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Moisture-dependent physical properties of green peas (*Pisum sativum* L.)

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Abstract

This study was conducted to evaluate some moisture-dependent physical properties of green peas (*Pisum sativum* L.) at the range of 75.15 to 15.21% w.b. In this moisture content range, the length varied from 10.48 to 7.28 mm, the width from 8.93 to 5.80 mm, the thickness from 8.61 to 5.15 mm, the arithmetic mean diameter from 9.34 to 6.07 mm, and the geometric diameter from 9.10 to 5.90 mm. Similarly, the sphericity from 86% to 81%, the aspect ratio from 85.20 to 79.67%, the surface area from 260.15 to 109.35 $mm^{2,}$ the one thousand mass from 547.46 to 188.89 g, the porosity from 42.02 to 40.75%, the angle of repose from 40.62° to 20.50°, and the terminal velocity from 11.88 to 9.21 m/s. In the same moisture range, the bulk and true density increased from 630.76 to 670.70 kgm^{-3} and from 1088 to 1132 kgm^{-3}, respectively. The static coefficient of friction showed a decrease of 30.64%, 23.53%, 27.76% and 27.50% for the surfaces of rubber, plywood, galvanised iron sheet and glass, respectively. Regression models adequately expressed the relationships existing between the physical properties of green pea seeds with the moisture content. In the considered range of moisture content, all of these physical properties exhibited moisture dependence according to linear relationships except the surface area which showed second-order polynomial.

Introduction

Green pea (*Pisum sativum* L.) is one of the most common and popular vegetables in the world which are widely cultivated in temperate zones (Ambrose, 1995; Zohary and Hopf, 2000). China, India, USA, France and Algeria are the leading producers. In Iran, the annual production of green pea was about 34423.00 tons (FAO, 2014). Green peas have a nutritionally favourable composition as they have a low fat and high fibre content (soluble and insoluble), vitamins (especially vitamins of B group), complex carbohydrates, minerals and also are considered to be an inexpensive source of proteins which especially rich in the essential amino acids tryptophan and lysine (21–25%) (Tiwari and Singh, 2012). Green peas also contain starch with a low glycemic index (Foster-Powell and Brand-Miller, 1995), ascorbic acid, β-carotene, thiamine and riboflavin and, compared to other vegetables, peas are rich in iron. Therefore, green peas contain biologically active component with health-promoting properties (Roy *et al*., 2010).

On the other hand, green peas have a relatively low content of anti-nutritional factors (Wang *et al*., 2008) and like other legumes are important in human and animal nutrition (Nguyen *et al*., 2015). They are widely used in soups, breakfast cereals, processed meats, health foods, pastas and purees or processed into pea flour, pea starch, or pea protein concentrates (Sharma *et al*., 2015). Therefore, thorough information regarding the physical properties is very important to optimize the equipment design for harvesting, transporting, cleaning, separating, packaging, storing and analysis of the product behaviour during different agricultural process operations. Size, shape and physical dimensions are important in sizing, sorting, sieving and other separation processes. Furthermore, these characteristic allow a calculation of the surface area and volume of biological materials which important for modelling of drying and ventilation (Al-Mahasneh and Rababah, 2007). The bulk and true density are used to determine the capacity of storage and transport, and to design proper separation equipment, respectively (Sologubik *et al*., 2013).

Terminal velocity is very critical in the design of pneumatic conveyor, transporting using air and separation of biological materials from undesirable materials such as shells, hulls, leaves and small branches. During harvesting, handling, processing and storage of biological materials, the products exert frictional forces on machinery components or storage structures. So, it is necessary to determine the frictional forces as the magnitude of these frictional forces affects the amount of power required to convey the material (Altuntas *et al*., 2005; Kashaninejad *et al*., 2006).

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In recent years, the physical properties of various crops such as okra seed (Sahoo and Srivastava, 2002), cornelian cherry (Demir and Kalyoncu, 2003), lentil seed (Amin *et al*., 2004), gumbo fruit (Akar and Aydin, 2005), fenugreek seed (Altuntas *et al.,* 2005), pine nut (Ozguven and Vursavus, 2005), pistachio nut (Kashaninejad *et al.,* 2006), cowpea seed (Kabas *et al*., 2007), tef seed (Zewdu and Solomon, 2007), sugar beet seed (Dursun *et al*., 2007), paddy grains (Zareiforoush *et al*., 2009), barley (Tavakoli *et al*., 2009; Sologubik *et al*., 2013) and *Moringa oleifera* seed (Aviara *et al*., 2013) have been studied.

