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Effect of moisture content on some physical properties of sugar beet seed

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ABSTRACT

Some seed physical properties of two sugar beet varieties, Shirin and Gadouk (436), were evaluated as a function of seed moisture content. Physical properties included length, width, thickness, arithmetic and geometric mean of dimensions, sphericity coefficient, 1000-seed weight, angle of repose, terminal velocity, true density, bulk density, porosity, and coefficient of static friction. Four moisture contents (8.4, 9.8, 11.9, and 14.0%) and two varieties were evaluated in a factorial arrangement based on completely randomized design. With increase in moisture content, the length, width, and thickness of the seeds were increased by 11.37, 15.61, 8.82%, respectively, for Shirin, and 5, 4.54, and 6.69%, respectively, for Gadouk. An increase of arithmetic and geometric mean of dimensions, sphericity coefficient, 1000-seed weight, angle of repose and terminal velocity was observed when moisture content increased, whilst true density, bulk density, and porosity were decreased linearly. Increasing moisture content was found to increase static friction coefficient of the both varieties on four structural surfaces including rubber, plywood layer, galvanized steel, and aluminium. The maximum and minimum values of static friction coefficient of the both varieties were obtained on rubber and galvanized steel surfaces, respectively. The regression equation of the relationship between physical properties and seed moisture content was obtained, and validated by analysis of variance. Results showed that the obtained equation can be used in prediction of seed physical properties for other moisture content levels.

Keywords: Variety, coefficient of static friction, relative humidity, seed diameter

INTRODUCTION

Sugar beet (*Beta vulgaris*) is a biennial plant from Chenopodiaceae family that grows in different climatic conditions. In 2011, 172 million tonnes sugar was produced in the world from which 20% was supplied by sugar beet and 80% by sugarcane. The area of sugar beet cultivation in Iran is about 100000 ha and the annual production is about 4 million tons (FAO 2011). Processed seeds are used for sugar beet planting. After harvest, seeds undergo various mechanical operations such as cleaning, grading, ventilation, pelleting, and pneumatic transfer (Kockelmann et al. 2010; Bisht and Ahlawat 1999; McCormack 2004). For designing, constructing, and optimizing the seed processing machines, it is necessary to obtain sufficient knowledge about seed's physical properties such as size, shape, volume, density, porosity, coefficient of static friction, velocity, etc. (Kassab 2006; Al-Mahasneh and Rababah 2007). In recent years, several studies were performed on physical and mechanical properties of agricultural crops. Singh et al. (2010) and Hazbavi et al. (2008) studied the physical properties of millet and eggplant seeds, respectively. Owing to the strategic importance of wheat and barley and also considering their physicochemical properties in the design and construction of related machines, extensive studies have been conducted onthese two crops (Rajabipour et al. 2006; Aghajani et al. 2012; Tabatabaeefar 2003; Al-Mahasneh 2006).

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Considering the physical properties of maize and flax seeds, Jayan and Kumar (2004) determined the parameters of designing planters. Frahangmehr et al. (2010) and Alemi et al. (2009) studied the physical properties of six soybean varieties. Similar studies were also performed on the seeds of other crops such as cotton (Ozarslan 2002), flax (Sacilik et al. 2003), quinoa (Vilche et al. 2003), lentil (Amin et al. 2004), canola (Razavi et al. 2009), *Laurus nobilis* (Kasap 2006), sugar beet (Dursun et al. 2007), rice (Kibar et al. 2010), and Karya (Ogunsina et al. 2011). The aforesaid studies, especially Kasap (2006) and Dursun et al. (2007) showed that some physical properties of the seeds which are used in processing, transportation, storage, and planting are often dependent on variety type and their moisture content. Owing to the lack of sufficient information regarding the physical properties of sugar beet seeds in Iran, the main purpose of this study was to evaluate the physical properties of two sugar beet varieties in order to provide required information for the design, construction and optimization of processing equipments and planting machines.

