Properties of Ground Shelled Corn as Related to Forces in Bulk Storage Structures

RP-253

O. J. Loewer, Jr., I. J. Ross, D. D. Kratzer, J. N. Walker
ASSOC. MEMBER ASAE — MEMBER ASAE — SENIOR MEMBER ASAE

GRANULAR materials such as shelled corn, soybeans, corn meal, soybean meal, citrus pulp, and many other grains and feeds are compressible under pressure to varying degrees. Clower, et al. (1973) have shown through a modification of Janssen's equations (1895) (Ketchum 1919) that the forces acting in stacks of granular materials can be a function of the compressibility of the material. The objectives of this study were to determine the influence of various levels of vertical pressure, moisture, and particle size on the bulk density and Janssen's K-Value of ground shelled corn.

REVIEW OF LITERATURE, EXPERIMENTAL PROCEDURE

The classic grain pressure theory as developed by Janssen (1895) is expressed by the equation

$$P = \frac{DR}{\mu K} [1 - \exp(-\mu K y/R)]$$

where

- P = unit vertical pressure at any depth y in a bin of granular material
- D = bulk density of the granular material
- R = "hydraulic radius" — area of horizontal cross-section of bin divided by the bin perimeter
- μ = coefficient of friction between stored material and bin wall
- K = ratio of unit lateral pressure to unit vertical pressure at any point in the grain mass
- y = depth from top of bin to point under consideration.

In the development of his equation, Janssen assumed that the bulk density, D, and the ratio of lateral to vertical pressures, K, are constant. Clower et al. (1973) has shown that this assumption is not valid and has developed an equation using Janssen's basic theoretical approach to predict pressures in grain bins which accounts for variations in bulk density within the granular mass in a storage bin. He found from his experimental work that bulk density and K-values can be represented as linear functions of vertical pressure. He did not consider other variables in his experiments. Variation in bulk density with vertical pressure was determined by measuring the linear compression of samples of granular materials of known thickness and uncompressed density. Variation in K-values with vertical pressure was determined by comparing the forces required to pull thin blades oriented in the vertical and horizontal planes through a sample of the material. A detailed discussion of past research as well as a complete description of the experimental procedure and test equipment used in this study may be found in Clower et al. (1973).

Shelled corn that had been dried to 12 percent moisture content was subdivided and ground with a hammer mill, using screens of three different sizes. The individual lots were categorized as containing either small, medium or large particles corresponding to a geometric mean diameter of 0.517, 0.581, and 0.616 mm, respectively, as determined by ASAE standard: ASAE S319, Yearbook (1975). The geometric standard deviations for these sizes were found to be 1.905, 2.473, and 1.909, respectively. Each category of particle size was subdivided and conditioned into lots containing approximately 8, 12, 16, 20, and 24 percent moisture, wet basis. After the moisture adjustments were made, the test material was sealed in plastic bags and stored at approximately 10 °C. With the use of the equipment and test procedures described by Clower, the lots were subjected to pressures of 6.9, 13.8, 27.6, 41.4, 55.2, and 69.0 kPa. The exact moisture content of the ground material was determined at the time of testing, using the oven drying technique.

RESULTS

Analyses of variance were conducted according to a split- split-plot design to determine if significant differences existed among the grinds, moisture contents, and pressures used. Based on these analyses and regression analyses, which used orthogonal polynomials and successive powers of the factor levels, prediction equations were developed for bulk density and Janssen K-value determination. The SAS's (Statistical Analysis System) regression procedure was used to compute statistical estimates of the parameters.

Bulk Density

The bulk density analysis of variance (ANOV) results indicated no significant difference among grinds. However, significant differences did exist among levels of moisture and pressure, with several interactions of these factors being highly significant.

A series of statistical fit techniques, based on the results of the ANOV, were used to obtain equations relating bulk density, moisture content, and pressure. The two equations given below were selected as those best representing the data and differ in their complexity and correlation coefficients:

$$D = 919.8 + 1.142*P - 21.14*M + 0.520*M^2 - 0.0745*P*M + 0.00430*P*M^2 \quad \ldots \quad [1]$$

and

Article was submitted for publication in February 1976; reviewed and approved for publication by the Structures and Environment Division of ASAE in September 1976. Presented as ASAE Paper No. 75-4509.

Paper is published with the approval of the Director of the Kentucky Agricultural Experiment Station and designated as Paper No. 75-2-185.

The authors are: O. J. LOEWER, JR., Assistant Extension Professor, I. J. ROSS, Professor, Agricultural Engineering Dept., D. D. KRATZER, Associate Professor, Animal Science and Statistics Dept., and J. N. WALKER, Chairman and Professor, Agricultural Engineering Dept., University of Kentucky, Lexington.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 20, No. 1, pp. 155, 156, 1977)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

TABLE 1. MEANS FOR BULK DENSITY TESTS.

Pressure, kPa	Bulk density, kg/m^3
6.9	718.8
13.8	748.8
27.6	778.3
41.4	791.2
55.2	798.0
68.9	802.5
Moisture, percent	
8	805.9
12	765.2
16	741.4
20	762.1
24	789.9
Grind	
Small	774.6
Medium	771.9
Large	772.3
Overall mean	772.9

$$D = 784.9 + 0.0250*P - 3.353*M + 0.0727*P*M \quad [2]$$

where

D = Bulk density, kg/m^3

P = Pressure, kPa, and

M = Moisture content, percent wet base.

