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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Effect of moisture on physical and mechanical properties of cassia

Bhupendra M. Ghodki[1] and T.K. Goswami[1]*

Abstract: Cassia is one of the widely used spices in the Food Industry due to its preserving and flavoring qualities. Physico-mechanical properties of spices are crucial in the machine designing and processing operations. In this study, physical properties and hardness of cassia bark were determined at five moisture levels, 6–14% dry basis (d.b.). The hardness test was performed along three orthogonal axes of the cassia bark using a texture analyzer. The size of the cassia viz., length (34.79 mm), width (13.79 mm), thickness (2.84 mm), geometric mean diameter (11.13 mm), and sphericity (0.32) were examined at 11.10% d.b. moisture level. Bulk density (238.66–255.86 kg m^{-3}), true density (691.82–795.13 kg m^{-3}), porosity (65.50–67.82%), angle of repose (39.42–42.78°), and static coefficients of friction of cassia bark increased linearly with an increase in moisture. Moreover, static coefficients of friction ranged from 0.59 to 0.67, 0.50 to 0.66, and 0.48 to 0.56 for mild steel, plywood and aluminium surface, respectively. The hardness showed a linear decrease along each orthogonal axis with the rise in moisture and ranged from 48 to 211 N. Hardness was highest for the minor axis followed by major and intermediate axis at all the moisture levels. The results were statistical significance at ($P \leq 0.05$) 95% confidence interval.

Subjects: Biophysics; Food Engineering; Statistics & Computing

Keywords: bulk density; cassia; hardness; moisture content; true density

ABOUT THE AUTHOR

T.K. Goswami is a recognized Professor of Food Engineering and Technology. He has more than 25 years of teaching and research experience. Dr Goswami has published nearly 100 research articles in renowned national and international journals. Also, he has two books, four book chapters and five patents to his credit. He has made significant contributions in the area of application of cryogenics to grinding of spices and preservation of cells, tissues, enzymes, etc. Further, he has developed quick freezing technology for prawn, and controlled and modified atmosphere storage of fruits and vegetables. He has applied the computational fluid dynamics (CFD) technique to estimate the transient refrigeration load in cold storage systems. He has been honored as Fellow of various Indian research academy/association: National Academy of Agricultural Sciences (NASS), Indian Society of Agricultural Engineers (ISAE), Institutions of Engineers (IEI), and Association for the Advancement of Biodiversity Science (AABS) for his continuous contribution to the research.

PUBLIC INTEREST STATEMENT

In this study, physical and mechanical properties of cassia (spice) were determined in the permissible moisture level, and significant models were developed to quickly access the properties of cassia. The research provides an opportunity for appropriate selection of the moisture level of cassia for the design of bulk storage, processing, handling and transportation structures. Hence, higher quality of end product can be assured by selecting safe and required moisture level in different processing operations.

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1. Introduction

Cinnamon and cassia spices have flavoring, preserving, and medicinal properties and accordingly have broad application in the Food Industries. Cinnamon is mainly used for flavoring foods in the kitchen as well as in Food Industries. While cassia is preferred over cinnamon in chocolate manufacturing and flavoring bakery products, liqueurs, cola type drinks, sauces as well as confectionery. Cassia bark oil is antifungal, antibacterial and slow down the meat spoilage; hence, it is used as a spice for meat dishes as well as a preservative (Peter, 2006).

Cinnamon and cassia are indigenous to South and South-East Asia and China. Moreover, they are the evergreen trees that belong to genus *Cinnamomum*, which is having 250 species and nearly all of them containing aromatic and flavoring components (Ghodki & Goswami, 2015). Harvesting of cassia and cinnamon trees is done by peeling off the bark on the trees and allowed to curl up in quills as the drying proceeds to a predetermined moisture level. The insect can crawl inside as the bark curls up, so it is essential to crack the pieces of whole cinnamon and cassia to check any dead or live insects. Cinnamon and cassia bark should contain on an average, less than 5% insect-infected pieces by weight, as per the recommendation of Food and Drug Administration (Tainter & Grenis, 2001). According to color and size quills are graded, cut, and sold in the commercial market. Indonesia and China are the major players in the world trade of cassia which corresponds to 20,000 to 25,000 tons of production annually, of which Indonesia shares for almost two-third and China most of the remainder (Iqbal, 1993). Minor producers include Vietnam and India. Annual export of cassia bark from Vietnam is about 2,000 to 3,000 ton (Iqbal, 1993).