Materials and Methods

This study was conducted in 2011 at the laboratory of Physicochemical Properties of Agricultural Crops in Shahrekord, Iran. Two sugar beet varieties including monogerm Shirin and 436 were received from Shahrekord sugar factory. Samples were cleaned manually and cracked or wrinkled seeds were removed. Moisture content of the samples was determined by oven drying at 105 ± 1 ^{o}C for 24 h (Gupta and Das 2000; Dursun et al. 2007). The required amount of distilled water was added to maintain the optimum moisture content. Samples were placed into plastic bags and then stored at 5 ^{o}C for up to 10 days to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantities of the seed were allowed to warm up to room temperature for 2 hours (Deshpande et al. 1993; Visvanathan et al. 1996; Altuntas and Yildiz 2007). The recommended moisture content for sugar beet seed processing and storage is less than 12% (Kockelmann 2010), therefore, the physical properties of the seeds were evaluated at four moisture levels including 8.4, 9.8, 11.9, and 14% (on the basis of dry weight). The experiment was conducted as factorial arrangement based on completely randomized design with five replications including four moisture content levels and two varieties.

In order to determine the average size of the seeds, 5 sub-samples each containing 100 seeds were randomly drawn from the bulk sample. For each individual seed, three principal dimensions, namely length (L), width (W) and thickness (T) were measured using an electric micrometer with an accuracy of 0.001 mm. The arithmetic (Da, mm) and the geometric mean diameter (Dg, mm) of the seeds were calculated using the relationships 1 and 2, respectively (Mohsenin, 1978):

$$D_a = \frac{L+W+T}{3} \quad (1)$$

$$D_g = (WLT) \wedge -3 \quad (2)$$

According to Mohsenin (1978), the degree of sphericity, φ (%), can be expressed as follow:

$$\varphi = \frac{D_g}{L} \quad (3)$$

In order to determine the 1000-grain weight (M1000), 5 sub-samples each containing 1000 seeds were randomly drawn from the bulk sample for each variety and were weighed with digital balance with an accuracy of 0.001 g. True density for four moisture levels was determined using the liquid displacement method (Mohsenin 1978). Toluene ($C_6H_5CH_3$) was used instead of water, because it is absorbed by seeds to a lesser extent. The volume of toluene displacement for 15-20g seeds was measured and thus the true density calculated (Sitkei 1976; Mohsenin 1978).

In order to measure the bulk density, the seeds were poured into a graduated cylinder up to 150 ml and weighed. The seeds were not compacted in any way. The bulk density was calculated on the basis of the seed mass and volume.

The porosity was calculated for all four moisture levels from the measured values of bulk density (P_b) and true density (P_t) using the relationship given by Mohsenin (1978). This relationship is presented in the form of equation 4:

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \quad (4)$$

where P_b and P_t are expressed as g cm^{-3} The discharge angle of repose was determined by using a topless and bottomless hollow cylindrical mould of 30×30×30 cm dimension. The cylinder was placed at the centre of a raised ridge, filled with seeds and lifted slowly until it formed a cone of seeds. The radius of sample distribution (R) and height (H) of the cone in the middle of the ridge were recorded. The discharge angle of repose (θ) was calculated by the following equation:

$$\theta = \tan^{-1}\frac{H}{R} \quad (5)$$

where *H* and *R* are expressed as mm. Terminal velocity was measured at various moisture levels by using a seed blower (air column system). For each experiment, a seed was dropped into the air stream from the top of the air column, in which air was blown to suspend the seed in the air stream. The air velocity near the location of the seed suspension was measured by an anemometer (Sacilik et al. 2003; Rajabipour et al. 2006). Each sample contained 20 seeds randomly drawn from the moisture level of interest.

The coefficient of static friction was determined with respect to four surfaces: plywood, rubber, aluminium and galvanized steel sheet. A plastic box measuring 100 mm in width, 50 mm in height and open at both ends was filled with the seeds at the desired moisture content and placed on an adjustable tilting surface such that the box did not touch the surface. The tilting surface was raised gradually (about 3 mm) by means of a screw device until the cylinder with seeds just started to slide down (Shepherd and Bhardwaj 1986; Gupta and Das 1997; Dutta et al. 1998; Nimkar and Chattopadhyay 2001; Owolarafe and Shotonde 2004). The angle of the incline (α) was read from a graduated scale and the coefficient of static friction (μ) was calculated from the following equation:

$$\mu = tg\alpha \quad (6)$$

where μ is the coefficient of friction and α is the angle of slope on the basis of degree unit.

