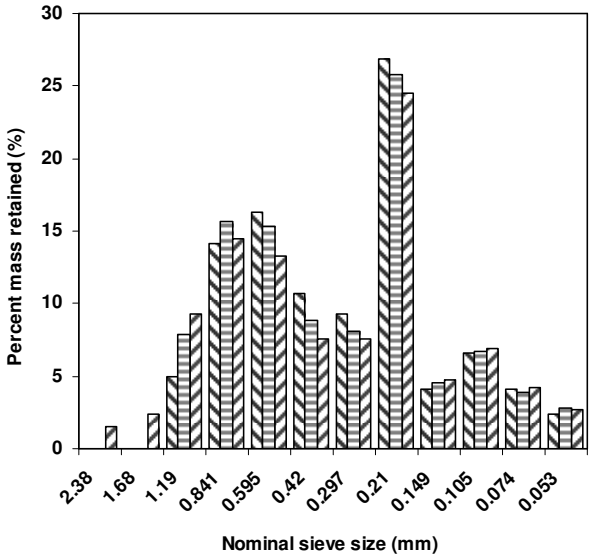

Figure 1. Particle size distribution of alfalfa grind (average of three tests): ▨= 2.38 mm screen size; ▤ = 3.36 mm screen size; ▧= 4.76 mm screen size.

Compressibility of grind may depend on the particle size distribution of the grind. If more fine particles are present in the grind sample, they will fill in the void space, resulting in higher compressibility.

Geometric mean particle diameters for three different hammer mill screen sizes are listed in Table 1. Comparison of means showed a significant ($P< 0.05$) difference between the mean values of bulk density at different moisture contents for three hammer mill screen sizes (Table 2). The bulk density of alfalfa grind increased with a decrease in geometric mean diameter of the grind. Grinds from the smallest screen size (2.38 mm) produced the highest bulk density at each level of moisture content. Since larger particles are reduced to small particle size, they occupy less volume and finer particles occupy the void spaces, resulting in an increase in bulk density (Mani *et al*., 2004b). Bulk densities of grinds from $SS_{4.76mm}$, $SS_{3.36mm}$ and $SS_{2.38mm}$ varied from 179.9 to 202.2, 176.2 to 194.7 and 161.6 to 177.8 kg m^{-3}, respectively, as moisture content increased from 8 to 11% (wb). With increase in moisture content, the bulk density increased linearly with coefficient of determination (R^2) value higher than 0.97 (Figure 2). The increase in bulk density was mainly due to the large increase in alfalfa grind mass compared to the increase in alfalfa grind volume. Similar results were reported for barberry (Fathollahzadeh *et al*., 2008), corn stover grind (Mani *et al*., 2004b), cherry laurel (Calisir and Aydin, 2004) and gumbo fruit (Akar and Aydin, 2005).

Coefficient of Static Friction

Table 1. Geometric means of particle diameter.

Hammer mill screen size (mm)	Geometric mean particle diameter (mm)
2.38	0.336 (0.357) [a]
3.36	0.402 (0.373)
4.76	0.422 (0.443)

[a] Number enclosed in the parenthesis is geometric standard deviation (n= 3).

Table 2. Effect of moisture content and screen opening on measured physical and mechanical properties.

Experimental factors		Bulk density (Kg/m^3)	Angle of repose (°)	Coefficient of static friction on surfaces				Coefficient of internal friction	Cohesion (kPa)	Adhesion on polished steel (kPa)
				Plexiglass	Galvanized sheet	Rubber	Polished steel			
Screen opening (mm)	2.38	190.30 [a]	47.848[c]	0.376[c]	0.442[c]	0. 699[c]	0.271 [c]	0.679[c]	7.243[a]	1.069[a]
	3.36	185.15[b]	49.190[b]	0.388[b]	0.432[b]	0.726[b]	0.276 [b]	0.734[b]	6.148[b]	0.873[b]
	4.76	169.20[c]	51.191[a]	0.408[a]	0.408[a]	0.746[a]	0.285 [a]	0.831[a]	5.224[c]	0.617[c]
Moisture content (%)	8	172.601[c]	46.436[c]	0.315[c]	0.356[c]	0.629[c]	0.269 [c]	0.794[a]	5. 793[c]	1.379[a]
	9.3	180.448[b]	49.168[b]	0.364[b]	0. 398[b]	0.706[b]	0.274 [b]	0.759[b]	6.116[b]	0.884[b]
	11	191.61[a]	52.625[a]	0.493[a]	0.528[a]	0.836[a]	0.289 [a]	0.690[c]	6.705[a]	0.296[c]