Review of literatures showed that there is a limited information on physical properties of green pea seeds as a function of wide ranges of moisture content except that published by Yalcin *et al*. (2007). Therefore, the objective of the present study was to determine some moisture-dependent physical properties of green pea seeds namely length, width, thickness, aspect ratio, surface area, sphericity, one thousand mass, bulk density, true density, porosity, terminal velocity, static coefficient of friction against different surfaces and angle of repose in the range of 75.15 to 15.21% w.b. moisture content which will be necessary for designing of equipment to handle, transport, process and store the crop.

Materials and Methods

In the present study, the fresh green pea (*Pisum sativum* L.) seeds were obtained from the local market in Zanjan (36°40′N 48°29′E), Iran. The green pea seeds were cleaned manually to remove all foreign matter, broken or immature seeds. The initial moisture content of the green pea seeds was determined using oven drying at 105±1°C for 24 h (AOAC, 1990). The initial moisture content of the green peas was found to be 75.15% w.b. The physical properties were determined at four moisture levels (15.21, 35.10, 55.18 and 75.15% w.b.). These values are within the range of moisture contents encountered for green pea seeds from harvest to storage. Moreover, it is recommended that the moisture content for green peas should be in the range of 10 to 16% for long storage period (Yalcin *et al*., 2007). Moisture levels lower than the initial moisture content of the sample was attained by drying the green pea seeds at 40°C.

100 green peas were randomly selected and their principal dimensions including length (L), width (W) and thickness (T) were measured using a digital caliper with an accuracy of 0.01 mm. The arithmetic mean diameter ($D_{a)}$ and the geometric mean diameter (D_g) were calculated by using the following equations, respectively (Mohsenin, 1970):

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

$$D_g = (LWT)^{1/3}$$

The shape of the green peas was expressed by its sphericity (ϕ). It was calculated by using the following equation (Mohsenin, 1970):

$$\emptyset = \left[\frac{(LWT)^{1/3}}{L}\right] \times 100$$

The aspect ratio (R_a) was calculated as follows (Omobuwajo *et al*., 1999; Altuntas *et al*., 2005):

$$R_a(\%) = \left(\frac{W}{L}\right) \times 100$$

The surface area (S) was determined by analogy of a sphere in mm^2 using the following equation (Mohsenin, 1970):

$$S = \pi D_g^2$$

The thousand green peas mass (M_t) was obtained using an electronic digital balance with an accuracy of 0.001 g. 100 green pea seeds were separated randomly for each moisture content from the lot and weighed (M). The number of green pea seeds (n) in the sample was counted and the mass of 1000 green pea seeds was calculated as follows (Mohsenin, 1986):

$$M_t = \frac{M}{n} \times 1000$$

Bulk density (ρ_b) was determined by filling an empty cylindrical container of predetermined in volume (500 mL total volume) with the green peas from a height of 150 mm at a constant rate, striking off the top level and then weighing the contents using an electronic digital balance with an accuracy of 0.001 g (Gupta and Das, 1997). Dropping the seeds from a height of 150 mm produces a tapping effect in the container to reproduce the settling effect during storage (Amin *et al*., 2004). The bulk density in kgm-3 was calculated from the mass of the green peas and the volume of the container.

True density (ρ_t) was determined using the toluene displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by green peas to a lesser extent. In addition of its low dissolution power, its surface tension is also low which allows filling of shallow dips in seeds (Kabas *et al*., 2007). The volume of toluene displaced was found by immersing a weighed quantity of green peas in the toluene (Mohsenin, 1986; Singh and Goswami, 1996).

