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Original Research Paper

A multi-sphere based modelling method for maize grain assemblies

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ABSTRACT

In this paper, the geometric shape, dimension parameters and density of maize grains were studied to establish a DEM analysis model of maize assemblies. According to the results, the shape of maize grains of the same variety can be divided into wide wedge, narrow wedge, ellipsoidal-conical and irregular shapes. Amongst these shapes, the quantity of wide wedge and narrow wedge shapes accounts for more than 90% of the total. When modelling maize assemblies, wedge shaped maize can be chosen to establish a geometric model with the upper base defined as the main dimension and other dimensions calculated based on the relationship with the main dimension. The geometric model of single maize grains was established using a Multi-Sphere (MS) model. This analysis model of maize grain is acceptable for scenarios with 14–16 sub-spheres. On the basis of this work, 2 varieties of maize grains are used as examples. The feasibility and validity of the modelling method of maize assemblies and single maize grains are preliminarily verified through comparison of experimental and simulated data to determine repose angles and bulk density.

0. Introduction

Discrete Element Method (DEM) was first proposed by Cundall and has become as a numerical tool for simulating the mechanical, static and dynamic behavior of granular materials following publication of the seminal study in 1979 [1]. Newton's second law of motion and Euler's dynamics equation are usually used to describe the translational and rotational movements of particulate assemblies [2,3]. The DEM has been widely used in many industrial, agricultural, mining and food industry settings [4–9].

The analysis model of particles needs to be established when applying the DEM to analyze the movement of particulates. Granular materials in nature often vary widely and have a range of complex shapes. For instance, maize grains have irregular shapes and even maize grains of the same variety have particles with greatly different shapes and dimensions. There is a need for further research on the analysis model of maize grain assemblies and single maize grains to more precisely model these structures.

Coetzee [10] used two spheres with different radii to describe a model of maize grains. Tao et al. [11] established the corn-shaped particle model using four overlapping spheres with the flow patterns, probability densities and voidage distributions of particles are in the moving bed. González-Montellano et al. [12] studied maize grains approximated to 6 sub-spheres and simulated the discharge flow of maize grains in silos. A comprehensive research of the adequacy of multi-sphere approximation for maize grains and the comparison of bulk density and discharge time with corresponding number has also been presented by Markauskas et al. [13].

When establishing a model of maize grains using the filling method described above, it is apparent that the higher the number of sub-spheres used in the model, the higher the level of accuracy that can be achieved in the approximation of the actual maize. However, computational time for the calculation of contact forces between the particles also increases. When a certain value is reached by sub-spheres, the maize grain model is reasonable in terms of both accuracy and computational resources. However, this specific value is not given in numerous reported studies. Furthermore, due to the different shapes and dimensions of the maize grains, studies also need to determine differences in maize grains of the same variety. The shape and size distributions of particle assemblies of a particular variety of maize using DEM simulation should be consistent with actual maize grain assemblies.

In this paper, two varieties of maize grains were chosen as the research subjects. The geometric shape, dimension parameters and density of the maize grain assemblies were tested and

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analyzed. The modelling method of maize assemblies and single maize grains, including the filling scheme and number of sub-spheres of a single maize grain is proposed. The feasibility and validity of the modelling method are verified by simulations and experimental results to determine angle of repose and bulk density.

1. Analysis of geometric shape, dimensions and maize grain density

1.1. Study of the geometric shapes of maize grains

After observing maize grains on the ear, it was found that the grains observed in the large end are irregularly shaped whereas the grains present in the smaller end show spherical, conical or irregular shapes. Grains between the large and small ends are regularly present and approximate to wedge shapes. Based on these observations, it can be concluded that the shapes of maize grains for the same variety can be generally divided into wide wedge, narrow wedge, ellipsoidal-conical or irregular shapes, as shown in Fig. 1.

Three thousand maize grains of the same variety were selected randomly for the current study. The number of grains of wide and narrow wedge, ellipsoidal-conical and irregular shapes was counted and the percentage of each shape of the total calculated. Two varieties of maize grains, Xianyu 335 and Baidan 678, were used as examples. The results indicated that the wide wedge shaped grains accounted for a large proportion, more than 80%, whilst the narrow wedge grains took second place (greater than 10%). Ellipsoidal-conical shaped and irregular shaped grains account for small proportions of 2% and 5% respectively. In addition, the wide and narrow wedge shaped grains approximate to the wedge shape as shown in Fig. 2a and b. The proportion of wedge shaped grains was more than 90%. In order to simplify the model, wedge shaped geometries of maize grain assemblies and single maize grains were used.

