ABSTRACT

During agricultural production, grain damage is a persistent problem that reduces grain quality. The goal of this study is to develop mechanics-based models that can accurately predict grain damage caused by mechanical handling processes and validate the models with lab-scale and industrial-scale test systems.

A discrete element method (DEM) simulation was developed to predict the impact damage of corn kernels in a Stein breakage tester. The DEM model relied on an empirically generated, three-parameter Weibull distribution describing the damage probability of repeated impacts. It was found that the DEM model was able to give good predictions on the kernel damage fraction for different sample sizes and operating times. The root-mean-square deviation between the damage fractions acquired from the simulation and experiment is 0.05. A sensitivity analysis was performed to study the effects of material and interaction properties on damage fraction. It was found that damage resistance parameters, coefficients of restitution, and particle shape representation had a significant effect on damage fraction. The statistics of the number of contacts and impact velocity were collected in the simulation to interpret the results of sensitivity analysis at the contact level. The locations where the damage occurs on the particle and in the operating device were also predicted by the model.

In addition to impact damage, another major type of grain damage is compression damage caused by mechanical harvesting and handling processes. A mechanistic model was developed to predict the compression damage of corn kernels using the DEM. The critical model input parameters were determined using a combination of single kernel direct measurements and bulk kernel calibration tests. The Young's modulus was measured with a single kernel compression test and verified with a bulk kernel compression test. An innovative approach was proposed to calibrate the average failure stress using a bulk kernel compression test. After implementation of the model, a validation test was performed using a Victoria mill. Comparing the simulation and the experimental results demonstrated that the simulation gave a good prediction of the damage fraction and the location of the damage when the von Mises stress damage criterion with a variable damage threshold was used. A sensitivity analysis was conducted to study the effects of selected model input parameters, including particle shape, Young's modulus, particle-particle coefficient

of friction, particle-boundary coefficient of friction, particle-boundary coefficient of restitution, and damage criterion.

An industrial-scale handling system was designed and built to validate the DEM-based grain impact damage model. The low moisture content corn and soybean samples were handled through the system at three impeller speed levels and two feed rate levels, and the amount of damage caused by handling was evaluated. DEM simulations with the impact damage model were constructed and run under the corresponding test conditions. The experimental results showed that grain damage increased with increasing impeller speed and decreasing feed rate, which aligned with the model predictions. The simulated damage fraction values were larger than the experimental measurements when the experimentally-measured DEM input parameters were used. The simulation predictions can be significantly improved by decreasing the particle-boundary coefficient of restitution (PB COR). The mean absolute error between the simulation and experimental results decreased from 0.14 to 0.02 for the corn tests and from 0.05 to 0.01 for the soybean tests after the reduction of PB COR.

The developed damage models can accurately predict the amount of grain damage and the locations where the damage occur within a grain handling system. The models are expected to be useful in providing guidance on designing and operating grain handling processes to minimize kernel damage and, thus, improve grain quality. To further improve the performance of the model, the methods that accurately and efficiently determine the model input parameters need to be explored. In addition, in this work, the models were only applied to corn and soybeans at specific conditions. The applicability of the model to other types of grain, such as rice, or other grain conditions, such as wet corn, should be investigated.