The porosity of green peas (ε) was calculated using the following relationship (Mohsenin, 1970):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100$$

For measuring the angle of repose, a plywood box of 200×200×200 mm, with a removable front panel, was used. The box was filled with the green peas from a constant height (150 mm) and the front panel was then quickly removed allowing the green peas to flow and assume a natural slope (Joshi *et al.*, 1993). The angle of repose was calculated from the measurements of the height (H) and diameter (D) of slope using the following relationship:

$$\theta = tan^{-1}\left(\frac{2H}{D}\right)$$

The static coefficient of friction (μ) against four different structural materials, namely rubber, plywood, galvanised iron sheet and glass was determined. A tilting platform was fabricated and used for experimentation. The green peas were placed on the surface and it was gradually raised until the peas started to slide down. The angle of tilt (α) was read from a graduated scale and the tangent of this angle recorded as the static angle of friction on that surface (Gezer *et al.*, 2002; Kabas *et al.*, 2007).

The terminal velocity of green peas was determined using a cylindrical air column in which a green pea was dropped into the air stream from the top of the cylindrical air column which air was blown to suspend the material in the air stream (Vishwakarma *et al.*, 2010). The minimum air velocity that held the green peas under suspension was recorded using a digital anemometer (±0.01 m/s).

All experiments were replicated ten times unless stated otherwise, and the average values were calculated. The experimental data were subjected to analysis of variance (ANOVA) and regression analysis was used to determine the relationships existing between the physical properties and green pea moisture contents using Statistica V.10.

Results and Discussion

Green pea seeds dimensions

The dimensional parameters including the length (L), width (W), thickness (T), the arithmetic mean diameter (D_a) and the geometric mean diameter (D_g) decreased significantly ($p<0.05$) with decreasing moisture content from 10.48 to 7.28 mm, 8.93 to 5.80 mm, 8.61 to 5.15 mm, 9.34 to 6.07 mm and 9.10 to 5.90 mm, respectively. These dimensions are important in determining the aperture size of machines, particularly for separation of different materials as discussed by Mohsenin (1986). The average values of experimental results with respect to the studied range of moisture content are shown in Figure 1. The Shrinkage of the green pea seeds as a result of moisture loss can lead to size reduction. The same trends have been reported for sugar beet seed (Dursun *et al.*, 2007), red kidney bean (Isik and Unal, 2007) and Tef seed (Zewdu and Solomon, 2007). The linear dependence of these properties with moisture content (m) could be represented by the following equations:

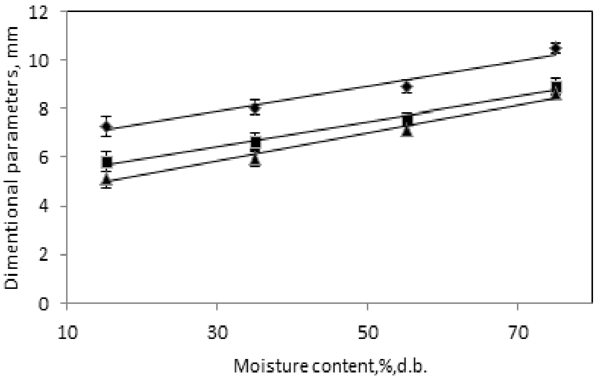

Figure 1. Effect of moisture content on seed length (♦), width (■) and thickness (▲).

$$L = 0.052m + 6.326 \quad R^2 = 0.968$$

$$W = 0.051m + 4.907 \; R^2 = 0.983$$

$$T = 0.057m + 4.117 \; R^2 = 0.982$$

$$D_a = 0.053m + 5.109 \; R^2 = 0.979$$

$$D_g = 0.052m + 4.959 \; R^2 = 0.980$$

Sphericity and aspect ratio

The sphericity (ϕ) was calculated from the values of the geometric mean diameter and the main axis of green pea seed defined as the length (L). The results of sphericity are presented in Figure 2(a). It is clear that the sphericity decreased significantly from 86% to 81% ($p<0.05$) with decreasing moisture content. The high sphericity value suggests that the green peas tend towards a spherical shape. Within the moisture ranges studied, the aspect ratio of green peas varied from 85.20% to 79.67%. These properties are relevant to the design of handling machinery and where ease of rolling is desirable (Oyelade *et al.*, 2005). The linear relationship between sphericity and moisture content (m) is presented as follows

$$\emptyset = 0.085m + 79.91 \quad R^2 = 0.995$$

The decrease in the sphericity may have been caused by a proportional decrease in the length, width and thickness. Similar trends have been reported for green gram (Nimkar and Chattopadhyay, 2001),