The data obtained were analysed separately for each parameter, variety and moisture level. Regression equations and coefficients of determination (R^2) were calculated using SPSS15 software.

Results and Discussion

The results of ANOVA showed that moisture content had significant effect ($p<0.01$) on all the traits measured. Also, variety type had significant effect ($p<0.01$) on physical properties except 1000-grain weight and terminal velocity.

Seed dimensions

As the moisture content increased from 8.4 to 14%, the length, width and thickness of the seeds varied from 5.10 to 5.68 mm (11.37% increase), 4.10 to 4.74 mm (15.61% increase), 2.38 to 2.59 mm (8.82% increase), respectively for Shirin variety, and from 5.40 to 5.67 mm (5% increase), 4.40 to 4.60 mm (4.54% increase), 2.39 to 2.55 mm (6.69% increase), respectively for 436 variety.

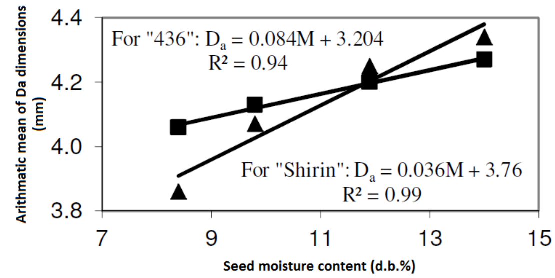

Figure 1. Average values of arithmetic mean dimensions of Shirin (■) and 436 (▲) varieties at different moisture contents

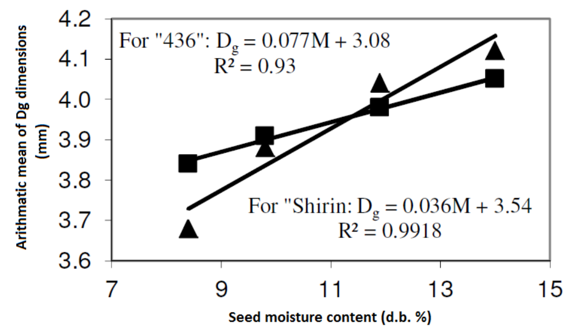

Figure 2. Average values of geometric mean dimensions of Shirin (■) and 436 (▲) varieties at different moisture contents

It was found that geometric and arithmetic mean dimensions of the two varieties increased with increase in moisture content (Figures 1 and 2). The regression equations between the arithmetic mean dimensions and moisture level along with the coefficient of determination are shown in Figures 1 and 2. The arithmetic mean dimensions (length, width, and thickness) increased from 3.86 to 4.34 mm with increase in moisture content for Shirin variety and from 4.06 to 4.27 mm for 436 variety, respectively (Figure 1). The arithmetic mean dimensions were significantly ($p<0.05$) correlated with moisture content of seeds (Figures 1 and 2). The geometric mean dimensions (length, width, and thickness) also increased from 3.68 to 4.12 mm with increase in moisture content for Shirin variety and from 3.84 to 4.05 mm for 436 variety, respectively. Similar results were reported by Dursun et al. (2007).

Sphericity

The sphericity increased gently and linearly with moisture content. The significant ($p \leq 0.05$) linear relationship and coefficient of determination between sphericity and moisture content are shown in Figure 3. Shirin variety had higher sphericity coefficient than the variety 436. These

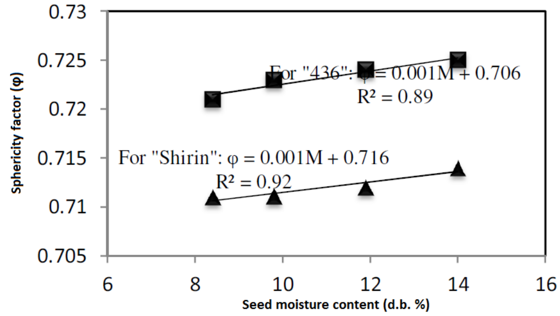

Figure 3. Relationship between sphericity of Shirin (■) and 436 (▲) varieties and moisture content

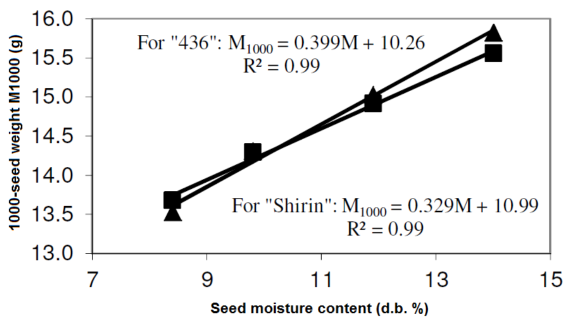

Figure 4. Relationship between 1000-grain weight of Shirin (■) and 436 (▲) varieties and moisture content

linear behaviours are in accordance with results reported by Dursun et al. (2007). However, the linear slope was negative in their study which is due to the variety difference.

