Distribution of Shelled Corn Throughput and Mechanical Damage in a Combine Cylinder

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Distribution of Shelled Corn Throughput and Mechanical Damage in a Combine Cylinder

Abstract
SINCE the introduction of field shelling of corn by combines, many farmers have changed from ear-corn harvesting to a high-moisture, field-shelling system. A field survey (USDA 1971) in the Corn Belt indicated the continued shift to combines for harvesting corn. The portion of acreage harvested by corn heads on combines reached 69 per-cent in some midwestern states for the 1971 season. The combine approach has gained such favor because combines are universal types of harvesters, which may be equipped with different head attachments, and, when appropriately adjusted, can be used to harvest all types of grains. Field combining of corn has brought into focus the problem of mechanical damage to corn kernels. Industry and researchers (Byg et al. 1966, Cooper 1968, Hall and Johnson 1970) have directed their efforts to improve the shelling performance by establishing optimum operating parameters, yet shelling damage continues at objectionable levels. Several research workers (Brass 1970, Fox 1969, USDA 1967) have developed a new shelling mechanism. The experimental shellers shell corn with less damage than conventional shellers, but inherent limitations and performance problems have been encountered. It thus seems that the full potential of the conventional cylinder-concave mechanism in shelling corn has yet to be realized. Basic research is needed to indicate where damage occurs and what modifications are needed to substantially reduce the level of damage. This must be done without adversely affecting the overall performance of the machine. The literature reviewed showed lack of quantitative evaluation of corn-kernel separation and damage distribution along the concave. Research was conducted with the specific objectives of investigating the distribution of through-put and mechanical damage of shelled corn in the combine-shelling mechanism (Mahmoud 1972)

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Distribution of Shelled Corn Throughput and Mechanical Damage in a Combine Cylinder

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Since the introduction of field shelling of corn by combines, many farmers have changed from ear-corn harvesting to a high-moisture, field-shelling system. A field survey (USDA 1971) in the Corn Belt indicated the continued shift to combines for harvesting corn. The portion of acreage harvested by corn heads on combines reached 69 percent in some midwestern states for the 1971 season. The combine approach has gained such favor because combines are universal types of harvesters, which may be equipped with different head attachments, and, when appropriately adjusted, can be used to harvest all types of grains.

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It thus seems that the full potential of the conventional cylinder-concave mechanism in shelling corn has yet to be realized. Basic research is needed to indicate where damage occurs and what modifications are needed to substantially reduce the level of damage. This must be done without adversely affecting the overall performance of the machine. The literature reviewed showed lack of quantitative evaluation of corn-kernel separation and damage distribution along the concave. Research was conducted with the specific objectives of investigating the distribution of throughput and mechanical damage of shelled corn in the combine-shelling mechanism (Mahmoud 1972).

EQUIPMENT AND PROCEDURE

The equipment constructed and used in the laboratory experiments is shown in Fig. 1. The main components used in the construction of the shelling mechanism are parts from the John Deere Model 95 combine. The relative positions of cylinder, beater, and concave are identical to manufacturer's specifications. The shelled-corn collection pan is connected to a hydraulic cylinder and is actuated by compressed air. Two electric arc welders were modified to operate the stationary sheller (Fig. 2). This power system was capable of producing up to 30 hp. The speed was controlled by the welder rheostat and ran up to 1800 rpm.

The stationary sheller was fed by a chain conveyor operated by a 3-hp motor. The samples collected in the grain pans were weighed on a Toledo scale and were divided into smaller samples for evaluation with a Boerner grain divider.

A review of the corn-shelling process...
from high-speed films showed that the corn, during the shelling process, undergoes different types of impacts in three distinctive zones along the concave. This suggested the following zone classifications:

1. Inlet impact zone
2. Compression and rubbing zone
3. Release zone

Past the concave, the discharged material is again subjected to impact by the beater to give the fourth zone:

4. Concave extension zone

In a combine, the discharge from the concave extension is caught by the straw walkers. In this study, this material was collected to represent another zone and is referred to as:

5. Cleaning zone

The relative positions of these zones are shown in Fig. 3. Because the objective of the study was to examine the distribution of shelled corn, as well as damage along the concave, the five zones just described were suitable for this purpose. The collection pan accordingly was partitioned into five compartments to catch the throughput of each zone. Each compartment was fitted with a canvas bag (Fig. 4) to facilitate the removal of the grain for weighing.

