Effects of moisture change on the physical and thermal properties of sericea lespedeza pellets

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Abstract: The bulk density, unit density, porosity, hardness, gross calorific value, thermal conductivity, thermal diffusivity, and specific heat at different moisture content were determined for sericea lespedeza (SL, *Lespedeza cuneata*) pellets. It was observed that most physical properties of the SL pellets were significantly affected by moisture contents varying from 7.26% to 15.55% wet mass basis (w.b.). The maximum values of bulk density and unit densities were 547.72 and 1101.74 kg/m^3, respectively. At higher moisture content (m.c.), there was a decrease in pellet hardness from 196.64 N at 7.26% m.c. to 68.76 N at 15.55% m.c. Gross calorific value decreased with increase in moisture content from 18.02 MJ/kg at 7.26% m.c. to 16.54 MJ/kg at 15.55% m.c. Over a moisture range of 7.26% to 15.55%, thermal conductivities, thermal diffusivities, and specific heats of the SL pellets were in the range of 0.030 to 0.033 W m^{-1} ℃$^{-1}$, 2.02×10^{-7} m^2/s to 2.18×10^{-7} m^2/s, and 260.14 kJ/kg ℃ to 314.85 kJ/kg ℃, respectively. The thermal conductivity and thermal diffusivity values of SL pellets were not significantly affected by change in moisture content.

Keywords: Sericea lespedeza, bulk density, hardness, pellets, physical properties, thermal properties

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1 Introduction

Gastrointestinal nematode (GIN) parasitism is the greatest threat to sheep and goat production in the southern USA. There is widespread prevalence of GIN resistance to broad-spectrum anthelmintics in this region (Terrill et al., 2009). A natural alternative for controlling GIN in small ruminants is feeding hay of sericea lespedeza [SL, *Lespedeza cuneata* (Dum.-Cours., G. Don)]. SL is a low-input forage crop for the southeastern USA because of its tolerance to drought and soil acidity (Terrill et al., 1994). Feeding SL hay that contains high level of condensed tannins to sheep and goats has reduced GIN fecal egg count (FEC) and worm numbers in the abomasums and small intestines (Terrill et al., 2007). Shaik et al. (2006) observed an 80% reduction in FEC in goats fed SL hay compared with a bermudagrass hay diet. Furthermore, it has been reported that pelleting SL hay enhanced its efficiency against parasitic nematodes (Terrill et al., 2007).

Some of the challenges of feeding hay to livestock in long form or as ground material are feed wastage, difficulty in mixing with other ration ingredients, cost, and difficulty of transport and storage (Terrill et al., 2007). Since pellets have better flow properties, densification into pellets can reduce material wastage and improve ease of transporting and storage (Adapa et al., 2006). For the proper design and selection of storage, handling and transportation systems, the physical and thermal properties of pellets have to be determined (Colley et al., 2006; White and Jayas, 2001).

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Setting up a pellet mill to make feed pellets is too expensive for the average producer, so they normally purchase pelleted feeds from a feed mill. The economics of making, transporting, and storing hay can be higher or lower than feeding pellets, based upon many factors. The equipment needed for cutting, curing, and baling hay is expensive, and many small farmers do not have the barn space to store hay properly. Advantages of pellets are easier storage and feeding (less dust, less wastage, lower labor costs) and more precise control over the desired ration for individual animals or groups of animals with greater nutritional needs, such as immature stock or lactating females. In higher humidity areas, hay wastage can be extreme, and feeding pellets are often more profitable. How much cost difference there is depends upon all of the factors described and will vary greatly from region to region, as well as on individual farms.

Extended stability of pelleted animal feed depends on effective cooling and drying immediately following the pelleting operations. For safe storage it is desirable to reduce pellet temperatures close to ambient as possible and less than 12% (w. b.) moisture content (Ray et al., 2003). This process improves pellet durability and reduces the possibility of spoilage from mold, so consequently sticking in bins will be prevented and breakage and crumbling during handling and transportation will be minimized (Ray et al., 2003). Heat and mass transfer characteristics of pellets are needed in the optimization of coolers for freshly made pellets and in managing storage schedules of pellets in silos and bins. Thermal properties are important parameters used to characterize the heat and mass transfer abilities of a material (Fasina and Sokhansanj, 1996). The determination of thermal properties of pellets may help in the modeling, designing or selecting of appropriate equipment for drying or cooling of pellets (Opoku et al., 2006).