1000-grain weight

One-thousand-grain weight increased with increase in moisture content from 13.7 to 15.6 g for variety Shirin, and from 13.5 to 15.8 g for variety 436, respectively. Variety had no significant effect on 1000-grain weight so that the regression equations between 1000-grain weight and moisture content for the both varieties are quite close to each other (Figure 4). These results are in accord with those of Kassap (2006) and Dursun et al. (2007).

True density

The variation of bulk density of two varieties with moisture content is depicted in Figure 5. It can be seen that as moisture content increased from 8.4 to 14%, true density decreased from 834.6 to 718 kg m^{-3} for variety Shirin, and from 860.8 to 725.2 kg m^{-3} for variety 436. The same trends have also been reported by Shepherd and Bhardwaj (1986); Deshpande *et al.* (1993); Gupta

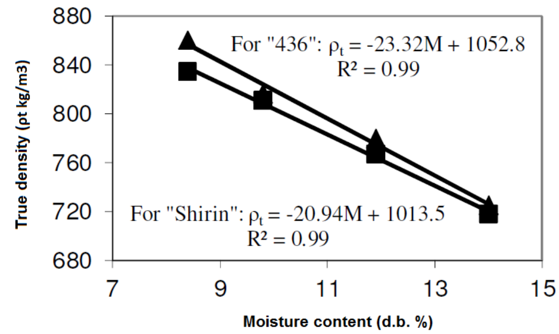

Figure 5. Relationship between true density of Shirin (■) and 436 (▲) varieties and moisture content

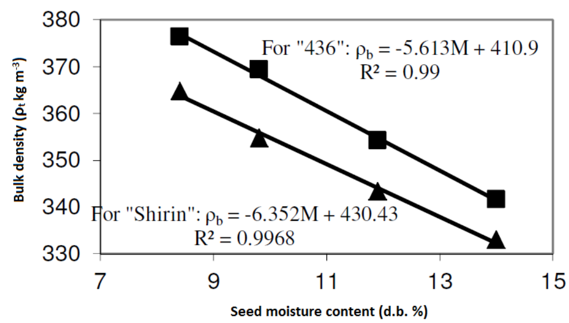

Figure 6. Relationship between bulk density of Shirin (■) and 436 (▲) varieties and moisture content

and Das (1997); Dutta *et al.* (1998), Bart-Plange and Baryeh (2003); and Dursun *et al.* (2007).

Bulk density

As moisture content increased from 8.4 to 14, bulk density decreased from 376.4 to 341.6 kg m^{-3} for variety Shirin, and from 364.8 to 333 kg m^{-3} for variety 436 (Figure 6). These seeds thus have lower weight increase in comparison with volume increase as their moisture content increases. The regression equations of bulk density with moisture contents and R^2 of the present study are presented in Figure 6.

Porosity

The porosity of the sugar beet seeds decreased with increase in moisture content (Figure 7) and ranged from 54.9 to 52.42% for variety Shirin and 57.61 to 54.07% for variety 436. The change in porosity with moisture content can be represented by the equations shown in Figure 7. Similar trends were reported by Tang and Sokhansanj (1993), Joshi et al. (1993), Sacilik et al. (2003), and Dursun et al. (2007).

