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Selected Physical Properties of Jointed Goatgrass (*Aegilops cylindrica Host.*)

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Abstract. *Selected physical properties of jointed goatgrass samples collected in western Nebraska and eastern Colorado were determined. Measured properties were spikelet dimensions (length 10.8 ± 0.35 mm; width 2.59 ± 0.25 mm), particle density (0.761 ± 0.016 g/m^3), bulk density (351 ± 26.9 kg/m^3), terminal velocity (301 ± 25.9 m/min), angle of repose (26.3 ± 0.286°), internal coefficient of friction (0.494 ± 0.007), and equilibrium moisture contents at 10% RH (6.56 ± 1.03% w.b.), 30% RH (7.43 ± 1.21% w.b.), 50% RH (9.01 ± 0.67% w.b.), 70% RH (11.89 ± 0.61% w.b.), and 90% RH (20.39 ± 2.38% w.b.). Jointed goatgrass had substantially lower particle density and bulk density values than those reported in the literature for hard red winter wheat.* **Keywords.** *Jointed goatgrass, Properties, Physical, Wheat.*

Jointed goatgrass (*Aegilops cylindrica Host.*), though originating in Asia, exists abundantly in grain fields in the Great Plains and Pacific Northwest regions of the United States (Lyon et al., 1994). It contaminates fields and crops, most typically winter wheat. This contamination adversely affects grain yields, products and profits.

Spikelets of jointed goatgrass are cylindrical in shape and approximately 10 mm long, with a diameter of about 3 mm (fig. 1). Jointed goatgrass is nearly identical in appearance to wheat except for the difference in the spikes of the plants. Stalks, which support seed spikelets, are long and slender with simple and alternate leaves. The spikelets are joined together end-to-end at the top of the stalk. Auricles extend from the base of the leaf blade which can be smooth or hairy. The seeds of jointed goatgrass ripen before those of winter wheat and they, along with the spikelets, are difficult to remove from winter wheat (Wicks et al., 1984).

As a winter annual weed, jointed goatgrass causes economic loss in winter wheat. Winter wheat fallow production regions of the Great Plains and Pacific Northwest are the most likely to be affected. Studies and surveys in Nebraska, Colorado, Oregon, New Mexico, Oklahoma, and Utah have found jointed goatgrass contamination in winter wheat samples ranging from 1 to 61% of samples. (Lyon et al., 1994; Donald and Ogg, 1991; Elmore, 1988; Willis et al., 1998; Mitich and Kyser, 1987).

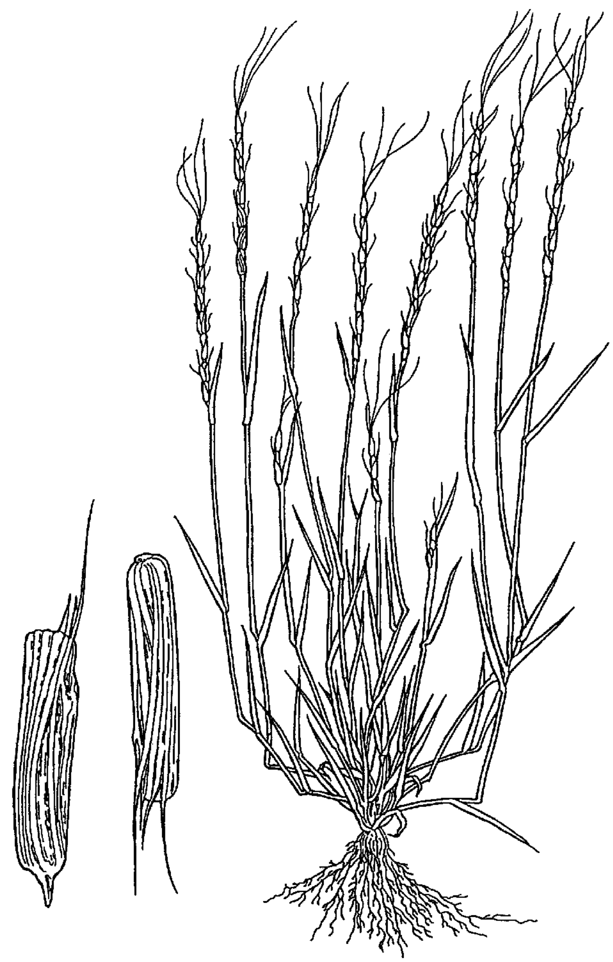

Figure 1–Two typical jointed goatgrass seeds (spikelets) on left expanded in view from jointed goatgrass plant on right (USDA-ARS 1970).