Mean values with different letters for each factor are significantly different (LSD) at $P< 0.05$.

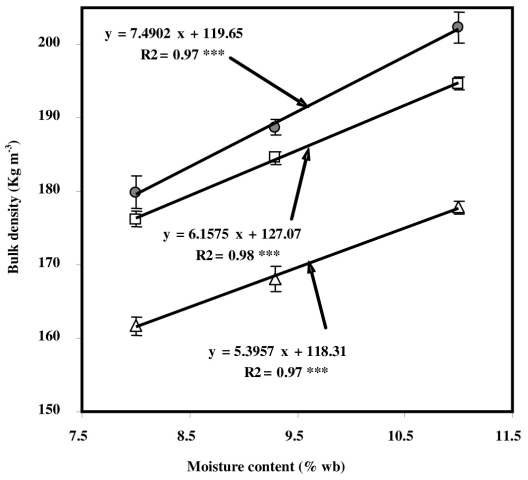

Figure 2. Effect of moisture content on bulk density: ● = 2.38 mm screen size; □ = 3.36 mm screen size; △ = 4.76 mm screen size; R^2 = Coefficient of determination; *** = Significant at confidence level of 0.1%, ‡ = The vertical bar on each point shows ± one standard deviation of the mean.

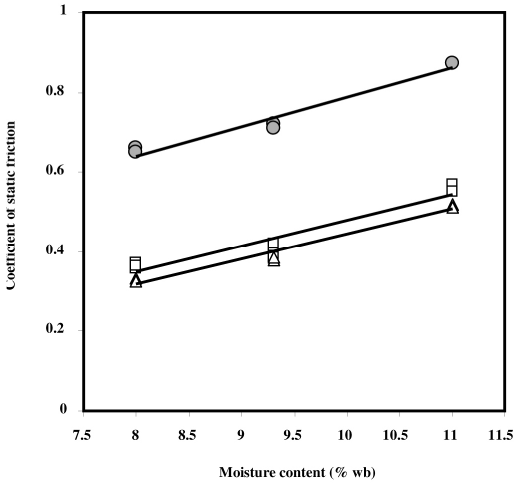

Figure 3. Effect of moisture content c coefficient of static friction of alfalfa ground wi hammer mill screen size of 4.76 mm: ● Rubber surface; □ = Galvanized iron surfac △ = Plexiglass surface.

Moisture content had a significant ($P < 0.001$) effect on the coefficient of static friction for all three sizes of grinds (Table 2). The relationships between the coefficient of static friction and moisture content of the alfalfa grind on the various surfaces are presented in Table 3. The relationship between the moisture content and the coefficient of static friction was linear for all screen sizes and surfaces. Figure 3 shows the effect of moisture content on coefficient of static friction for $SS_{4.76mm}$. Increase in coefficient of static friction with moisture content may be explained by the increase in adhesion between the grinds and the surface at higher moisture contents. The surface becomes stickier as the moisture content increases. Rubber showed the highest coefficient of friction followed by galvanized iron and Plexiglass. This might be due to the surface roughness, which is the largest in the case of rubber and the least for Plexiglass. Similar findings were reported for wheat (Tabatabaeefar, 2003), green wheat (Al-Mahasneh and Rababah, 2006) and Hungarian, Common Vetch Seeds (Faruck Taser *et al*., 2005) and sunflower seeds (Gupta and Das, 1997). The coefficient of static friction was found to increase with increase in particle size for all three moisture contents. At moisture contents of 8, 9.3 and 11%, the coefficient of

Table 3. Relationships between coefficient of static friction (μ_s) of alfalfa grind and moisture content (M_c, % wb).