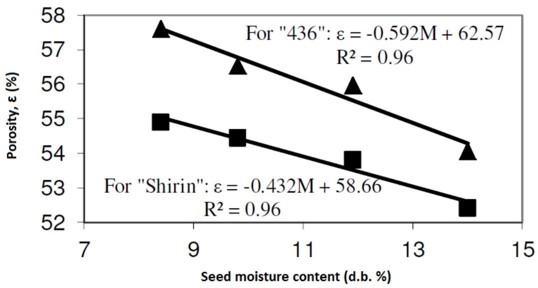

Figure 7. Relationship between porosity of Shirin (■) and 436 (▲) varieties and moisture content

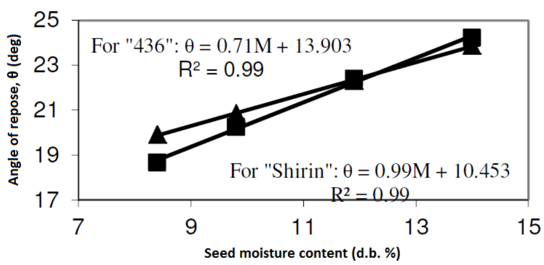

Figure 8. Relationship between angle of repose of Shirin (■) and 436 (▲) varieties and moisture content

Emptying angle of repose

The experimental data for emptying angle of repose of sugar beet seeds are presented in Figure 8. The emptying angle of repose increased linearly as the seed moisture content increased for both varieties, and it can be expressed by the relations shown in Figure 8. The angle of repose for varieties Shirin and 436 increased to 29.8 and 19.95%, respectively as the moisture content ranged from 8.4 to 14%. The increase might be due to the differences in surface roughness of seeds.

A linear increase in angle of repose with moisture content was reported by Dursun *et al.* (2007) and Kassap (2006).

Terminal velocity

The variation of the terminal velocity of sugar beet seeds with moisture content is plotted in Figure 9. As it is seen, the terminal velocity increased with increase in moisture content and ranged from 3.59 to 4.55 m S^{-1} for variety Shirin and 3.67 to 4.43 m S^{-1} for variety 436 Increased terminal velocity due to increased moisture content can be attributed to increase in individual seed weight per unit area opposite to the air stream. Similar trends were reported by Suthar and Das (1996), Nimkar and Chattopadhyay (2001), Konak *et al.* (2002), Gezer *et al.* (2002), and Sacilik *et al.* (2003), and Dursun *et al.* (2007).

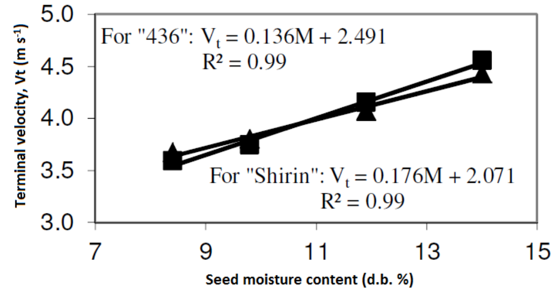

Figure 9. Relationship between terminal velocity of Shirin (■) and 436 (▲) varieties and moisture content

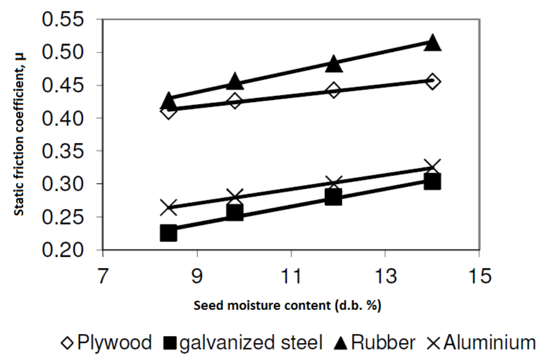

Figure 10. Relationship between static friction coefficient of variety Shirin and moisture content

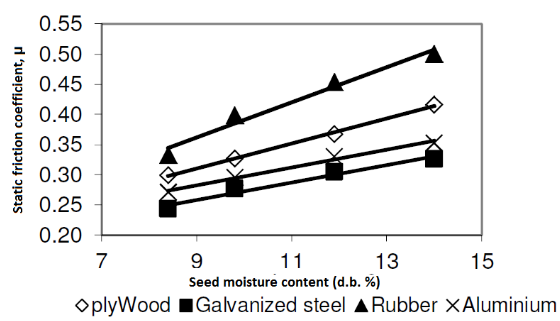

Figure 11. Relationship between static friction coefficient of variety 436 and moisture content

Coefficient of static friction

The coefficients of static friction for both varieties with respect to rubber, plywood layer, galvanized steel, and aluminium at different moisture levels are presented in Figures 10 and 11. It was observed that the coefficient of static friction increased with increase in moisture content for all the surfaces tested. Increase in static friction coefficient with moisture content may be explained by increased cohesive force of wet seeds with the structural surface, since the surface become stickier as moisture content increases. Similar findings were reported by Shepherd and Bhardwaj (1986), Dursun *et al.* (2007), Dutta *et al.* (1998), Carman (1996), Suthar and Das (1996), and Kassap (2006).