Cassia (*Cinnamomum loureirii* Nees L.) is one of the species of the genus *Cinnamomum* belonging to the family of *Lauraceae*, grown principally in Vietnam, hence also called as Vietnamese or Saigon Cassia. Cassia is the most common spice in commercial trade due to its higher volatile oil and flavoring attributes as well as it is listed in the Code of Federal Regulations as Generally Recognized as Safe (Goswami & Ghodki, 2015).

Physical and mechanical properties of cassia are significantly influenced by the change in moisture content. The knowledge of these properties is essential in designing, transportation, processing, storage and grinding aspects. The mechanical properties such as hardness and compression characteristics are of principal importance for size reduction operation (Murthy & Bhattacharya, 1998). Efforts have been made to review the work carried out by various research workers in this direction that involved the study of essential physical and mechanical properties such as bulk density, true density, angle of repose, static coefficient of friction, hardness, etc. of different biomaterials (Amin, Hossain, & Roy, 2004; Dash, Pradhan, Das, & Naik, 2008; Dutta, Nema, & Bhardwaj, 1998; Joshi, Das, & Mukherjee, 1993; Manuwa & Muhammad, 2011; Razavi, Rafe, Moghaddam, & Amini, 2007; Singh & Goswami, 1996, 1998).

Physical properties like size, shape and coefficient of friction of cassia bark are critical factors for designing feeder, separator, and grinding machines. The properties such as bulk density, true density, and porosity influence the structural loads. Moreover, angle of repose is necessary for designing storage facilities, hopper, and conveying structures. Especially, for the design of size reduction machines such as a grinder or a cryogenic grinder, it is essential to identify the physical properties and response of cassia to applied load under the different orientation of cassia. Processing of agricultural materials, particularly for making powder, consists of mechanical treatment during grinding. When cassia bark is mechanically grounded, it experiences the compound acting forces, which includes compressive, frictional and shearing force (Ghodki & Goswami, 2015). Establishing the relationship between the mechanical properties and milling quality is an essential basis for an improving design of spice grinders. The fracture caused by the force exerted on the average size cassia can be analyzed with the knowledge of mechanical properties. The physical and mechanical properties are often required to facilitate and improve the design of equipment for handling, transportation, storage, grading machines and other postharvest machines, and also for assessing the product quality (Kashaninejad, Mortazavi, Safekordi, & Tabil, 2006; Manuwa & Muhammad, 2011). The physical

properties of biomaterial should be taken into design consideration; else the system models may lead to inadequate applications (Sessiz, Esgici, & Kızıl, 2007). Thus, the information on the physical and mechanical properties of cassia is of utmost interest to the food engineers, food scientists, and food processors because of their relationship with product quality, as well as their effect on processing behavior.

Published literature on the physical and mechanical properties of the cassia (*Cinnamomum loureirii* Nees L.) bark as a function of moisture content is scanty. Hence, the study was undertaken to determine moisture dependent physical properties like bulk density, true density, porosity, angle of repose and coefficient of static friction for different surfaces viz., mild steel, plywood and aluminium sheet, in the moisture content ranging from 6 to 14% d.b. Also, to investigate the effects of compression along orthogonal axes on the hardness viz., the maximum peak of the force-time curve in the same moisture range.

2. Materials and methods

This section involves the collection of the raw materials, moisture content determination, and its adjustment as well as measurement of physical and mechanical properties.

2.1. Raw material

Cassia was obtained from Tien Thanx Trading and Production Co., Ltd. Hamo commune Village, Dan Phuong District, Hanoi City, Vietnam. Cassia bark was subjected to manual cleaning by removal of broken, foreign matter, cracked, split and immature barks. The cleaned cassia bark was then broken into small pieces of length less than or equal to 50 mm for the determination of physical properties (Ranganna, 1986).

2.2. Determination of moisture content

Moisture content was determined using Entrainment method based on the recommendation of US ISO 939 (Ghodki & Goswami, 2016a, 2016b; Goswami & Ghodki, 2015). Moisture contents in a range of 6–14% d.b. (6, 8, 10, 12, and 14% d.b.) were selected each with a standard deviation of ± 0.1% d.b. to study, the influence of moisture on physical and mechanical properties of cassia. To maintain and preserve the cassia sample at different moisture content similar procedure was followed as reported for cassia bark sample (Ghodki & Goswami, 2015). Proper care was taken to check the moisture level of the sample before determination of the properties (Altuntaş & Yıldız, 2007). Five replicates were made for all the moisture content, and average values were reported.

