Measuring Density and Porosity of Grain Kernels Using a Gas Pycnometer

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ABSTRACT

Porosities, true densities, and apparent densities of corn, wheat, and sorghum kernels were determined with a gas pycnometer. Average true densities for corn, wheat, and sorghum grain were 1.45, 1.47, and 1.46 g/cm^3, respectively. Average apparent kernel densities for corn, wheat, and sorghum grain were 1.27, 1.39, and 1.32 g/cm^3, respectively. Average kernel porosities for corn, wheat, and sorghum were 12.5, 5.2, and 9.8%, respectively. More than 80% of void spaces in corn kernels were isolated from the outside. For wheat and sorghum grain, the isolated void spaces were 30 and 52%, respectively.

Porosity and density of grain kernels are important parameters that affect the kernel hardness, breakage susceptibility, milling, drying rate, and resistance to fungal development.

Information on the porosity, apparent density, and true density of grain kernels is very limited. Some reported values of true kernel density were determined by a gas pycnometer (Chung and Converse 1969, Gustafson and Hall 1972). Because of the isolation of void spaces or intercellular spaces in grain kernels from the kernel surface (MacMasters 1962), kernel volume determined by a pycnometer could include some of these spaces. Therefore, the density determined might not be the true density.

Zink (1935) determined the volume of grain and the void spaces between grain kernels by the displacement of mercury. Lorenzen (1958) measured the volumes of wheat, corn, barley, rice, and milo by the displacement of toluene. Ross (1960) determined the volumes of corn, oats, and soybeans by water displacement. He noted that oats presented a particular problem, because their rough and hairy hulls prevented water from entering the spaces between the kernels. Mercury might present even more serious problems in filling the void spaces between grain kernels because of its high surface tension. Due to this surface tension and possible absorbance, liquids probably are not adequately suited for determining void spaces for most grain and seed kernels. Thompson and Isaacs (1967) determined the bulk porosity of various grains and seeds using an air-comparison pycnometer. The porosity values they obtained were 5 to 10% higher than those determined by the mercury displacement method.

The objectives of this study were to determine the porosity, apparent density, and true density of grain kernels and to determine if the true whole kernel density can be determined by a gas pycnometer.

MATERIALS AND METHODS

Experiments were conducted on two varieties or hybrids each of hard red winter wheat, soft red winter wheat, corn, and grain sorghum. The varieties or hybrids and their moisture contents are given in Table I.

A gas pycnometer (model SPY2, Quantachrome Corp., Syosset, NY) with helium was used to determine the volumes of grain samples. The pycnometer operates on Archimedes principle of gas displacement to determine the volume. Figure 1 shows the schematic of the pycnometer. The shaded area is empty and sealed sample cell volume V_c. By opening the vent valve, the system is brought to ambient pressure, P_a, after being purged with helium. The state of the system is then defined as

$$P_a V_c = NRT_a \quad (1)$$

where N is the moles of gas occupying volume V_c at pressure P_a, R is the gas constant, and T_a is the ambient temperature in degrees Kelvin. When a solid sample of volume V_p is placed in the sample cell, equation (1) can be rewritten as

$$P_a (V_c - V_p) = N_1 RT_a \quad (2)$$

where N_1 is the moles of gas in the sample cell. When the system is pressurized to P_2 above ambient, equation (2) becomes

$$P_2 (V_c - V_p) = N_2 RT_a \quad (3)$$

where N_2 represents the total moles of gas in the sample cell. When the selector value is turned to connect the added volume V_a to the sample cell, the pressure will fall to a lower value P_3 given by

$$P_3 (V_c - V_p + V_a) = N_2 RT_a + N_a RT_a \quad (4)$$

where N_a is the moles of gas contained in the added volume when at ambient pressure. The terms $P_a V_a$ can be used in place of $N_a RT_a$ in equation (4), and substituting equation (3) into equation (4) one obtains

$$V_c - V_p = V_a (P_a - P_3)/(P_3 - P_2) \quad (5)$$

Because P_a is made to read zero, that is, all pressure measurements are relative to P_a, which is zeroed before pressurizing, equation (5) becomes

$$V_p = V_c + V_a/(1 - P_2/P_3) \quad (6)$$

V_c and V_a in equation (6) are known. By measuring pressures P_2 and P_3, the sample volume V_p can be calculated from this equation. Density of the sample can be determined from the sample weight and sample volume. It should be noted that the void spaces inside the sample that are inaccessible to helium are included in the volume of the sample. The void spaces that helium could penetrate are excluded from the volume of the sample.