In the recent years, physical and thermal properties have been studied for various pellets such as alfalfa (Adapa et al., 2004 and 2006; Fasina and Sokhansanj, 1993 and 1996), switchgrass (Colley et al., 2006), peanut hulls (Fasina, 2007), poultry litter (McMullen et al., 2004), corn-soybean (Parsons et al, 2006), canola (Opoku et al., 2007; White and Jayas, 2001) and sunflower meal (White and Jayas, 2001). However, no information is available in the literature about physical and thermal properties of SL pellets. This study was therefore carried out to determine: (a) physical properties (bulk density, unit density, porosity and hardness); and (b) thermal properties (thermal conductivities, thermal diffusivities, specific heat and gross calorific values) of SL pellets at different moisture contents.

2 Materials and methods

SL pellets were manufactured at the Georgia Small Ruminant Research and Extension Center, Fort Valley State University, Fort Valley, GA., using a laboratory pellet mill (Series CL, California Pellet Mill Co., Crawfordsville, IN). Table 1 shows the composition of the pellets.

Table 1 Composition of sericea lespedeza pellets

Composition ingredients	Percentage (w/w, dry matter basis)
Sericea lespedeza leaf meal	75
Ground corn	14
Soybean meal	6
Molasses, dry	4
Trace mineralized salt	0.5
Vitamin premixed	0.5

2.1 Moisture content determination and adjustment

The evaluation of the effect of moisture content on the physical and thermal properties of SL pellets was carried out at five moisture levels (7.26%, 8.32%, 11.01%, 12.91%, and 15.55%). All the moisture contents were measured on a wet mass basis (w.b.). The pellets had an initial moisture content of 11.01%. For the lower moisture contents (7.26% and 8.32%), the pellets were dried at 70℃ in an incubator for about 45 min to 1½ h (Opoku et al., 2006). For the higher moisture contents (12.91 and 15.55%), the pellets were conditioned by adding predetermined amounts of distilled water onto the sample (White and Jayas, 2001). The amount of distilled water to be added was calculated as shown in Eq. (1) (Coşkun, Yalçin and Özarslan, 2005):

$$Q = W_i (M_f - M_i)/(100 - M_f) \quad (1)$$

Where, Q is the mass of distilled water added, kg; W_i is the initial mass of the pellets, kg; M_i is the initial moisture content of the pellets in % (d.b.); M_f is the final moisture content of the pellets (d.b.).

The pellets were then transferred to separate Ziploc® bags (S.C. Johnson Co., Racine, WI) and sealed tightly. The Ziploc bags were kept at 4℃ in a refrigerator for 24 h to enable the moisture to be distributed uniformly throughout the pellets (Tavakoli, Rajabipour and Mohtasebi, 2009). Before measuring the moisture, the pellets in Ziploc bags were allowed to reach thermal equilibrium with room temperature (Adapa et al., 2006). The moisture contents of the samples were determined in quintuplicate by drying 5 g samples in an air convection oven (Cole Parmer, Vernon Hills, IL) at (103±1) ℃ for 24 h. The initial and final masses were measured using a digital balance (0.0001 resolution; model A-250, Denver Instruments, Denver, CO). The moisture content of the pellets on w.b. was calculated from the initial and the final masses. All the physical and thermal properties of the pellets were assessed at moisture levels as stated above.

Production of high quality pellets is possible only if the moisture content of the feed is between 8% and 12% (w.b.). Moisture content above and below this range may lead to lower quality pellets (Kaliyan and Morey, 2006). An optimum moisture content of 8% to 9% (w.b.) has been suggested for producing alfalfa pellets. It has also been reported that pellet-mill dies tend to choke when the moisture content of the conditioned feed mash is 16% to 18% (w.b.). The excess heat and moisture should be removed from the pellet for safe storage. In general, the final moisture content of the pellets should be less than 13% (w.b.) for safe storage (Kaliyan and Morey, 2006).