2.3. Physical and mechanical properties

Size, sphericity and geometric mean diameter of cassia bark were determined at the initial moisture content of 11.10% d.b. While, other physical properties like bulk density, true density, porosity, angle of repose and coefficient of static friction at various surfaces were determined at different moisture contents varying from 6 to 14% d.b. Hardness viz., maximum peak of the force-time curve was determined at three loading position for a moisture range of 6–14% d.b.

2.3.1. Size

To determine the average size of the cassia, 100 samples were randomly picked. Moreover, three principal dimensions of the samples, namely length, breadth, and thickness were measured at three different points of the respective dimensions, viz., endpoints and midpoint using a dial caliper with an accuracy of ± 0.02 mm (Mitutoyo Corporation, Japan) as shown in Figure 1. The average values hundred replicates were recorded.

2.3.2. Geometric mean diameter and sphericity

Geometric mean diameter (D_g) and sphericity (ϕ) of cassia bark were calculated using Equations 1 and 2, respectively as recommended for biomaterials (Mohsenin, 1970):

$$D_g = LBT^{1/3}$$

(1)

Figure 1. Representation of the three axes and three perpendicular dimensions of cassia bark: *X*-axis, longitudinal axis (major axis, length, *L*); *Y*-axis, transverse axis containing the intermediate dimension (intermediate axis, width, *W*) at right angles to the longitudinal axis; *Z*-axis, transverse axis containing the minor dimension (minor axis, thickness, *T*).
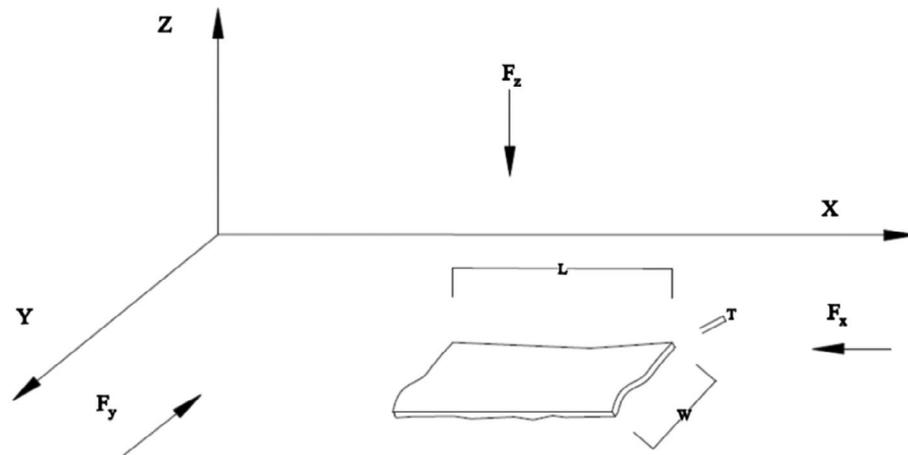
$$\phi = \frac{(LBT)^{1/3}}{L} \tag{2}$$

where *Dg* is the geometric mean diameter of cassia bark sample (mm); ϕ is the sphericity of cassia bark sample (decimal); *L* is the length of cassia bark sample (mm); *B* is the width of cassia bark sample (mm); and *T* is the thickness of cassia bark sample (mm).

2.3.3. Bulk density

Average bulk density of the cassia bark at five different moisture levels was investigated using a circular container of volume 1.482×10^{-3} m³ that was filled to full volume with the cassia bark and was gently tapped with proper care to avoid compaction of the bark in the container. Bulk density was calculated as the ratio of the weight of the sample to the volume of the container (Balasubramanian & Viswanathan, 2010).