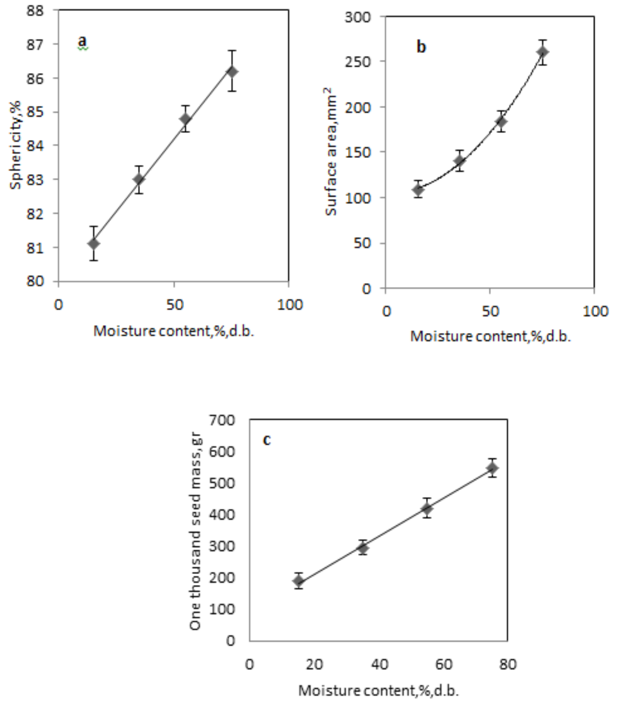

Figure 2. Effect of moisture content on sphericity (a), the surface area (b) and 1000 seed mass (c) of green peas.

sugar beet seed (Dursun *et al*., 2007) and pea seed (Yalcin *et al*., 2007).

Surface area

It is important to determine the surface area of grains or any particulate materials as it affects the rate of moisture loss during drying process. The surface area (S) of green pea seeds as a function of moisture content is plotted in Figure 2(b). The figure indicates that the surface area decreases nonlinearly with decrease in seeds moisture content. The second-order polynomial relationship between the moisture content (m) and the surface area can be expressed as follows

$$S = 0.02m^2 - 0.062m + 104.8 \quad R^2 = 0.998$$

Similar trends have been reported for millet (Baryeh, 2002), popcorn (Karababa, 2006) and green wheat (Al-Mahasneh and Rababah, 2007).

One thousand seed mass

The mass of one thousand green pea seeds decreased linearly from 547.46 to 188.89 g as the moisture content decreased from 75.15 to 15.21% w.b. (Figure 2(c)). The relationship between mass of one thousand green pea seeds and moisture content (m) found to be linear as described below

$$M_t = 6.008m + 92.39 \quad R^2 = 0.998$$

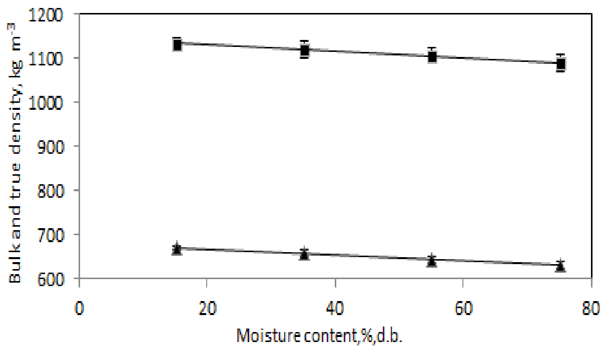

Figure 3. Effect of moisture content on the bulk density (▲) and true density (■) of green peas.

A linear relationship between thousand seed mass and moisture content was reported for green gram (Nimkar and Chattopadhyay, 2001), cotton seed (Ozarslan, 2002), green wheat (Al-Mahasneh and Rababah, 2007), pea seed (Yalcin *et al*., 2007) and Tef Seed (Zewdu and Solomon, 2007).