	Hammer mill screen size (mm)		
Experimental surface	2.38	3.36	4.76
Rubber	$\mu_s = 0.065M_c + 0.083$ $R^2 = 0.96^{***}$	$\mu_s = 0.068M_c + 0.805$ $R^2 = 0.98^{***}$	$\mu_s = 0.074M_c + 0.047$ $R^2 = 0.96^{***}$
Galvanized iron	$\mu_s = 0.050M_c - 0.072$ $R^2 = 0.96^{***}$	$\mu_s = 0.058M_c - 0.118$ $R^2 = 0.95^{***}$	$\mu_s = 0.065M_c - 0.174$ $R^2 = 0.92^{***}$
Plexiglass	$\mu_s = 0.055M_c - 0.149$ $R^2 = 0.95^{***}$	$\mu_s = 0.061M_c - 0.188$ $R^2 = 0.96^{***}$	$\mu_s = 0.063M_c - 0.193$ $R^2 = 0.97^{***}$

***, Significant at confidence level of 0.1%.

static friction on rubber surface varied from 0.6 to 0.65, 0.69 to 0.71 and 0.79 to 0.87, respectively.

Angle of Repose

Comparison of means revealed a significant (P< 0.05) difference between the mean values of angle of repose (Θ) for the different moisture contents and hammer mill screen sizes (Table 2). Figure 4 exhibits a linear increase in angle of repose with increase in moisture content from 8 to 11% (wb). It was observed that with increase in moisture content from 8 to 11% (wb), the angle of repose of the grinds from $SS_{2.38mm}$, $SS_{3.36mm}$ and $SS_{4.76mm}$ increased from 45.1 to 50.7º, 46.4 to 52.5º and 47.7 to 54.3º, respectively. It seems that at higher moisture contents, the stickiness of the particle surfaces was increased and therefore, the easiness of the particles sliding on each other was confined. Similar results were found for ground marigold petals (Hauhouot-O'Hara *et al*., 2003), chickpea (Konak *et al*., 2002), cumin seed (Singh and Goswami, 1996) and cater seed (Dursun and Dursun, 2005).

The angle of repose (Θ) increased with increase in particle size. The cone formed by the material was higher for larger particle sizes *i.e*., angle of repose was greater for larger particle sizes. This occurs because larger particles tend to pile on top of each other instead of rolling as do the smaller particles. Hauhouot-O'Hara *et al*. (2003) also observed the increase in angle of repose with increase in particle size of the ground marigold petals. The variations of the angle of repose with particle size (S_G) and their R^2 are represented by the following relationships:

$\Theta=1.10\ S_G+42.61$; (R^2= 0.98^{***}) for moisture content of 8% (2)

$\Theta=1.59\ S_G+43.59$; (R^2= 0.96^{***}) for moisture content of 9.3% (3)

$\Theta=1.46\ S_G+47.42$; (R^2= 0.98^{***}) for moisture content of 11% (4)

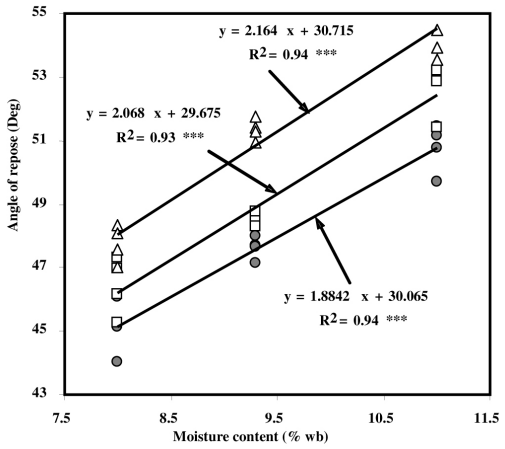

Figure 4. Variation of angle of repose (Θ) with moisture content for three screen sizes: ● = 2.38 mm screen size; □ = 3.36 mm screen size; △ = 4.76 mm screen size; R^2= Coefficient of determination, *** = Significant at confidence level of 0.1%.