2.2 Evaluation of pellet dimensions

The pellets were cylindrical in shape. In order to determine dimensions and unit mass, fifty SL pellets were randomly selected at each moisture level. Linear dimensions, namely, length and diameter were measured using a vernier caliper (Fowler Tools and Instruments, Newton, MA). To obtain unit mass, each pellet was weighed using a precision digital balance (0.0001 resolution; model A-250, Denver Instruments, Denver, CO).

2.3 Evaluation of bulk properties

2.3.1 Bulk density

Bulk densities were calculated as the ratio of the masses of samples to the volume of the container. The material was leveled with the top surface of the container and weighed. Pellet bulk density (ρ_b) was obtained from the ratio of measured mass of the sample in the container to the volume of the container (Colley et al., 2006). Bulk density of SL leaf meal was also measured.

2.3.2 Unit density

Densities of individual pellets were determined by weighing the individual pellets and calculating the volumes from their linear dimensions (Adapa et al., 2006; McMullen et al., 2004) as per the following equations:

$$V_u = \pi/4 d^2 L \tag{2}$$

$$\rho_u = m_u/V_u \tag{3}$$

Where, V_u is the volume of individual pellet, mm^3; d is the diameter of pellet, mm; L is the length of pellet, mm; ρ_u is the unit density, g/mm^3; m_u is the mass of individual pellet, g.

2.3.3 Porosity

Porosity can be defined as the percentage of total container volume occupied by air spaces when pellets are placed in a container. From the measured bulk density and calculated unit density, the porosity (ε) was calculated using the following mathematical equation (Colley et al., 2006; Ray et al., 2003):

$$\varepsilon = 1 - \rho_b/\rho_u \tag{4}$$

Where, ρ_b and ρ_u are bulk density and unit density of pellets, kg/m^3, respectively.

2.4 Evaluation of hardness

Hardness represents the rigidity of pellets and may be expressed in terms of firmness. Hardness can also be related to the chewability or palatability of pellets (Adapa et al., 2006). The hardness of SL pellets was determined using a TA-XT2i texture analyzer (Stable Micro Systems, Scarsdale, NY). Fifty randomly selected pellets from each moisture level were used in this test. A single pellet was placed on the platform of the texture analyzer in its natural position (Colley et al., 2006) and was compressed with a crosshead speed of 2 mm/s. The compression strain was set at 25%. The maximum force was taken as a measure of pellet hardness. Compressive resistance test simulates the crushing (i.e. chewing) of feed pellets between animal teeth (Kaliyan and Morey, 2006).

2.5 Evaluation of thermal properties

2.5.1 Gross calorific values

Calorific value is the amount of energy per unit mass released upon complete combustion (Llorente and Garcia, 2008). It is obvious that digestible energy is not equivalent to combustible energy of SL pellets. However, calorific values are used to compare the nutritional value of the pellets. The IKA C2000 calorimeter system (IKA Works, Inc., Wilmington, NC) was used to determine the gross calorific values of pellets. About 0.5 g of pellet was introduced in the bomb, which had a volume of 210 mL and was charged slowly with pure oxygen (>99.95 vol. %, quality 3.5) to a pressure of 3.0±0.2 MPa without displacing the original air (Llorente and Garcia, 2008).

2.5.2 Thermal conductivity, thermal diffusivity and specific heat

The thermal properties were determined by using the KD2 thermal properties analyzer (Decagon Devices, Inc., Pullman, WA). The thermal properties analyzer has a needle length of 60 mm and diameter of 0.9 mm. Its accuracy of measuring thermal conductivity is 5% and that of thermal diffusivity is 10%. Fifteen replications were conducted at each moisture content. Specific heat was calculated by using Eq. (5):

$$\alpha = k/(\rho C_p) \quad (5)$$

Where, α is thermal diffusivity, m^2/s; k is thermal conductivity, W/m ℃; ρ is bulk density, kg/m^3; C_p is specific heat of pellets, kJ/kg ℃.

2.6 Data analysis

Data were analyzed using the general linear models (GLM) procedures of the Statistical Analysis System version 9.1 (SAS, 2003). The differences were considered significant at $p < 0.05$.