True density of grain was defined as the ratio of the grain sample weight to the true volume of the sample. For the determination of the true volume of grain, the sample was ground in a micro hammer mill (Glen Mills Inc., Maywood, NY) through a 2-mm round-hole screen. The ground sample was placed in a sample container for weight measurement and volume determination using a pycnometer. The average particle size distribution for each type of ground grain sample is given in Table II. About 50% of particles were smaller than 500 μm.

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TABLE I
Porosity and Density of Grain Kernels

Grain	Variety or Hybrid	Moisture Content (%, wb)	Kernel Density (g/cm^3) True	Apparent	Control	Interior Kernel Porosity (%)	Pore Spaces Inaccessible (%)
Corn	BoJac	11.8	1.452 (0.53)[a]	1.258 (0.72)	1.271 (0.37)	13.3	92
	Stauffer	12.0	1.450 (1.29)	1.280 (0.50)	1.305 (0.52)	11.7	84
Hard wheat	Newton	13.8	1.476 (0.42)	1.423 (0.81)	1.460 (0.68)	3.6	29
	Centurk	13.8	1.469 (0.54)	1.396 (1.15)	1.442 (0.57)	5.0	36
Soft wheat	Hart	13.6	1.478 (1.13)	1.374 (2.23)	1.448 (0.64)	7.0	27
	Pike	13.5	1.463 (0.44)	1.385 (1.41)	1.438 (0.63)	5.3	31
Sorghum	Ferry Morse	12.7	1.471 (0.68)	1.340 (0.52)	1.397 (0.35)	8.9	54
	Funk	11.2	1.448 (0.60)	1.295 (0.54)	1.368 (0.43)	10.6	50

[a]Coefficient of variation (%).

TABLE II
Particle Size Distribution of Ground Samples

Grain	Particle Size Distribution (%)[a] <250 μm	<500 μm	<1,000 μm	<2,000 μm
Corn	18	54	82	100
Hard wheat	18	48	80	100
Soft wheat	19	53	81	100
Sorghum	19	49	81	100

[a]Average values of four replications.

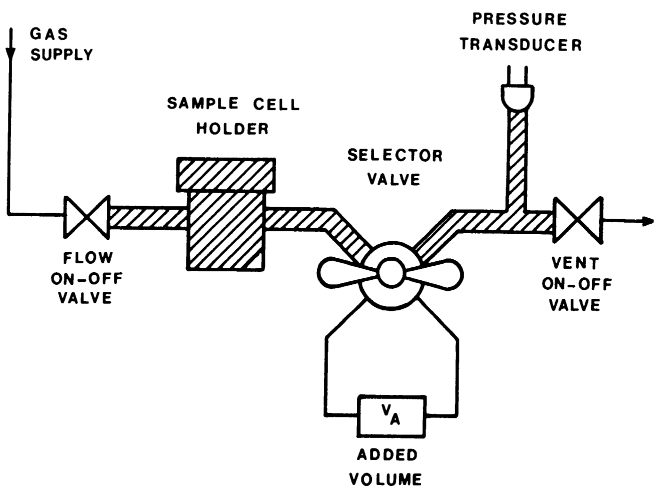

Fig. 1. Schematic of the gas pycnometer.

The apparent kernel density of grain was determined from the grain kernel weight and the apparent volume of grain kernels, which included all pore spaces inside the kernels. For the determination of apparent volume, each individual kernel in a sample was coated by dipping in heated liquid paraffin wax, so all pore spaces inside the grain kernels were isolated from the outside and thus inaccessible to the test gas used in the pycnometer. The amount of wax coated on each sample was determined from the weight difference before and after wax coating. The determination of the specific volume of the wax will be described later. Each sample of wax-coated kernels was then placed in a sample container for weight measurement and volume determination with a pycnometer. The apparent volume of the sample was obtained by subtracting the volume of wax from the total volume of wax-coated kernels.

The control density of the grain kernels was defined as the ratio of kernel weight to kernel volume as determined for grain kernels without any wax treatment. The kernel volume determined included all void spaces inaccessible to helium.