Bulk and true densities

The variation of bulk density and true density of green pea seeds with moisture content is shown in Figure 3 from 630.76 to 670.70 and 1088 to 1132 Kgm^{-3}, respectively. The linear relationships of bulk density and true density with moisture content (m) can be expressed as the following correlations:

$$\rho_b = 681.1 - 0.6676m \quad R^2 = 0.999$$

$$\rho_t = 1144 - 0.7311m \quad R^2 = 0.995$$

This behaviour could be attributed to the fact that decreased mass of green pea seeds associated with decreased humidity resulted lower than the volumetric expansion experienced by green pea seeds. In fact, the volume of air entrained between the wetter green pea seed was larger than the volume of the inter-green pea air in dried green pea seeds. Therefore, this would cause the effect of having greater compaction in dry green pea seeds compared with wet green pea seeds (Sologubik *et al*., 2013). A similar linear increase in bulk density with decrease in moisture content was found for amaranth seeds, pea seed, parboiled paddy and sorghum seeds (Reddy and Chakraverty, 2004; Mwithiga and Masika Sifuna, 2006; Yalcin *et al*., 2007) while a linear increase in true density of roselle seeds, sorghum seeds and lentil seed with decrease in moisture content (Amin *et al*., 2004; Mwithiga and Masika Sifuna, 2006; Yalcin *et al*., 2007; Sanchez-Mendoza *et al*., 2008).

Porosity

The porosity of green pea seeds was decreased from 42.02 to 40.75% when the moisture content decreased from 75.15 to 15.21% w.b. as shown in Figure 4(a). This behaviour could be explained using

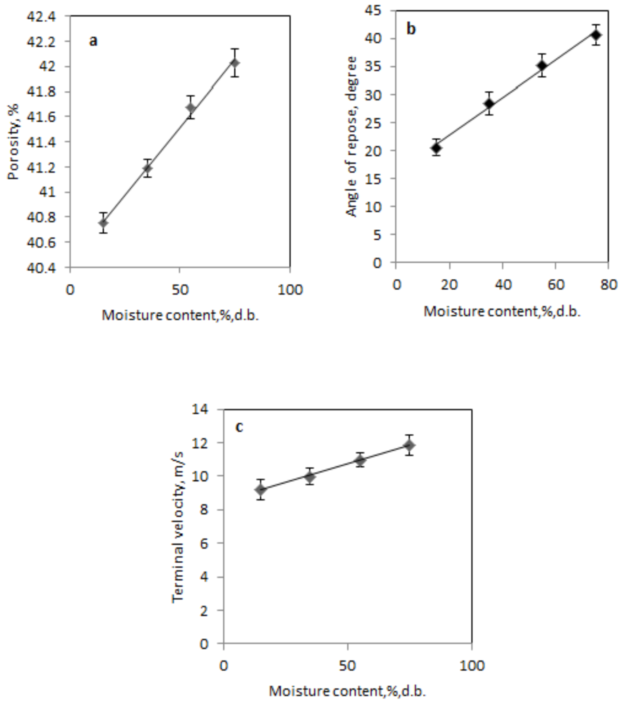

Figure 4. Effect of moisture content on the porosity (a), the angle of repose (b) and terminal velocity (c) of green peas.

the fact that the volume of the green peas decreases during moisture loss, especially due to the decrease of their length; consequently, the shape, and their bulk volume of the seed changes. This behavior causes the number of seeds occupying a fixed volume to increase, and then the bulk density decreases (Solomon and Zewdu, 2009; Sologubik *et al.*, 2013). The relationship between porosity and moisture content (m) for green pea seeds derived from the data was

$$\varepsilon = 0.021m + 40.441 \quad R^2 = 0.996$$

A similar trend was reported for amaranth seeds (Abalone *et al.*, 2004), lentil seeds (Amin *et al.*, 2004), sorghum seeds (Mwithiga and Masika Sifuna, 2006) and pea seed (Yalcin *et al.*, 2007).