3 Results and discussion

3.1 Pellet dimensions

Measured linear dimensions and unit mass of SL pellets are presented in Table 2. The data presented are the mean of measurements made on 50 pellets at each moisture level. The mean length of pellets ranged between 25.06 and 27.93 mm. Colley et al. (2006) observed a slight initial increase in the average length of switchgrass pellets when the m.c. was increased from 6.3% to 8.6%. But further increase in m.c. to 11.0%, 14.8%, and 17.0%, respectively reduced the average length of the switch grass pellets. The diameter of SL pellets ranged between 4.92 and 4.96 mm and showed an increase in diameter with increase in moisture content (Figure 1). The change in dimension of the pellets could be due to water filling the void spaces of the pellets and disrupting bonds formed during the pelletization process.

Table 2 Dimensional properties and unit mass of SL pellets

Moisture content /% w.b.	Length ± S.D. /mm	Diameter ± S.D. /mm	Mass ± S.D. /g
7.26	26.75 ± 2.99[ab]	4.92 ± 0.04[a]	0.55 ± 0.07[ad]
8.32	26.59 ± 3.39[ab]	4.93 ± 0.05[ab]	0.56 ± 0.73[ab]
11.01	27.93 ± 2.66[a]	4.95 ± 0.06[c]	0.58 ± 0.06[bc]
12.91	25.78 ± 2.92[bc]	4.94 ± 0.05[bc]	0.54 ± 0.07[ad]
15.55	25.06 ± 3.58[c]	4.96 ± 0.05[c]	0.58 ± 0.09[d]

Note: Means in the same column sharing a common letter(s) are not significantly different at $p = 0.05$.

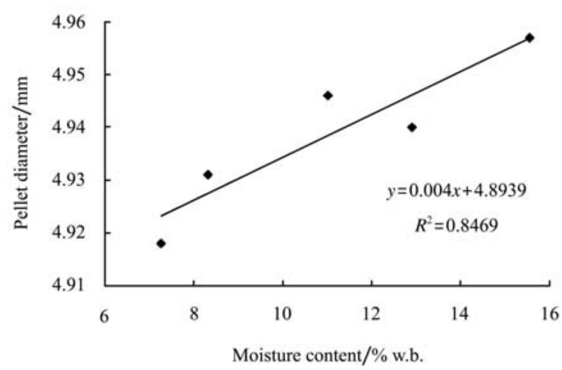

Figure 1 Effect of moisture content on SL pellet diameter

3.2 Bulk properties

Bulk properties presented represent the mean of five measurements. The bulk density of ground SL leaf meal was 153.89 kg/m^3. Bulk density of SL pellets ranged from 547.72 kg/m^3 at 7.26% moisture content to 451.61 kg/m^3 at 15.55% moisture content (Figure 2). Bulk density of the pellets decreased with the increase in moisture content and there were significant differences between moisture contents in terms of bulk density (p<0.05) except between 11.01% and 12.91%.

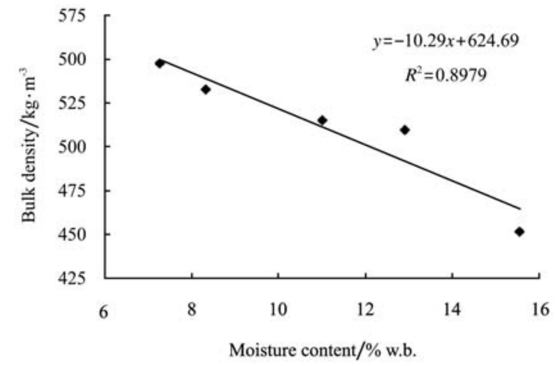

Figure 2 Effect of moisture content on bulk density of SL pellets

The decrease was due to the expansion of the pellets, thus resulting in increase in the volume of the pellets. Pelleting therefore reduced the amount of storage space by three fold. Fasina (2007) reported a four-fold reduction of storage space due to the pelletization of peanut hulls.

White and Jayas (2001) reported that increasing moisture content had no significant effect on bulk density of canola meal pellets; however, they reported that an increase in moisture content did lower the bulk density in the case of sunflower meal pellets. Fasina and Sokhansanj (1993) reported a bulk density range of 578.3 to 643.2 kg/m^3 for dehydrated alfalfa pellets with a diameter of 6.4 mm. The bulk density of canola meal pellets with a diameter of 8.0 mm ranged from 554.8 to 670.9 kg/m^3 (White and Jayas, 2001).