Table 1. Mean and standard error for mean dimensions as a function of moisture content in two sugar beet varieties

	Variety							
	Shirin				436			
Moisture content (%)	8.4	9.8	11.9	14	8.4	9.8	11.9	14
Length (mm)	5.10±0.04	5.36±0.02	5.57±0.01	5.68±0.01	5.40±0.01	5.50±0.00	5.58±0.01	5.67±0.01
Width (mm)	4.10±0.02	4.39±0.01	4.63±0.01	4.74±0.01	4.40±0.00	4.48±0.00	4.54±0.00	4.60±0.00
Thickness (mm)	2.38±0.03	2.48±0.01	2.55±0.01	2.59±0.01	2.39±0.01	2.42±0.00	2.49±0.00	2.55±0.00

Table 2. Intercept, regression coefficient, and R^2 values of $\mu = A + BM$ equation for determination of the static friction coefficient of sugar beet seeds on different surfaces

Variety	Surface tested	Intercept (A)	Regression coefficient (B)	R^2
Shirin	Rubber	3030.0	15.0	0.99
	Plywood layer	346.0	8.0	0.98
	Aluminium	174.0	18.0	0.99
	Galvanized steel	118.0	13.0	0.97
	Rubber	099.0	3.0	0.97
436	Plywood layer	124.0	21.0	0.99
	Aluminium	149.0	15.0	0.99
	Galvanized steel	128.0	14.0	0.97

Rubber surface showed the highest static friction coefficient followed by plywood layer, then aluminium, and finally galvanized steel.

The relationship between static friction coefficient and moisture content can be explained by the following equation:

$$\mu = A + BM$$

in which μ is static friction coefficient, and A and B are intercept and regression coefficient, respectively. The values for both varieties are represented in Table 2.

Conclusion

The results of this study showed that all physical properties were associated with moisture content. For all moisture content levels, geometric and arithmetic mean dimensions, 1000- grain weight, sphericity coefficient, terminal velocity, and angle of repose were increased with moisture content increase for both varieties. Sphericity coefficient is used as an index to show the similarity of the crop to a perfect sphere which is utilized in the design of planting equipments. High sphericity index indicates the optimum potential of the seeds to pass the circular pores and also their capability in rolling. The terminal velocity values are used as important aerodynamic features of sugar beet seeds in the design of seed furrows, pneumatic transferring systems, and cleaning equipments. In this study, the lowest terminal velocity values were observed in lower moisture content levels. Therefore, for operations such as cleaning or pneumatic transfer, lower moisture content results in lower blower energy consumption. In addition, the non significant effect of variety on terminal velocity indicates that similar equipments can be used for this operation.

Angle of repose shows the seed ability to stream which can be used in design of seed silo and storage facilities. Low angle of repose makes the seeds spread out wider on a plain surface compared to high angle of repose. So, to facilitate seed storage unloading, lower limits of seed moisture content are recommended.

In this study, bulk density, true density, and porosity values were decreased with moisture content increase. These parameters can be used in the design of seed planting equipments, calculation of the weight and heat transfer during drying and aeration processes. Seeds having lower porosity are more resistant against water evaporation during drying. Therefore, these processes can be performed on seeds with low moisture content and high porosity by using fans with less power which reduces operating costs.

Increase in static friction coefficient for both varieties and in all surfaces tested showed that higher moisture content resulted in more toughness of the seeds which increased water absorption by the seeds and also the rate of viability. In general, in terms of designing and constructing processing equipments and seed tank for planting machines, static friction coefficient increase is not helpful. Thus, the operation in lower moisture content (<10%) is more appropriate.

The results of this study are presented for the first time which can be used for the design of planting, harvesting, transferring, storage, ventilation, and processing equipments.

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