2.3.4. True density

True density of grain is defined as the ratio of the mass of a sample of grain to the substantial volume occupied by the sample (Deshpande, Bal, & Ojha, 1993). True density was determined by a method specified for cinnamon bark (Balasubramanian, Singh, Mohite, & Zachariah, 2012) and defined as the ratio of the mass of bark to its pure volume as determined using the nitrogen gas replacement in the pycnometer. Average true density at various moisture levels was determined by pycnometer (Model: Multivolume pycnometer 1305, make Micromeritics, USA). After calibration, the samples were weighed and placed in a sample chamber for determination of the sample volume and its true density. True density of cassia was calculated using Equations 3 and 4:

$$\rho_t = \frac{W_{samp}}{V_{samp}} \tag{3}$$

$$V_{samp} = V_{cell} - \frac{V_{exp}}{\left[\left(\frac{P_1}{P_2}\right) - 1\right]} \tag{4}$$

where W_{samp} is the weight of sample kept in pycnometer (g); V_{samp} is the volume of sample (cm³); V_{cell} is the volume of cell (142.91 cm³); V_{exp} is the volume observed in experiment (70.24 cm³); and P_1 and P_2 are the pressure of multivolume pycnometer before and after nob revolution (psi).

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2.3.5. Porosity

Porosity is defined as the void space in the bulk grain that is not occupied by the grain (Vilche, Gely, & Santalla, 2003). Porosity is represented as the ratio of the difference between true density and bulk density to the true density, i.e., a percentage of the volume of voids (Mohsenin, 1970). Porosity was calculated using Equation 5:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{5}$$

where ε is the porosity (%); ρ_b is the bulk density(kg m^{-3}); and ρ_t is the true density (kg m^{-3}).

2.3.6. Static coefficient of friction

Static coefficient of friction of cassia was determined against three surfaces, namely, mild steel, plywood, and aluminium sheet following the methodology recommended by many researchers (Dutta et al., 1998; Joshi et al., 1993). Polyvinyl chloride pipe of 50 mm height and 50 mm diameter was placed on an adjustable tilting plate, faced with the surface and filled with the cassia bark sample. Then the cylinder was raised about 2 mm above the base of the bulk cassia bark so that the cylinder maintains a proper gap with the adjustable tilting plate surface. Structural surface with the cylinder resting on it was inclined gradually with a screw device until the cylinder along with the sample just started to slide down, and angle of tilt was read from a graduated scale. The coefficient of friction was calculated using Equation 6:

$$\mu = \tan\varphi \tag{6}$$

where μ is the coefficient of friction (dimensionless); and φ is the angle of tilt (degree).

2.3.7. Angle of repose

Angle of repose was determined by the method specified for cinnamon bark (Balasubramanian et al., 2012). Cassia bark samples were discharged through tapering horizontal iron hopper opening (top face cross section 250 mm^2 and bottom face cross section 20 mm^2) and were allowed to fall freely on a circular disc of 100 mm diameter to form a conical shaped heap. To regulate the opening during the test, a horizontal sliding gate was provided right below the hopper. Equation 7 shows that the angle of repose was determined by the height and diameter of the naturally formed heap of cassia bark on a circular plate:

$$\tan\theta = \frac{2h}{D} \tag{7}$$

where θ is the angle of repose (degree); h is the height of the cassia bark pile (mm); and D is the diameter of the circular disc (mm).

2.3.8. Hardness

Hardness was determined by Texture Analyzer TA-XT2i (Stable Micro Systems, England) under compression along three orthogonal directions, namely, major axis (length), intermediate axis (width) and minor axis (thickness) as shown in Figure 1. Stainless steel plate (diameter 75 mm) compressed a cassia bark on a mounted fixed table. A 25 kg load cell (Rahman & Al-Farsi, 2005) was used for the test. Moreover, the equipment was set to zero automatically by lowering the plate until the bottom surface of the plate just contacted the table. Cassia bark of different moisture was taken out randomly from sealed package and was observed for cracks and any other form of damage with the magnifying glass to ensure that the best cassia samples were used for the test. After measuring the three principal dimensions (major, intermediate and minor axis) of cassia bark, it was pressed under a flat surface metal cylinder. Other experimental conditions like pre-test speed of 1 mm s^{-1}, test speed of 0.5 mm s^{-1}, post-test speed of 0.5 mm s^{-1}, compression distance of 30% and rupture test distance of 1% were kept constant in all the experiments. Texture Analyzer automatically controlled all operating conditions and recorded the force-time curve. Further, hardness was calculated as the maximum peak of the curve.