The specific volume of wax was determined by using a pycnometer to measure the volume of a known weight (approximately 1 g) of wax coated on the surfaces of two 16-mm-diameter steel balls.

The porosity of grain kernels was defined as the ratio of void spaces inside the kernels to the apparent volume of kernels:

$$P = [(V_2 - V_1)/V_2] \times 100 = [(D_1 - D_2)/D_1] \times 100 \quad (7)$$

where P = porosity (%); V_1 = true specific volume (cm^3/g); V_2 = apparent specific volume (cm^3/g); D_1 = true density (g/cm^3); and D_2 = apparent density (g/cm^3).

The percentage of inaccessible pore spaces was defined as the ratio of the volume of pore spaces inaccessible to helium to the total volume of pore spaces inside the kernels.

For each variety of grain, 20 replicated samples were prepared. Each corn sample contained 25 kernels that weighed about 8 g. For wheat and sorghum, each sample weighed about 8 g, and the number of kernels was not counted. Each individual kernel used in this study was a hand-selected sound kernel with no visible damage. For each variety, weight and volume were measured for all 20 samples of grain to determine the control density. Ten of the 20 samples were then ground with the micro hammer mill and measured for weight and volume to determine the true density of each sample. The remaining 10 samples were coated with a thin layer of wax on each individual kernel. Weight and volume of each wax-coated sample were then measured to determine the apparent kernel density.

RESULTS AND DISCUSSION

Results of true density, apparent density, control density, kernel porosity, and the percentage of inaccessible pore spaces for all three kinds of grain are given in Table I.

True density, apparent density, and control density for the two varieties or hybrids of the same kind of grain were similar. The kernel porosity of corn was high, about 12 to 13%, and more than 80% of the pore spaces inside the corn kernels were isolated from the outside and inaccessible to helium. The kernel porosity of wheat was about 4 to 7%, the lowest among the three kinds of grain. About 70% of pore spaces inside wheat kernels were accessible to helium. Sorghum had a porosity of about 9 to 11% and about half of the pore spaces inside the kernels were accessible to the helium.

The difference between true and apparent densities of corn was large. This was an indication of high porosity. The small difference between apparent density and control density of corn indicated that most of the void spaces in the corn kernels were isolated from the outside.

The apparent density of hard wheat was slightly higher than that of soft wheat. The differences between true and apparent densities for both hard and soft wheat (approximately 3 to 7%) were smaller than those for corn. The small difference between true and apparent density was an indication of low porosity for both hard and soft wheat.

True density of sorghum was about 10% higher than its apparent density. The control density of sorghum was at the midpoint of its true and apparent densities, which indicated that about one-half of the void spaces in the sorghum kernels were isolated from the outside.

It should be noted that results of these experiments are valid for only the varieties and hybrids of grain tested.

CONCLUSIONS

1) True kernel densities for wheat, corn, and sorghum were similar. 2) The apparent density of wheat kernels was higher than those of corn and sorghum kernels. 3) Internal porosity of corn kernels was higher than those of wheat and sorghum. 4) More than 80% of the pore spaces in corn kernels were isolated from the outside. 5) Because a portion of pore spaces inside the grain kernels are inaccessible to the gas, the density of whole grain kernels determined by a pycnometer is not the true density.

LITERATURE CITED

CHUNG, D. S., and CONVERSE, H. H. 1969. Effect of moisture content on some physical properties of grains. Am. Soc. Agric. Eng. Paper 69-811. The Society: St. Joseph, MI.

GUSTAFSON, R. J., and HALL, G. E. 1972. Density and porosity changes of shelled corn during drying. Trans. ASAE 15:523.

LORENZEN, R. T. 1958. Effect of moisture on weight-volume relationships of small grain. Am. Soc. Agric. Eng. Paper 58-111. The Society: St. Joseph, MI.

MacMASTERS, M. M. 1962. Important aspect of kernel structure. Trans. ASAE 5:247.

ROSS, I. J. 1960. Forces acting in particle stacks and the capacities of enclosed screw conveyors. Ph.D. thesis, Purdue Univ., Lafayette, IN.

THOMPSON, R. A., and ISAACS, G. W. 1967. Porosity determinations of grains and seeds with an air-comparison pycnometer. Trans. ASAE 10:693.

ZINK, F. J. 1935. Specific gravity and air space of grain and seeds. Agric. Eng. 16:439.

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