In above equations Θ is angle of repose, (◦); *SG* is screen size (mm); R^2 is coefficient of determination in % and *** significant at confidence level of 0.1%.

Adhesion and Coefficient of Friction on Polished Steel

Results showed that moisture content and screen size had a significant (P< 0.05) effect on the coefficient of friction and adhesion such that with increasing moisture content, the coefficient of friction increased but adhesion decreased (Table 2). The coefficient of friction and adhesion for the grinds from the three screen sizes and three levels of moisture contents are given in Table 4. As the moisture content of the alfalfa grind increased, the coefficient of friction slightly increased. The coefficient of friction of alfalfa grind varied between 0.26 and 0.29. This result was in good agreement with the results reported by other researchers for alfalfa (Shinners *et al*., 1991; Afzalinia and Roberge, 2007) and corn stover grinds (Mani *et al.*, 2004b).

The adhesion for the grinds from $SS_{2.38mm}$ decreased from 1.54 to 0.41 when the

Table 4. Coefficients of friction (μ_s) and adhesion (C_a) of alfalfa grind as affected by moisture content.

Hammer mill screen size (mm)	Moisture content (% wb)					
	8		9.3		11	
	μ_s	C_a	μ_s	C_a	μ_s	C_a
2.38	0.26±0.01*	1.54±0.32	0.26±0.00	1.23±0.07	0.28±0.00	0.41±0.15
3.36	0.26±0.00	1.42±0.16	0.27±0.00	0.92±0.14	0.28±0.00	0.26±0.05
4.76	0.27±0.00	1.16±0.09	0.28±0.00	0.48±0.19	0.29±0.00	0.19±0.03

* Average±Standard deviation.

moisture content increased from 8 to 11%. The reduction could be related to the lubrication of the steel surface by water released from the moist alfalfa grind under pressure. However, Mani *et al*. (2004b) reported that moisture content had no significant effect on adhesion of corn stover grind. A typical relationship between shear strength and normal stress of the grinds from $SS_{2.38mm}$ at three levels of moisture contents is shown in Figure 5.

With increase in screen size from 2.38 to 4.76 mm, the adhesion of alfalfa grind decreased from 1.54 to 1.16 kPa at moisture content of 8% (wb), whereas the coefficient of friction increased from 0.26 to 0.27. The results show that moisture content had a higher effect than the particle size on adhesion. A typical trend of changes in adhesion and coefficient of friction with particle size at 9.3% moisture content is shown in Figure 6. As Figure 6 shows, contrary to adhesion, the coefficient of friction on polished plate increased with an increase in particle size.

Cohesion and Coefficient of Internal friction

Effects of moisture content and screen size on cohesion and coefficient of internal friction were significant (P< 0.05) (Table 2). The coefficient of internal friction and cohesion of alfalfa grind at different screen sizes and moisture contents are given in

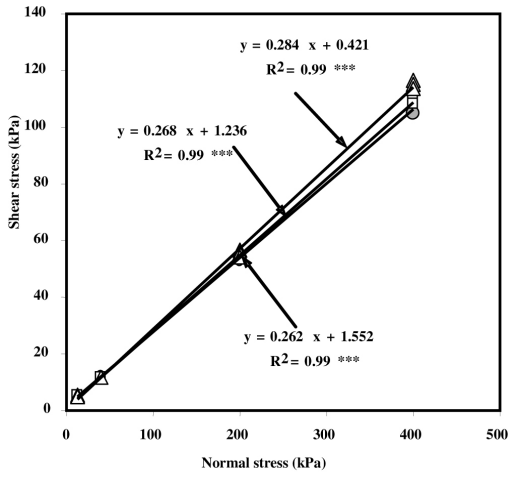

Figure 5. Relationship between normal stress and shear strength for alfalfa grind with screen size of 2.38 mm: ● = 8% (wb); □ = 9.3% (wb); △ = 11% (wb); R^2 = Coefficient of determination, *** = Significant at confidence level of 0.1%.

