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Principal component modeling of energy consumption and some physical-mechanical properties of alfalfa grind

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Abstract

The objectives of this study were determining the relationships between physical (bulk density) and mechanical properties (cohesion, coefficient of internal friction, adhesion and coefficient of external friction) and their effects on specific energy consumption for alfalfa grind. Alfalfa chops were ground using a hammer mill with three screen sizes of 2.38, 3.36 and 4.76 mm at moisture content of 8% (w.b.) and passed through sieve sizes of 18, 15 and 12 mm. The energy consumption during grinding in hammer mill was measured with a watt-hour meter. According to the correlation coefficients (Pearson's matrix), it was found that all the physical and mechanical properties significantly ($P<0.001$) correlated with together. Coefficient of internal friction and coefficient of external friction on polished steel was negatively (-0.84 and -0.59 respectively) correlated with the specific energy consumption. The highest correlation coefficient (0.99) was observed between bulk density and coefficient of internal friction. Principle component analysis identified one component which explained 78% of the total variation among physical and mechanical properties.

Keywords: alfalfa grind, internal friction, physical properties, modeling, specific energy

Abbreviations:
C= cohesion, (kPa)
C_a = adhesion, (kPa)
d_{gw} = geometric mean of particle diameter (mm)
E_{sc} = specific energy consumption (kJ/kg)
GMD= geometric mean diameter
GML= geometric mean length
MSE = mean square error
N = force unit (Newton)
τ = shear stress (kPa)
PCA = principal component analysis
R^2 = coefficient of determination
r = coefficient of correlation
S_{gw}= geometric standard deviation of particle diameter by mass (mm)
SS = screen size (mm)
w.b. = wet basis (%)
μ = coefficient of internal friction
μ_s = coefficient of static friction
σ = normal stress (kPa)

Introduction

Alfalfa (*Medicago sativa, L.*) contains digestible fibers and useful range of minerals, vitamins and protein in animal feed (Haiqing, 2004). Alfalfa leaves are high in protein and carotenoids, low in fiber and are useful to feed mono-gastric animals such as poultry and swine or as a protein supplement for ruminant ration. Fiber of alfalfa stems are high and can be used for paper production, ruminant feed, hardboard, and energy production (biofuel/ethanol) (Adapa et al., 2007). Physical and mechanical properties of alfalfa grind are required for optimum design of equipments which are being used in transporting, processing and storage. Measuring the energy requirement for reduction of alfalfa size would be useful in developing the strategies to reduce input energy in process of converting to bio-energy. Particle size, shape, true density, bulk density, moisture content of particles after grinding are important for downstream processing (Manlu et al., 2006). Tabil (1996) obtained consumption of specific energy for alfalfa pellet mill at two hammer mill screen sizes of 2.4 and 3.2 mm using a watt-hour meter with a data logger attachment and sampling time of 15 s. Specific energy consumption of grinding material depends on moisture content, bulk and particle densities, feed rate of the material, particle size distribution (initial/final particle size) and machine variables (Lopo, 2002). Several models such as Kick (Henderson and Perry, 1970), Rittinger (Henderson and Perry, 1970) and Bond (Bond, 1961) have been used to predict the required specific energy consumption for grinding agricultural materials. They explained that size reduction process depends on initial and new surface area. Energy consumption of alfalfa grind may be depends on physical and mechanical properties of biomass, bulk density, cohesion and coefficient of internal friction. Geometric mean diameter and particle size distribution of biomass grind are important factors affecting on binding characteristics. These factors also