2.4. Statistical analysis
Five replicas were taken for all the experiments, and average values are reported. The results of physical and mechanical properties were subjected to analysis of variance (ANOVA) to evaluate a statistical significance of observed differences among treatment means at ($p \leq 0.05$) 95% confidence interval using SPSS 20.0 software (IBM Corporation, USA), while regression analysis was performed using Microsoft Excel 2007 software.

3. Results and discussion

3.1. Dimensions of cassia
The mean length, width, and thickness of cassia bark were 34.79 ± 1.71, 13.97 ± 0.79 and 2.84 ± 0.02 mm, respectively at an initial moisture content of 11.10% d.b.

3.2. Geometric mean diameter and sphericity
It was observed that geometric mean diameter and sphericity of the cassia barks at the moisture content of 11.10% d.b. were 11.13 ± 0.56 and 0.32 ± 0.01 mm, respectively.

3.3. Bulk density
Bulk density at different moisture levels varied from 238.66 to 255.86 kg m^{-3} ($p \leq 0.05$) and indicated an increase with a rise in moisture content of cassia bark from 6 to 14% d.b. as shown in Figure 2A. The volumetric expansion of the bark becomes proportionally lesser as compared to increase in mass owing to increasing moisture content of cassia bark that resulted in an increase in the bulk density. Moreover, the bulk density of the cassia bark bears a linear relationship with moisture content and can be represented by Equation 8:

$$\rho_b = 2.26M + 223.40 \qquad (R^2 = 0.95) \tag{8}$$

where M is the moisture content of cassia (% d.b.); ρ_b is the bulk density of cassia (kg m^{-3}); and R^2 is the coefficient of determination.

The results are consistent with the report available for various biomaterials such as for karingda seeds (Suthar & Das, 1996), cumin seed (Singh & Goswami, 1996), sunflower kernel (Gupta & Das, 1997), edible squash seed (Paksoy & Aydin, 2004) and caper fruit (Sessiz et al., 2007).

3.4. True density
True density increased linearly from 691.82 to 795.13 kg m^{-3} ($p \leq 0.05$) with the increase in moisture content from 6 to 14% d.b. as shown in Figure 2B. The true density of the cassia bark bears the following linear relationship (Equation 9) with moisture content:
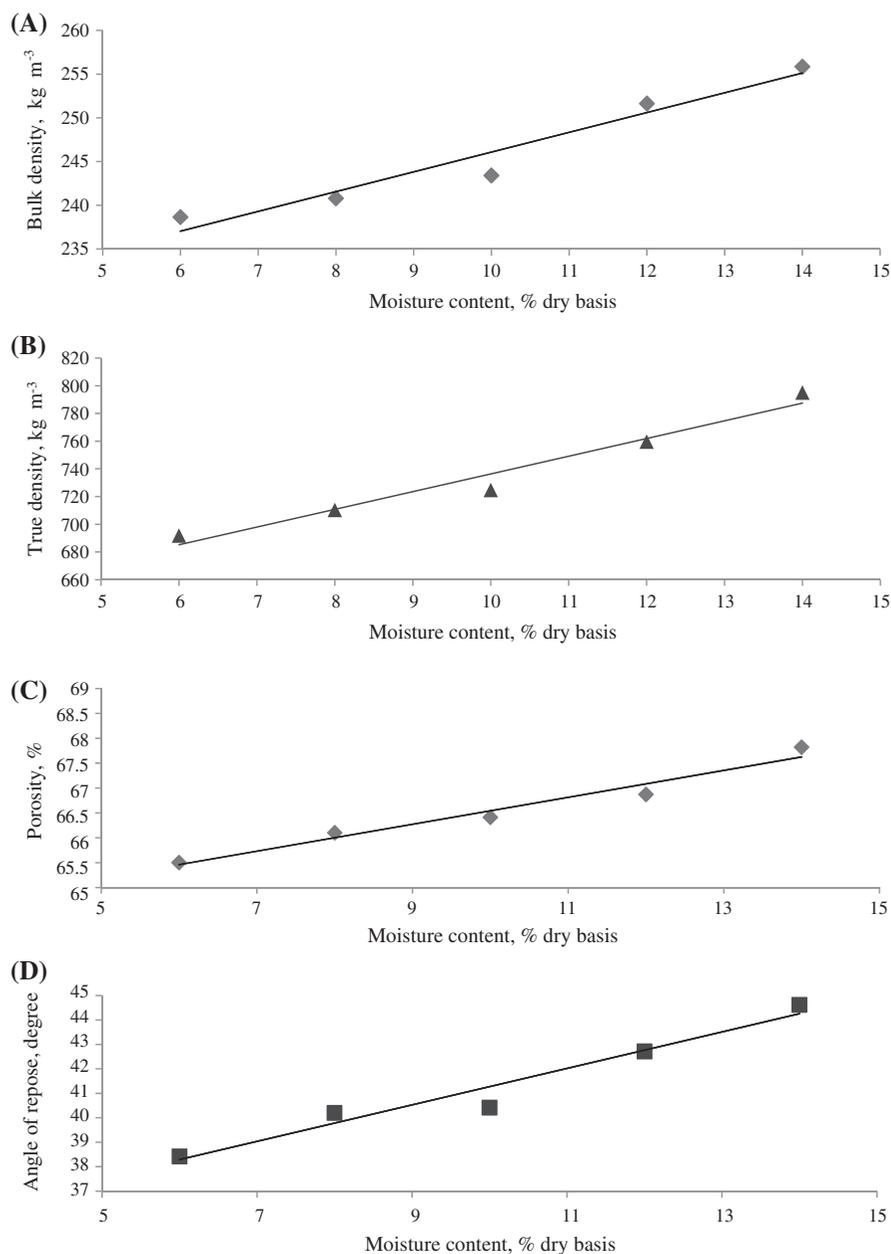
$$\rho_t = 12.79M + 608.30 \qquad (R^2 = 0.96) \tag{9}$$