Field competition studies have noted losses in winter wheat yields of 25 to 29% due to jointed goatgrass (Rydrych, 1983). Information about the physical properties of jointed goatgrass is needed to design a feasible method for either sterilizing jointed goatgrass seeds and spikelets, or

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separating them from grain at harvest or before processing. If jointed goatgrass has potential as a feed crop, reference data are needed to explore the processing possibilities. References on physical properties of jointed goatgrass have not been found. The objective of this study was to determine selected physical properties of jointed goatgrass, namely spikelet dimensions, particle density, bulk density, terminal velocity, angle of repose, internal coefficient of friction, and equilibrium moisture contents.

Methods and Results

Jointed goatgrass spikelet samples from western Nebraska and eastern Colorado were collected, stored and used in this experiment. The samples were hand-separated from winter wheat grain. After collection, the samples were sealed in plastic bags and stored at a 50% relative humidity (RH) and 25°C for one month before testing. Jointed goatgrass samples were tested to determine values for particle density, bulk density, terminal velocity, angle of repose, and internal coefficient of friction. All these properties were measured at a moisture content (m.c.) of 9% (w.b.). Spikelet dimensions and equilibrium moisture contents at 10,30, 50, 70, and 90% RH were measured as well.

Spikelet Dimensions

Jointed goatgrass spikelets were long, cylindrical-shaped particles. As such, each spikelet had an obvious major dimension (length) but no clear intermediate or minor dimension since the diameter of a cylinder was approximately the same no matter which axis was measured. Therefore, intermediate and minor dimensions were treated as interchangeable. Calipers were used to measure length and diameter of each of 250 jointed goatgrass spikelets. Mean values for length and diameter were determined to give an estimate of average goatgrass spikelet size.

Spikelet Dimensions — Results and Discussion. Jointed goatgrass spikelets were on average 10.78 mm long with a mean diameter of 2.59 mm. Reportedly, wheat kernels, long and slightly cylindrical but more square in shape than jointed goatgrass spikelets, were 7.32 mm long, with a major diameter of 2.97 mm and a minor diameter of 2.82 mm (Mohsenin, 1986). Jointed goatgrass and wheat particles differed in size with jointed goatgrass spikelets being longer and slightly more narrow than wheat. Differences in shape make possible separation by sieving or a similar method. However, the values are probably too similar to accurately allow for high speed separation of the two particle types. A sieve created to separate the smaller jointed goatgrass spikelets from the wider wheat kernels would most likely allow unacceptable levels of wheat kernels through as well.

Particle Density

Two methods, one utilizing 95% ethanol displacement and the other using a helium pycnometer, were used to determine particle density of jointed goatgrass samples. The first method, displacement of 95% ethanol, was similar to the method described in Mohsenin (1986) for determining particle density of fruits. Density of the 95% ethanol used in the experiment was 0.785 g/cm^3. Previously recorded particle mass was divided by the volume of ethanol displaced by the submerged jointed goatgrass particle, which gave particle density of jointed goatgrass. The volume of spikelets was determined by:

$$V_s = (M_f - M_o)/\rho_l \quad (1)$$

where V_s was the volume of the jointed goatgrass particle (mL or cm^3), M_f was the mass of beaker, ethanol and submersed jointed goatgrass particle (g), M_o is the mass of beaker and ethanol (g), and ρ_l is the density of ethanol solution (g/mL or g/cm^3). Particle density for 25 samples of spikelets was calculated as:

$$\rho_s = M_s/V_s \quad (2)$$

where ρ_s is the particle density of jointed goatgrass sample (g/cm^3), M_s is the mass of sample (g), and V_s is the volume of sample (cm^3).

Particle density of jointed goatgrass also was determined using a Micromeritics Multivolume Helium Pycnometer 1305 following the procedure given in the manufacturer's manual (Micromeritics, 1987). The pycnometer determined volume by comparing the difference in pressure between empty chamber runs and runs where the chamber was filled with sample.

Helium gas was used as reference fluid in the pycnometer because of its penetrative nature. Pores and voids within spikelets and surface irregularities were all filled by helium, increasing the accuracy of particle density values observed for the samples. Particle density of each sample was calculated by first calculating the volume of the sample and using this and a previously recorded mass to find the particle density of the sample. Volume of 38 samples of jointed goatgrass spikelets was calculated as:

$$V_s = V_c - \left[\frac{V_e}{\left(\frac{P_1}{P_2} - 1 \right)} \right] \quad (3)$$

where V_s is the sample volume (cm^3), V_c is the empty volume of sample cell with empty insert in place (cm^3), V_e is the expansion chamber volume, added when prep test valve is rotated to test position (cm^3); P_1 is the initial pressure of sample chamber before test valve opened (Pa); and P_2 is the pressure recorded after test valve opened (Pa). Particle density was again calculated using equation 2.

