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 
Converson 1968, Gustafson and Mills 1972). Because of the isolation 
of void spaces or intercellular spaces in grain kernels from the 
surface (MacMasters 1963), 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, rye, and milo 
by the displacement of volume. Ross (1960) determined the 
volumes of corn, oats, and soybeans by water displacement. Be 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 Isacso (1967) determined the bulk porosity of 
various grains and seeds using an air-compression 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 1.

A gas pycnometer (model SPY2, Quantachrome Corp., Sycscott, 
NY) was used to determine the volume 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.

By opening the vent valve, the system is brought to ambient pressure, P0, after being purged with helium. The state of the system is then defined as

\[
P0V0 = NRT0\]

(1)

where \( N \) is the moles of gas occupying volume \( V \) at pressure \( P0 \) 
and \( T0 \) is the gas constant, and \( T0 \) is the ambient temperature in degrees 
Kelvin. When a solid sample of volume \( V0 \) is placed in the sample 
cell, equation (1) can be rewritten as

\[
P0(V0 + V) = NRT0 \]

(2)

where \( N \) is the moles of gas in the sample cell. When the system's 
pressure is increased to \( P \), above ambient pressure, equation (2) becomes

\[
P(V0 + V) = NRT \]

(3)

where \( N \) represents the total moles of gas in the sample cell. When 
the selector valve is turned to connect the added volume \( V \) to the 
sample cell, the pressure will fall to a lower value \( P1 \) given by

\[
P1(V1 + V) = N1RT + NRT \]

(4)

where \( N \) is the moles of gas contained in the added volume when 
at ambient pressure. The terms \( P1V1 \) can be used in place of \( N1RT \) in 
equation (4), and substituting equation (5) into equation (4) one obtains

\[
V1 = V0(V0 - P0)/(P0 - P) \]

(5)

Because \( P0 \) is made to read zero, that is, all pressure measurements are relative to \( P0 \), which is zero before pressurizing, equation (5) becomes

\[
V1 = V0(1 - P0/P) \]

(6)

and \( V0 \) and \( V1 \) in equation (6) are known. By measuring pressures 
\( P0 \) and \( P \), the sample volume \( V \) 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 excluded 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 \( \mu \text{m} \).

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2 Mention of firm names or trade products does not constitute endorsement by the 
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TABLE I

<table>
<thead>
<tr>
<th>Grain</th>
<th>Variety</th>
<th>Moisture Content (%)</th>
<th>Kernel Density (g/cm²)</th>
<th>Total Kernel Porosity (%)</th>
<th>% Inaccessible</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hybrid</td>
<td></td>
<td>True</td>
<td>Apparent</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>Bulke</td>
<td>11.6</td>
<td>1.452 (0.53)</td>
<td>1.294 (0.72)</td>
<td>1.271 (0.37)</td>
</tr>
<tr>
<td></td>
<td>Stauffer</td>
<td>12.0</td>
<td>1.450 (0.29)</td>
<td>1.280 (0.50)</td>
<td>1.305 (0.52)</td>
</tr>
<tr>
<td>Hand wheat</td>
<td>Nuvar</td>
<td>13.8</td>
<td>1.478 (0.42)</td>
<td>1.425 (0.01)</td>
<td>1.460 (0.68)</td>
</tr>
<tr>
<td></td>
<td>Cottum</td>
<td>13.8</td>
<td>1.409 (0.34)</td>
<td>1.306 (1.15)</td>
<td>1.442 (0.57)</td>
</tr>
<tr>
<td>Soft wheat</td>
<td>Hart</td>
<td>13.6</td>
<td>1.478 (1.13)</td>
<td>1.374 (2.23)</td>
<td>1.448 (0.64)</td>
</tr>
<tr>
<td></td>
<td>Pike</td>
<td>13.5</td>
<td>1.453 (0.46)</td>
<td>1.385 (1.41)</td>
<td>1.438 (0.63)</td>
</tr>
<tr>
<td></td>
<td>Sargam</td>
<td>12.7</td>
<td>1.471 (0.68)</td>
<td>1.340 (0.52)</td>
<td>1.397 (0.73)</td>
</tr>
<tr>
<td></td>
<td>Funk</td>
<td>11.2</td>
<td>1.448 (0.60)</td>
<td>1.295 (0.54)</td>
<td>1.366 (0.43)</td>
</tr>
</tbody>
</table>

*Coefficient of variation (%).

TABLE II

Particle Size Distribution of Ground Samples

<table>
<thead>
<tr>
<th>Grain</th>
<th>&lt;250 µm</th>
<th>&lt;50 µm</th>
<th>&lt;1,000 µm</th>
<th>&lt;250 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>18</td>
<td>54</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>Hard wheat</td>
<td>18</td>
<td>48</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>Soft wheat</td>
<td>19</td>
<td>53</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>Sorghum</td>
<td>19</td>
<td>48</td>
<td>81</td>
<td>100</td>
</tr>
</tbody>
</table>

*Average values of four replications.

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:

\[ P = \frac{(V_L - V_s)}{V_t} \times 100 = \frac{(V_t - D_1 D_2 D_3)}{V_t} \times 100 \]

where \( P \) = porosity (%), \( V_L \) = true specific volume (cm³/g), \( V_s \) = apparent specific volume (cm³/g), \( D_1 \) = true density (g/cm³), and \( D_2 \) = apparent density (g/cm³).

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

For each variety of grain, 20 replicated samples were prepared. Each grain 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

Fig. 1. Schematic of the gas pycnometer.
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 pores present 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


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