Angle of repose

The angle of repose (θ) determined at different moisture contents is shown in Figure 4(b). The angle of repose decreased from 40.62° to 20.50° when moisture content decreased from 75.15 to 15.21% w.b. This trend could be due to the fact that moisture in the surface layer of biological material keeps them bound together by surface tension effect (Pradhan *et al.*, 2009). Other researchers have observed linear dependence of the angle of repose on moisture content for millet and quinoa seeds (Baryeh, 2002; Vilche *et al.*, 2003). Moreover, the angle of repose was found to be a linear function of moisture content (m) as follows

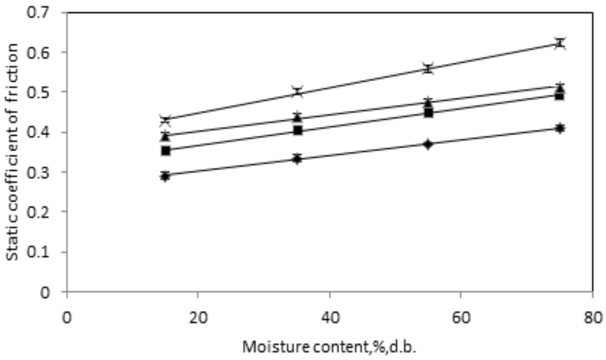

Figure 5. Effect of moisture content on the static coefficient of friction of green peas, glass (♦), Galvanized iron sheet (■), Plywood (▲) and Rubber (×).

$$\theta = 0.336m + 16.05 \quad R^2 = 0.993$$

Terminal velocity

The experimental results for the terminal velocity of green pea seeds at different moisture contents are depicted in Figure 4(c). The terminal velocity was found to decrease as moisture content decreased. The relationship between terminal velocity and moisture content (m) is represented as

$$V_t = 0.0449m + 8.489 \; R^2 = 0.998$$

The decrease in terminal velocity with decrease in moisture content can be attributed to the decrease in mass of seed per unit frontal area across the air path and also due to friction of the edges of the seed in motion (Joshi *et al.*, 1993). Several researches have reported a similar relationship for variation of terminal velocity as a function of moisture content (Nimkar and Chattopadhyay, 2001; Sacilik *et al.*, 2003; Dursun *et al.*, 2007; Yalcin *et al.*, 2007).

Coefficient of static friction

The static coefficient of friction on the four surfaces including rubber *(Ru)*, plywood *(Pl),* galvanised iron sheet *(Ga)* and glass *(Gl)* showed a significant decrease ($p<0.05$) with the moisture content in the range of 75.15-15.21% w.b. (Figure 5). This is due to decreased adhesion between the green pea seeds and the surfaces at lower moisture content. These frictional properties will find useful application in design and construction of hopper for gravity flow. The static coefficient of fraction showed a decrease of 30.64%, 23.53%, 27.76% and 27.50% for the surfaces of rubber, plywood, galvanised iron sheet and glass, respectively. The reason for this decrease may be due to the fact that lower moisture content decreases the water present in the biological materials and the material has a lesser force of friction with the contact surface (Visvanathan *et al*., 1996). It was also pointed out that the smoothness and porosity of surface materials affect the coefficient of friction (Singh and Goswami, 1996; Tavakoli *et al*., 2009). Similar results were also reported for hemp seed (Sacilik *et al*., 2003), fenugreek seeds (Altuntas *et al*., 2005), sugar beet seed (Dursun *et al*., 2007) and Tef seed (Zewdu and Solomon, 2007). The relationship between the static coefficient of friction of green pea seeds on rubber (μ_{Ru}), plywood (μ_{Pl}), galvanised iron sheet (μ_{Ga}) and glass (μ_{Gl}) with moisture content *(m)* can be expressed as follows

$$\mu_{Gl} = 0.002m + 0.262 \quad R^2 = 0.998$$

$$\mu_{Ga} = 0.0023m + 0.322 \quad R^2 = 0.997$$

$$\mu_{Pl} = 0.002m + 0.362 \quad R^2 = 0.995$$

$$\mu_{Ru} = 0.0032m + 0.384 \quad R^2 = 0.998$$

Conclusion

Several physical properties of the green pea (*Pisum sativum* L.) seeds were determined in the range of moisture contents from 75.15 to 15.21% w.b. The results obtained revealed that all the physical properties of green pea seeds were dependent on the moisture contents. The dimensions, sphericity, 1000 seed weight, porosity, static coefficient of friction and angle of repose of the seeds decreased linearly with the decrease of the seed moisture content while bulk density and true density increased linearly with the decrease of moisture content. At the same time, the surface area varied nonlinearly in the considered range of moisture content. The information presented in this study would be used in the design and development of more efficient sizing mechanisms and other postharvest processing machinery.

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