Particle Density — Results and Discussion. The two different methods for determining particle density of jointed goatgrass spikelets gave differing results. Mean particle density values of 0.761 g/cm^3 and 1.38 g/cm^3 were measured for jointed goatgrass using ethanol displacement and a helium pycnometer, respectively. A particle density value reported for wheat was 1.48 g/cm^3 at a m.c. of 8.5% (w.b.) (Mohsenin, 1986).

The differing values for particle density of jointed goatgrass were most likely due to the penetrative nature of the helium gas used in the pycnometer. Helium gas, under pressure, so completely penetrated inner void spaces of the jointed goatgrass spikelet, that the volume reading did not accurately reflect the amount of "apparent" space occupied

Table 1. Physical properties of jointed goatgrass compared to wheat values — various references

Phys. Property Measured	Jointed Goatgrass*	Wheat
Bulk density (kg/m^3)	351 (26.9)	648 ~ 778§
Particle density (g/cm^3)†	0.761 (0.016)	1.48 (0.025)§
Particle density (g/cm^3)‡	1.38 (0.112)	1.48 (0.025)§
Term. velocity (m/min)	301 (25.9)	342 ~ 600§
Angle of repose (%)	26.3 (0.286)	25 ~ 31‖
Coeff. of friction	0.494 (0.007)	0.30 ~ 0.55‖
Length (mm)	10.8 (0.35)	7.32 (0.43)§
Width, major (mm)	2.59 (0.25)	2.97 (0.23)§
Width, minor (mm)	2.59 (0.25)	2.82 (0.28)§

* All values reported with standard deviations in parenthesis.
† Particle density by ethanol displacement.
‡ Particle density by helium pycnometer.
§ Mohsenin (1986).
‖ Stoskopf (1985).

by a jointed goatgrass particle. Each value recorded was the volume occupied by the solid material in each particle and not the volume occupied by an "apparent" particle with an impervious exterior and no inner void spaces.

Ethanol did not penetrate into inner void spaces in jointed goatgrass samples as much as helium. Thus, the ethanol displacement method was more effective in measuring the "apparent" total volume occupied by each particle. Water has a density of approximately 1 g/cm^3. Jointed goatgrass particles floated in water so it was reasonable to assume that the particles had a density less than 1 g/cm^3. Thus, 0.761 g/cm^3 from ethanol displacement seemed more valid than 1.38 g/cm^3 from the helium pycnometer. The values are reported in table 1.

Bulk Density

Bulk density of four samples of jointed goatgrass samples was determined using a standardized volumetric feeding apparatus with an attached scale arm for determining mass. The apparatus was one commonly used in determining bulk density of seeds and grains. Values given by the apparatus were in lb/bushel but were converted to kg/m^3. The standard procedure of the Federal Grain Inspection Service (1986) was followed. Bulk density was calculated as:

$$\rho_b = M/V \qquad (4)$$

where ρ_b was the bulk density (kg/m^3), M was the mass (kg), and V was the volume (m^3).

Bulk Density — Results and Discussion. The mean bulk density value for jointed goatgrass was 351 kg/m^3 (27.3 lb/bu). Reportedly, bulk density for wheat ranges from 648 to 778 kg/m^3 (50.3 to 60.4 lb/bu), depending on the type, at a m.c. between 6.2 and 8.5% (w.b.) (Mohsenin, 1986). This reported bulk density for wheat was nearly double the bulk density value determined for jointed goatgrass of similar m.c. Wheat was expected to have a greater bulk density since the shape of wheat allowed for greater packing density. The particle density of wheat also was greater than the particle density of jointed goatgrass (table 1).

Terminal Velocity

Terminal velocity values for five samples of jointed goatgrass were measured using a variable-flow fan (Dayton Model No. 46013, Chicago, Ill.) apparatus which channeled airflow into a square plenum structure (approx. 15 cm sides, square). This structure was fitted with a wire mesh guard perpendicular to the wind flow inside the channel and with openings small enough to prevent jointed goatgrass spikelets from falling into the fan chamber. The jointed goatgrass spikelets were placed sparsely to cover the mesh surface. The inlet opening was adjusted so air flow in the plenum was sufficient to cause the jointed goatgrass spikelets to float approximately 1 mm above the surface of the wire mesh. A hot-wire anemometer was used to determine air speed (Kurz, 1986). The mean of the measurements recorded with the anemometer was the terminal velocity.