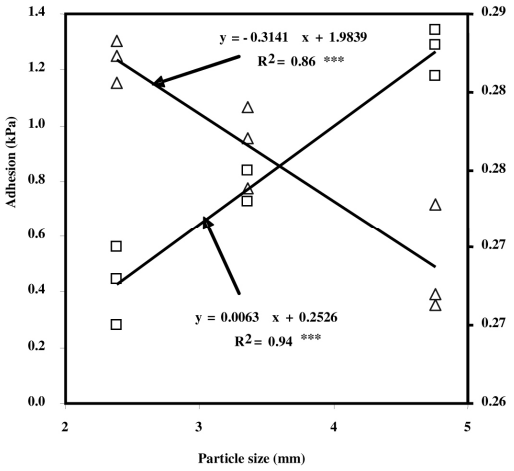

Figure 6. Trend of changes in adhesion a coefficient of friction on polished steel plate w particle size at moisture content of 9.3% (wb): □ Coefficient of static friction; △ = Adhesion; *R* Coefficient of determination, *** = Significant confidence level of 0.1%.

Table 5. Coefficients of internal friction (μ) and cohesion (C) of alfalfa grind as affected by moisture content.

Hammer mill screen size (mm)	Moisture content (% wb)					
	8		9.3		11	
	μ	C	μ	C	μ	C
2.38	0.71±0.01[a]	6.87±0.09	0.66±0.0	7.19±0.07	0.64±0.01	7.65±0.12
3.36	0.77±0.01	5.68±0.39	0.73±0.01	6.02±0.08	0.67±0.01	6.72±0.22
4.76	0.88±0.0	4.80±0.1	0.85±0.0	5.13±0.0	0.74±0.0	5.73±0.2

Table 5. Cohesion increased with increasing moisture content. For instance, the cohesion for $SS_{2.38mm}$ increased by 11.4% when the moisture content increased from 8 to 11% (wb). A typical relationship between shear strength and normal stress for three different screen sizes at moisture content of 9.3% (wb) is shown in Figure 7. Coefficient of internal friction decreased with an increase in moisture content for the three hammer mill screen sizes. The coefficient of internal friction decreased by 10% for $SS_{2.38mm}$ when moisture content increased from 8 to 11% (wb). Zou and Brusewitz (2001) reported a decrease in coefficient of internal friction of ground marigold petals with an increase in moisture content. Peleg and Mannheim (1973) suggested that the liquid layer formed on the powder surface due to moisture uptake acted as a lubricant when shear force was applied and thus decreased the coefficient of internal friction for powder sucrose.

The direction of changes in cohesion and coefficient of internal friction with moisture content for alfalfa grind with $SS_{2.38mm}$ is shown in Figure 8. Cohesion decreased with increasing screen size from 2.38 to 4.76 mm. The reduction of the cohesion at the larger screen size could be related to the reduction of contact area between the larger particles, resulting in a smaller specific surface area (surface area per unit volume). Tabil and Sokhansanj (1997) obtained values of cohesion for alfalfa grind at two sizes which were close to the results of this study.