For equation [1], the R-square term was 0.6705, the coefficient of variation was 3.305 percent, the standard deviation was 25.6 kg/m^3 and the mean was 772.9 kg/m^3. For equation [2], these values were 0.4604, 4.214 percent, 32.6 kg/m^3 and 772.9 kg/m^3, respectively. Variable means are given in Table 1. Either equation can be used for estimating bulk density. Estimates made with equation [1] will better represent the values found in these tests, but computations will be somewhat more difficult. A graph of equation [1] showing bulk density as a function of moisture content for various pressures is presented in Fig. 1.

TABLE 2. MEANS FOR K-VALUE TESTS.

Pressure, kPa	K-value
6.9	0.459
13.8	0.545
27.6	0.685
41.4	0.715
55.2	0.728
68.9	0.753
Moisture, percent	
8	0.574
12	0.588
16	0.706
20	0.648
24	0.722
Grind	
Small	0.644
Medium	0.628
Large	0.671
Overall mean	0.647

K-Value

An analysis of variance indicated significant differences in K-Values among levels of moisture, pressure, and the moisture-pressure interaction. Grind (particle size) differences were not significant at the 0.05 level.

Equations were developed from the ANOV to reflect the relationship between the K-Value, moisture content, and pressure. The two equations selected as best representing that data were:

$$K = 0.0519 + 0.0240*P - 0.000436*P^2 + 0.00000284*P^3 + 0.0156*M + 0.0000857*M*P - 0.00000792*M^2*P \quad [3]$$

and

$$K = 0.2260 + 0.00756*P + 0.01563*M - 0.000185*P*M \quad [4]$$

where

K = ratio of lateral to vertical pressures,

P = Pressure, kPa, and

M = Moisture content, percent wet basis:

For equation [3] the R-square, coefficient of variation, standard deviation, and mean are 0.4068, 23.18 percent, 0.1501 and 0.6475, respectively. For equation [4] these values are 0.3478, 24.17 percent, 0.1565, and 0.6475, respectively. Variable means are given in Table 2. Either equation can be used for estimating the K-Value. Equation [3] will give better estimates of the values found in these tests. A graph of equation [3] showing K-Values as a function of moisture content for various pressures is presented in Fig. 2.

SUMMARY

The influence of various levels of vertical pressure, moisture and particle size on the bulk density and Janssen K-Value have been determined for ground shelled corn. Extensive statistical analyses have been made and models of varying complexity selected to represent these data.

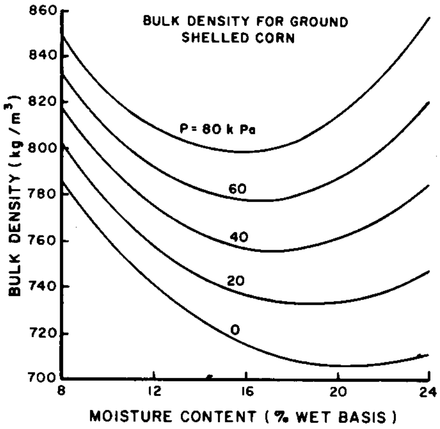

FIG. 1 A graph of equation [1] showing bulk density as a function of moisture content for various pressures.

Moisture content and vertical pressure significantly affected both bulk density and K-Value. Grind did not significantly affect either dependent variable. Depending on the complexity of the models, vertical pressure and moisture can be used to predict approximately 55 percent and 35 percent of the variation in bulk density and Janssen K-Value, respectively.

References

1 Agricultural Engineering Yearbook. 1975. p. 690. American Society of Agricultural Engineers, St. Joseph, MI 49085.

2 Clower, R. E., I. J. Ross, and G. M. White. 1973. Properties of compressible granular materials as related to forces in bulk storage structures. TRANSACTIONS of the ASAE 16(3):478-481.

3 Ketchum, M. S. 1919. The design of walls, bins, and grain elevators. 3rd Edition, McGraw-Hill, New York, NY.

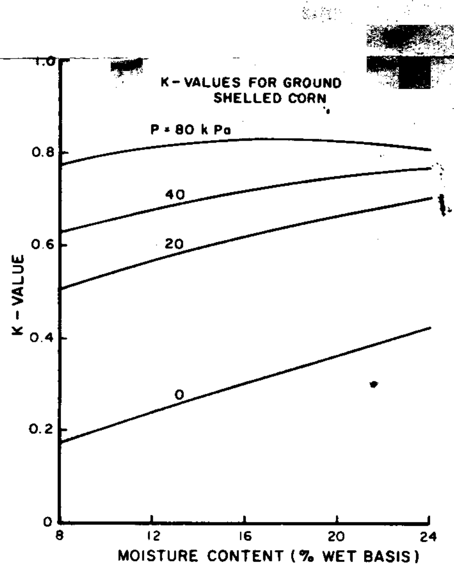

FIG. 2 Graph of equation [3] showing K-Values as a function of moisture content for various pressures.