1.2. Tests and analysis of the dimensions of maize grains

For wide and narrow wedge shaped maize grains, the size features including the upper base (W_1), under base (W_2), height (H_1), height (H_2), thickness (T_1), thickness (T_2), are shown in Fig. 2. 100 grains were selected randomly from those of wide and narrow wedge shape and wedge shape (with a ratio of 88 wide wedge shaped grains and 12 narrow wedge shaped grains) of two varieties of maize. Digital calipers with an accuracy of 0.01 mm were used to measure the dimensions of the grains which proved to be in compliance with a normal distribution. The distribution of the upper base of wide wedge shaped Xianyu variety grains is shown in Fig. 3.

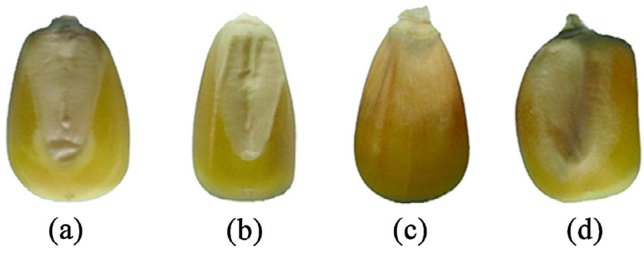

Fig. 1. Geometric shape classification of maize grains of the same variety, wide wedge shape (a), narrow wedge shape (b), ellipsoidal conical shape (c) and irregular shape (d).

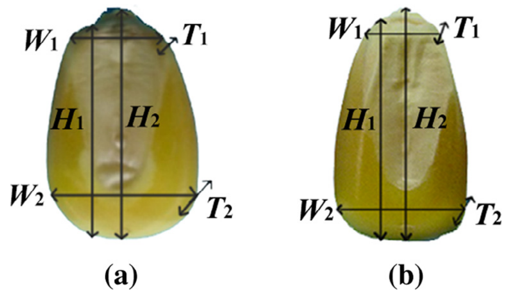

Fig. 2. Dimension parameters of wedge shaped maize grains, wide wedge shape (a) and narrow wedge shape (b).

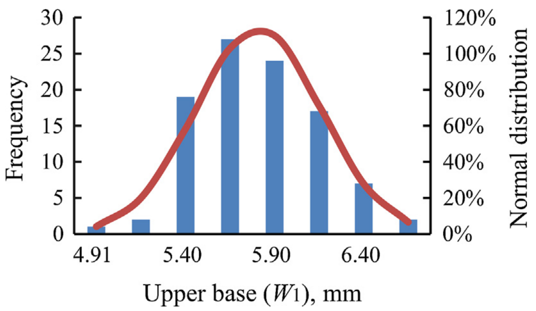

Fig. 3. Distribution of upper base of wide wedge shaped maize grains of Xianyu.

Based on this analysis, there is a functional relationship between height, the under base, thickness and the upper base parameters of the grains as shown in Fig. 4. As a result of this analysis, the upper base can be chosen as the main dimension and other dimensions calculated according to the relationship to the main dimension. The dimensions and distributions of such maize assemblies are close to that of the actual maize grains as demonstrated in Fig. 4.

1.3. The effect of moisture content on maize grain dimensions

To study the effect of moisture content on maize grains, 100 wide and narrow wedge shaped grains of Xianyu and Baidan varieties were selected randomly. The dimensions of these grains at the original moisture content were measured. In addition, the dimensions of the strains under four different moisture content conditions were obtained through humidification.

The geometric dimensions of grains, such as the upper base (W_1), under base (W_2), height (H_1), thickness (T_2), increased with increasing moisture content within a moisture range of 7.87–24.36% w.b. for the Xianyu variety and 8.10–22.20% w.b. for the Baidan variety. For wide wedge shaped maize grains of the Xianyu variety, the upper base (W_1), under base (W_2), height (H_1),

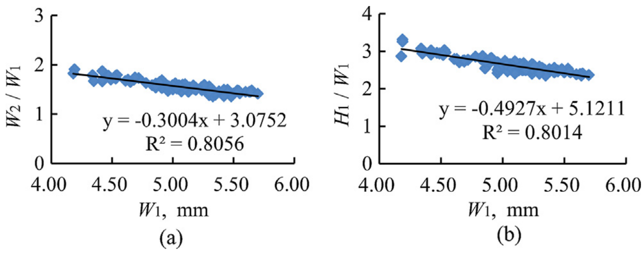

Fig. 4. The relationship between dimensions of narrow wedge shaped maize grains of the Xianyu variety. Under base and upper base (a), and height and upper base (b).