Specific Index of Separation (S.S.I.):
An engineering term is needed to describe the distribution of throughput of shelled corn in the shelling mechanism. Since the concave and concave extension were considered in this study, a term suitable for describing the throughput in the two components was developed. The index used in the analysis of the data was a measure of the percentage of the total shelled corn that passed through 1-in. of concave length. This index is defined by the equation:

$$S.S.I. = \frac{(w/W) \times 100}{L} \quad [1]$$

where

- S.S.I. = specific index of separation, percent weight per in.
- w = weight of grain collected from a zone, lb
- W = total weight of shelled corn collected in the five zones, lb
- L = zone length measured along concave profile, in.

The effects of the following independent variables on the specific separation index and damage were evaluated:

1. Variety at two levels
2. Moisture content at five levels
3. Concave clearance at two levels
4. Cylinder speed at two levels
5. Concave zone at four and five levels for S.S.I. and damage, respectively.

Two commercial varieties of corn, Pioneer 3369A and DeKalb XL66, were used in the experiments. The corn was hand picked and husked from Agricultural Engineering Research Center fields. The moisture-content distribution varied throughout the fields. Because of this, more than one moisture level was available for testing at a time. The levels of kernel-moisture content used were: 30, 27, 25, 22, and 18 percent (wet basis)

Front concave clearance was limited to two spacings: 1 and 1-1/4 in. with the rear concave clearance fixed at 5/8 in. Two levels of cylinder speed were used: 450 and 600 rpm. The five zones designated in Fig. 3 are the locations along the concave where the specific index of separation was investigated. The feed rate of 300 bu per hr was used in the study.

The weight of ear-corn required to yield 1 bu of shelled corn for each variety at the desired level of moisture content was obtained from a conversion chart developed by Schmidt (1948). The equivalent weight of 1/8 of a bu was determined for individual tests. The prepared sample was randomly placed on the specified conveyor length, which was timed for the feed rate of 300 bu per hr.

**Statistical Analysis:** The different levels of the main effects (variety, moisture content, concave clearance, and cylinder speed) at three replications of each treatment resulted in 120 treatment combinations for the specific separation index. Corresponding parameter values were set on the shelling unit, and the ear corn then was run through the shelling mechanism. The catch on each zone was weighed and recorded. The grain in all the zones was then thoroughly mixed, and three 100-g samples were obtained by Boerner divider for moisture content (wet basis) determination by using the whole kernel, oven-dry method.

Because the treatment combinations could not be randomized over zones (i.e., each zone was receiving the same treatment at the same time), the analysis of variance for the data collected was made on the basis of a split plot-like design (Draper and Smith 1966) by virtue of the restricted randomization.

**RESULTS AND DISCUSSION**

The analysis of variance indicated that all the main effects but variety have a highly significant effect on the specific separation index (S.S.I.). Also, several interactions were significant. The signifi-
The nonlinear terms in equation [2] accounted for 22.5 percent of the data scatter, while the linear terms accounted for 63 percent of the scatter.

The exponentially decaying-like trend of the S.S.I. versus zone suggests the development of an exponential type of prediction equation that would readily describe the situation. The same regression analysis procedures were used in formulating the exponential prediction equation. The knowledge gain in developing the polynomial type of equation, as well as the levels of significance of variables in the analysis of variance, were used as guides in formulating the exponential function. The prediction equation in the exponential form obtained is:

\[ \text{S.S.I.} = \alpha e^{\beta(Z + C)} \]  \hspace{1cm} [3]

where

- \( \text{S.S.I.} \) = specific separation index, percent weight per in.
- \( Z \) = zone or distance along concave, in.
- \( C \) = front concave clearance
- \( \alpha \) = 0.51
- \( \beta \) = 3.00

The coefficient of determination \( (R^2) \) for equation [3] is 0.815 and is slightly less than that of the polynomial form (equation [2]).

The relative fitness of the prediction equations is illustrated in Fig. 6 for different machine settings. Since the coefficients of determination \( (R^2) \) were 0.855 and 0.815 for the polynomial and exponential equations, respectively, the difference in the \( R^2 \) values and the type of equation account for the discrepancies between the two fitted equations and the experimental data.

**Damage Distribution:** The experimental procedure outlined concurrently was used for the specific separation index and the damage-distribution studies. The grain for damage determination, however, was obtained from all five zones shown in Fig. 4. A sample of approximately 500 g was obtained from each zone by Boerner grain divider.