Unit density of the SL pellets ranged from 1,074.96 to 1,101.74 kg/m^3 but did not show any particular trend. There were no significant differences between moisture contents in terms of unit density (p>0.05). The porosity of the SL pellets ranged from 0.49 to 0.58 and increased with the increase in moisture content (Figure 3). There

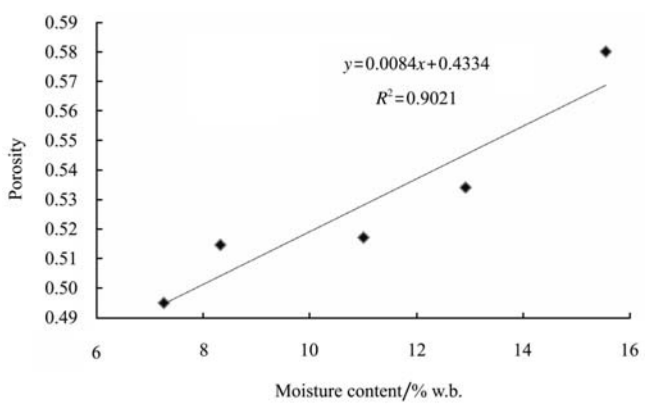

Figure 3 Effect of moisture content on the porosity of SL pellets

were significant differences between moisture contents in terms of porosity (p<0.05) except between the 8.32% and 11.01% moisture contents.

3.3 Pellet hardness

Pellet hardness varied from 196.64 N at 7.26% moisture content to 68.76 N at 15.55%. Similar to bulk density, pellet hardness decreased with the increase in moisture content (Figure 4). There were significant differences between moisture contents in terms of pellet hardness (p<0.05). Absorbed moisture weakened the bonds holding the pellet particles together.

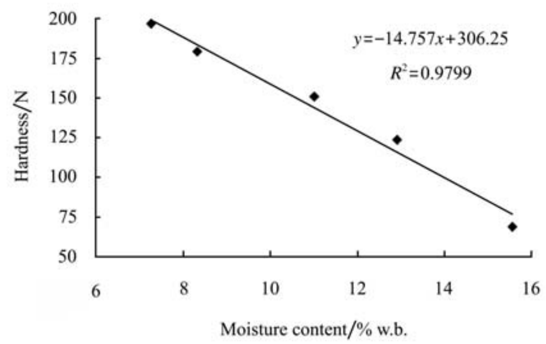

Figure 4 Effect of moisture content on SL pellet hardness

Adapa et al. (2004) reported the hardness of dehydrated alfalfa pellets as 651 N for alfalfa leaf content of 75%. The hardness of ground canola feed blend pellets varied from 368.6 to 511.0 N in the moisture range of 11 to 12% w.b. (Opoku et al., 2007). The force required to rupture switchgrass pellets varied from 32 N at 6.3% moisture content to 22 N at 17.4% moisture content (Colley et al., 2006). McMullen et al. (2004) reported similar results for pellets produced from poultry litter. Hardness and bulk density of pellets decreased with increasing moisture content. In contrast, Adapa et al. (2006) reported that higher moisture content gave significantly higher hardness values in the case of fractionated alfalfa grinds. Parsons et al. (2006) used a TA-HDi texture analyzer with a Warner-Bratzler blade to determine breaking force of pelleted poultry feed (corn-soybean based diet). The authors reported that the breaking force ranged between 1,162.45 to 1,856.4 g (16.3 to 18.21 N).

3.4 Thermal properties

3.4.1 Gross calorific values

The gross calorific value of SL pellets varied from

18.02 MJ/kg at 7.26% moisture content to 16.54 MJ/kg at 15.55% moisture content (Figure 5). The decrease in gross calorific value of pellets at higher moisture content was due to the fact that more heat energy was used to evaporate the water in these pellets. Increasing moisture content had a significant effect on gross calorific values (p<0.05) except between moisture contents of 7.26% and 8.32%.