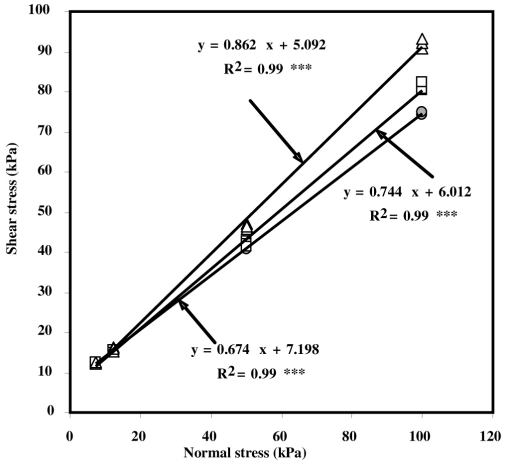

Figure 7. Relationship between normal stress and shear strength for moisture content of 9.3% (wb) for the first group of vertical loads: ●= 2.38 mm screen size; □= 3.36 mm screen size; △= 4.76 mm screen size; R^2= Coefficient of determination, ***= Significant at confidence level of 0.1%.

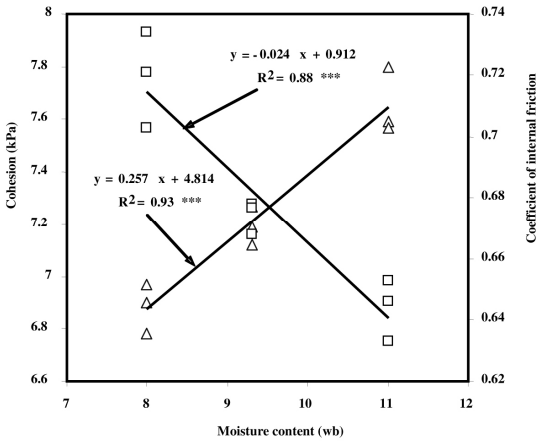

Figure 8. The direction of changes in cohesion and coefficient of internal friction with moisture content for alfalfa grind with 2.38 mm screen size: □= Coefficient of internal friction; △= Cohesion; R^2= Coefficient of determination, ***= Significant at confidence level of 0.1%.

The coefficient of internal friction was the highest for $SS_{4.76mm}$, followed by $SS_{3.36mm}$ and $SS_{2.38mm}$. This increase in coefficient of internal friction may be due to higher degree of packing.

The relationship between the shear strength and normal stress for $SS_{2.38mm}$ and $SS_{3.36mm}$ at the second group of vertical loads at moisture content of 9.3% is shown in Figure 9. With an increase in vertical load range, i.e., second group of loads, the cohesion of alfalfa grind for $SS_{2.38mm}$ and $SS_{3.36mm}$ increased from 7.2 to 33.4 and 6.0 to 27.5 kPa whereas the coefficient of internal friction decreased from 0.66 to 0.57 and 0.73 to 0.60, respectively. This results show that the strength parameters of the alfalfa grind are a function of normal load such that with increasing normal load the coefficient of internal friction decreased but cohesion increased.

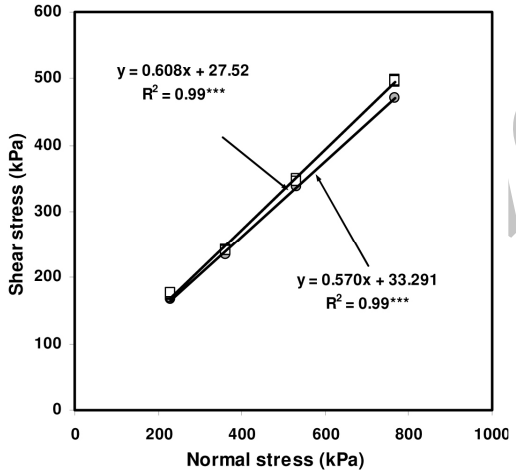

Figure 9. Relationship between normal stress and shear strength for alfalfa grind at the 9.3% moisture content for the second group of vertical loads: ● = 2.38 mm screen size; □ = 3.36 mm screen size; R^2= Coefficient of determination, *** = Significant at confidence level of 0.1%.