Each sample was dyed in a Fast Green FCF dye for 4 min and placed on
a strainer; excess dye was washed away with running water. Dyed samples were spread on paper mats to dry for 24 hr before being assessed for damage. Approximately a 100-g subsample was obtained from each sample by the grain divider for damage examination. A kernel was considered damaged if it was broken, cracked, chipped, had bruised pericarp, or any hairline crack in the pericarp. Green dye stained the damaged parts and made the inspection easier. The damaged kernels were weighed, and the percentage damage was computed on weight basis for each sample.

With damage as the dependent variable, the computed percentages for damage in the five zones were statistically analyzed by the same model used for the specific separation index. The analysis of variance for damage showed that all the main effects are significant. The two most highly significant interactions (at the 1-percent level) are shown in Fig. 7. Damage increased with increase in distance along the concave at all moisture contents, and it was minimum at about 20-percent moisture content for all zones (Fig. 7a). The two varieties tested sustained higher levels of damage with increase in cylinder speed. DeKalb XL66 had a higher rate of increase than Pioneer 3369A (Fig. 7b).

The regression equation obtained for damage is:

\[
D = 98.2 - 0.046(Z) - 7.11(M) + 0.16(M^2) - 6.8(C) + 0.002(rpm \times Z)
\]

where

- \(D\) = damage, percent weight
- \(Z\) = distance along the concave, in.
- \(M\) = moisture content, w.b.
- \(C\) = concave clearance
- \(rpm\) = cylinder speed

The coefficient of determination \(R^2\) for equation [4] = 0.88, and all coefficients are significant at the 1-percent level.

The contribution of the nonlinear terms and the concave clearance term \((M^2 \times rpm \times Z, C)\) to \(R^2\) of equation [4] was only 8.5 percent. When these terms were deleted, the linear terms of zone \((A)\) and moisture \((M)\) accounted for 79.5 percent of the data scatter, and equation [4] was reduced to the form:

\[
D = 0.19 + 0.93(Z) + 0.69(M)
\]

The relative fitness of equations [4] and [5] on experimental data collected at cylinder speed of 450 rpm and 1-in. front concave clearance is illustrated in Fig. 8a, for moisture content of 18 percent, and Fig. 8b, for moisture content of 30 percent. The close fitness of equations [4] and [5] illustrated in these figures indicates that the linear terms can adequately account for the damage.

FIG. 7 Significant mechanical damage interactions: a. effect of zone and moisture damage; b. effect of variety and cylinder speed on damage.

FIG. 8 Damage predictions equations superimposed on experimental data: a. 18 percent moisture content; b. 30 percent moisture content.

SUMMARY AND CONCLUSION

A laboratory sheller was constructed from conventional combine parts. The distribution of shelled corn throughput and mechanical damage along the shelling mechanism were investigated. The throughput distribution was defined by the specific separation index (S.S.I.) as the percent weight of shelled corn that passes through 1 in. of concave length. The S.S.I. was adequately described by the decaying exponential function:

\[
S.S.I. = 0.51 \frac{e^3}{(C+Z)}
\]

The only parameters causing significant variation in the exponential equation are the concave clearance and distance along the concave. Cylinder speed, moisture content, and variety were statistically insignificant.

The mean S.S.I. at concave inlet and concave extension was 5.0 and 2.0, respectively. The average throughput in the shelling mechanism was 63 percent through the concave (zone 1, 2, and 3), 26 percent through the concave extension, and 11 percent past concave extension.

Mechanical damage across the shelling mechanism was linearly expressed in terms of zone and moisture by a regression equation of the form:

\[
D = 0.19 + 0.93(Z) + 0.69(M)
\]

The mean for mechanical damage increased from 15 percent at concave inlet (zone 1) to 45 percent past the concave extension (zone 5). The longer the kernel stayed in the shelling crescent, the more damage it suffered. The increase in damage along the concave was caused by the repetitive impacts from the rasp bars of the cylinder as ears and shelled kernels traveled down the shelling crescent. It is conceivable that damage could be reduced if the repetitive impacts are reduced by modifying the shelling mechanism. Because shelling becomes easier after some kernels have been detached, a shelling mechanism that would provide less agitation after the initial impacts might reduce mechanical damage.

References