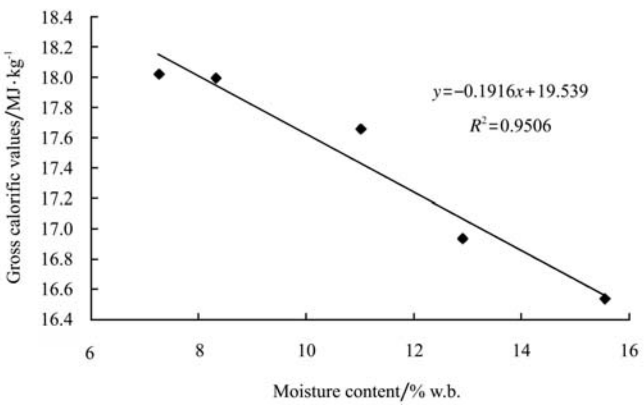

Figure 5 Effect of moisture content on SL gross calorific values

3.4.2 Thermal conductivity, thermal diffusivity and specific heat

Table 3 shows the thermal properties of SL pellets determined with the KD2 thermal properties analyzer (Decagon Devices, Inc., Pullman, WA).

Table 3 Thermal properties of SL pellets

Moisture content /% w.b.	Thermal conductivity ± S.D. /W · m^{-1} ℃	Thermal diffusivity± S.D. /mm^2 · s^{-1}	Calculated specific heat capacity ± S.D. /J · kg^{-1} ℃
7.26	0.031 ± 0.003^a	0.217 ± 0.015^a	260.14 ± 41.01^a
8.32	0.030 ± 0.000^a	0.214 ± 0.013^a	264.38 ± 16.32^a
11.01	0.033 ± 0.004^a	0.202 ± 0.015^b	314.84 ± 52.15^b
12.91	0.032 ± 0.004^a	0.208 ± 0.016^{ab}	305.98 ± 64.53^b
15.55	0.031 ± 0.003^a	0.218 ± 0.017^a	314.85 ± 52.77^b

Note: Means in the same column sharing a common letter(s) are not significantly different at p = 0.05.

The thermal conductivity values of the SL pellets ranged from 0.030 to 0.033 W/m ℃. There was no statistical difference between the mean thermal conductivity values measured at five moisture levels (p>0.05). Opoku (2006) reported that the thermal conductivity of timothy hay varied from 0.028 W/m^{-1} ℃$^{-1}$ at 7.7% moisture content to 0.061 W/m^{-1} ℃$^{-1}$ at 17.7% moisture content (w.b.). Fasina and Sokhansanj (1996) reported that over a temperature range of 2 to 110℃, estimated particle thermal conductivities of alfalfa pellets varied from 0.04 to 0.19 W/m ℃.

The mean thermal diffusivities ranged from 2.02× 10^{-7} m^2/s to 2.18×10^{-7} m^2/s. Similarly, the mean thermal diffusivity did not differ significantly at the 5% level. Opoku (2006) reported that thermal diffusivity of timothy hay showed little or no association between moisture contents. The mean specific heat values of SL pellets ranged from 260.14 kJ/kg ℃ to 314.85 kJ/kg ℃.

4 Conclusions

It can be concluded from this study that moisture content significantly affects the physical characteristics of SL pellets. Pelleting increased the bulk density of the SL by three fold, thus reducing the amount of space required for transportation and storage. Increasing moisture content slightly increased the diameter of the pellets. Porosity was increased by 17%. Hardness was decreased by 186%. There is a need to determine the optimum moisture content and hardness levels for SL pellets.

There were no significant differences between moisture contents in terms of thermal conductivity and thermal diffusivity. The moisture content of SL pellets has a greater affect on the physical properties than on the thermal properties (thermal conductivity and thermal diffusivity). The gross calorific value was decreased by 8.2%.

Pelleting SL hay could potentially increase the utility of this leguminous forage as a natural deworming agent for small ruminants. Pelleting could also add value by increasing its flexibility for feeding. Densification of SL into pellets could reduce costs and problems with handling, transportation, and storage. This research represents an initial stage in value-added product development using SL and could provide guidelines for animal scientists and pellet manufacturers about the role of moisture content on SL pellet physical and thermal properties.

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