CONCLUSIONS

In this paper, physical and mechanical properties of alfalfa grind including bulk density, coefficient of static friction, filling angle of repose, cohesion, coefficient of internal friction, and adhesion to polished steel were investigated as a function of moisture content and grind size. Information on these characteristics are necessary in order to design equipment and machines for the transporting, handling, processing, drying and storing alfalfa grind. From the results of this investigation the following conclusions can be drawn:

As the moisture content increased from 8 to 11% (wb), the bulk density of alfalfa grind increased, whereas with increasing screen size from 2.38 to 4.76 mm the bulk density decreased.

For all screen sizes, as the moisture content increased, the filling angle of repose and coefficient of static friction increased linearly.

The highest static friction was observed on rubber surface and the lowest on Plexiglasss surface.

The angle of repose increased with increase in moisture content and particle size. The largest particles with the highest moisture content had the highest angle of repose (54.5°).

The coefficient of friction on polished steel increased from 0.26 to 0.29 when the moisture content increased from 8 to 11% whereas the adhesion of alfalfa grind decreased from 1.54 to 0.41 when the moisture content increased from 8 to 11% for screen size of 2.38 mm.

Samples with smaller particles at higher moisture content had the highest cohesion (7.65 kPa) and the lowest coefficient of internal friction (0.64).

Nomenclature

C cohesion, (kPa)
C_a adhesion, (kPa)
d_{gw} geometric mean diameter or median size of particle by mass (mm)
M_c moisture content, % wb
R^2 coefficient of determination
S_G screen size (mm)
S_{gw} geometric standard deviation of

particle diameter by mass (mm)
θ angle of repose, (°)
σ normal stress, (kPa)
τ shear stress, (kPa)
μ coefficient of internal friction
μ_s coefficient of static friction

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خصوصیات فیزیکی و مکانیکی یونجه آسیاب شده تحت تاثیر اندازه ذره و محتوای رطوبتی

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چکیده

اطلاع از خصوصیات فیزیکی و مکانیکی یونجه (*Medicago sativa, L.*)آسیاب شده در طراحی تجهیزاتی که در انتقال، فرآوری و انبارداری این محصول به کار می‌روند، ضروری است. در این تحقیق تأثیر سه درجه آسیاب شدگی (۲/۳۸، ۳/۳۶ و ۴/۷۶ میلی‌متر) در سه سطح رطوبتی (۸، ۹/۳ و ۱۱٪ بر مبنای وزن تر) بر برخی از خواص فیزیکی و مکانیکی یونجه آسیاب شده تعیین گردید. خواص اندازه‌گیری شده عبارت بودند از: میانگین قطر هندسی، چگالی ظاهری، ضریب اصطکاک استاتیکی (بر روی ورق گالوانیزه، پلکسی‌گلاس، لاستیک و فولاد صیقلی)، زاویه‌ی پایداری (پرشدگی)و ضریب اصطکاک داخلی، چسبندگی و دگرچسبی بر روی سطح فولاد صیقلی. چگالی ظاهری از ۱۶۱/۶ تا ۲۰۲/۲ کیلوگرم بر متر مکعب متغیر بود. ضریب اصطکاک استاتیکی از ۰/۲۶ بر سطح فولاد صیقلی تا ۰/۸۷ بر سطح لاستیک متغیر بود. ذرات بزرگتر با محتوای رطوبتی بالاتر بیشترین زاویه پایداری (۵۴/۵ درجه) را دارا بودند. ضریب اصطکاک داخلی از ۰/۶۴ تا ۰/۸۸ متغیر بود. یونجه آسیاب شده با توری به قطر روزنه ۲/۳۸ میلی متر در محتوای رطوبتی ۱۱ ٪ و با توری به قطر روزنه ۴/۷۶ میلی متر در محتوای رطوبتی ۸٪ به ترتیب بیشترین و کمترین چسبندگی (۷/۶۵ و ۴/۸۰ کیلوپاسکال) را به خود اختصاص داده بودند. دگرچسبی بر سطح فولاد صیقلی از ۰/۱۹ تا ۱/۵۴ کیلوپاسکال متغیر بود.