Terminal Velocity — Results and Discussion. The mean terminal velocity of jointed goatgrass was 301 m/min. This value is below the reported range of terminal velocity values for wheat of 342 to 600 m/min at unspecified m.c. (Mohsenin, 1986).

Wheat, which has a lower surface to volume ratio and higher density, should fall faster than jointed goatgrass or, in other words, have a higher terminal velocity.

The observed difference in terminal velocities is important because use of air velocity for separation of seeds and plugs would be relatively easy and inexpensive. However, the large range for the terminal velocity value of wheat could cause difficulty in determining an accurate value to use for a separation method.

Angle of Repose

The static angle of repose of jointed goatgrass upon itself was measured. A simple device and procedure for measuring the angle of repose, similar to those used by Kramer (1944), were used for the experiment. The angle of the tilting surface was measured using a protractor. Angle of repose was the angle at which the top layer of jointed goatgrass spikelets began to slide over the layer of spikelets immediately below the top layer.

The internal coefficient of friction of a jointed goatgrass sample is the tangent of the angle of repose of that sample. It is expressed by:

$$\Omega = \tan(\beta) \qquad (5)$$

where Ω is the internal coefficient of friction (unitless) and β is the angle of repose (° or radians).

Angle of Repose — Results and Discussion. The mean value for the angle of repose for 15 samples of jointed goatgrass was 26°. A slightly greater angle of repose value, 28°, was reported for wheat at unspecified m.c. (Mohsenin, 1986). Both values fall within the range of repose angles (25-31°) reported by Stoskopf (1985). Separation of jointed goatgrass spikelets from wheat kernels, using inclination, a gravity table or a frictional method, would be time-consuming and impractical for large-scale operation.

Mean internal coefficient of friction of jointed goatgrass was 0.494. A reference value reported for wheat was 0.53 at an unspecified m.c. (Mohsenin 1986). The internal coefficient of friction for the jointed goatgrass was within the range of values of Stoskopf (1985) for the coefficient of friction of wheat. This similarity of values also suggests that jointed goatgrass would be difficult to separate from wheat by means of gravity tables or other gravity settling methods.

Equilibrium Moisture Contents

Jointed goatgrass spikelets were dried (0% m.c.) in a convection oven at 100°C for one week. The spikelets were then tested for equilibrium moisture content values after equilibrating at room temperature (25°C) under 10, 30, 50, 70 or 90% RH for two weeks. Ten samples of approximately 1 g were initially placed in each of the environments. These relative humidity environments were created in desiccators using appropriate saturated salt solutions (Wolfe et al., 1984). Equilibrium m.c. was calculated by:

$$\% \text{ M.C.} = [(M_f - M_i)/M_f] \times 100\% \qquad (6)$$

where % M.C. is the percent equilibrium moisture content at a RH (%w.b.), M_f is the final mass of sample after equilibrating at a RH (g); and M_i is the initial mass of sample after drying in convection oven (g).

Equilibrium Moisture Contents — Results and Discussion. Mean m.c. values for jointed goatgrass at room temperature (25°C) were 6.56 ± 1.03% at 10% RH, 7.43 ± 1.21% at 30% RH, 9.01 ± 0.67% at 50% RH, 11.89 ± 0.61% at 70% RH, and 20.39 ± 2.38% at 90% RH. Reported m.c. values for wheat at 25°C were 5.7% at 10% RH, 9% at 30% RH, 11.9% at 50% RH, 14.7% at 70% RH, and 17.1% at 90% RH (ASAE, 1991). Values for the jointed goatgrass samples and wheat reference were similar.

Summary of Results

Physical properties of jointed goatgrass that were measured included bulk density, particle density, equilibrium moisture content, terminal velocity, spikelet dimensions, angle of repose, and internal coefficient of friction. Jointed goatgrass and wheat kernels exhibited very similar values for most physical properties. The greatest differences between jointed goatgrass and wheat were in bulk and particle densities. The accepted particle density value of jointed goatgrass was the value determined using ethanol displacement. Separation of jointed goatgrass and wheat particles by methods incorporating particle density differences seems very plausible. Further research beyond the reported research addressing speed and efficiency of separation based on differences in particle density is needed.

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