where M is the moisture content of cassia (% d.b.); ρ_t is the true density of cassia (kg m^{-3}); and R^2 is the coefficient of determination.

This increase in the true density indicates that with the increment in the moisture level of the cassia there was a minor increase in the sample volume as compared to increase in its mass. Similar findings were reported for sunflower with an increase in value of true density from 706 to 765 kg m^{-3} for a moisture content range of 4 to 20% d.b. (Gupta & Das, 1997) and for quinoa seeds the rise in the value was from 928 to 1188 kg m^{-3} with the increase in moisture from 4.6 to 25.8% d.b. (Vilche et al., 2003).

3.5. Porosity
Porosity increased from 65.50 to 67.82% ($p \leq 0.05$) with the increase in moisture content from 6 to 14% d.b. as shown in Figure 2C. The porosity of the cassia bark bears the following linear relationship (Equation 10) with moisture content:

Figure 2. Variation in (A) bulk density, (B) true density, (C) porosity and (D) angle of repose with moisture content of cassia bark.

$$\varepsilon = 0.27M + 63.83 \qquad (R^2 = 0.96) \qquad\qquad (10)$$

where M is the moisture content of cassia (% d.b.); ε is the porosity of cassia (kg m⁻³); and R^2 is the coefficient of determination.

This finding agrees with the reports of many researchers such as for gram (Dutta et al., 1998), cumin seed (Singh & Goswami, 1996), sunflower (Gupta & Das, 1997), guna seeds (Aviara, Gwandzang, & Haque, 1999) and quinoa seeds (Vilche et al., 2003).

3.6. Angle of repose

The angle of repose increased linearly from 39.42 to 42.78° ($p \leq 0.05$) with an increase in moisture content from 6 to 14% d.b. as shown in Figure 2D. The angle of repose of the cassia bark bears the linear relationship with moisture content and can be represented by a regression equation (Equation 11):

$$\theta = 0.75M + 33.81 \qquad (R^2 = 0.95) \tag{11}$$

where M is the moisture content of cassia (% d.b.); θ is the angle of repose cassia (kg m^{-3}); and R^2 is the coefficient of determination.

The rise in surface roughness of the cassia bark at the higher moisture level may be responsible for the increasing trend of the angle of repose. Similar results were observed for gram (Dutta et al., 1998), pigeon pea (Shepherd & Bhardwaj, 1986), oilbean seed (Oje & Ugbor, 1991), pumpkin seed (Joshi et al., 1993), cumin seed (Singh & Goswami, 1996), karingda seeds (Suthar & Das, 1996), sunflower (Gupta & Das, 1997), guna seeds (Aviara et al., 1999), green gram (Nimkar & Chattopadhyay, 2001), fenugreek seeds (Altuntaş, Özgöz, & Taşer, 2005), and minor millets (Balasubramanian & Viswanathan, 2010).

3.7. Static coefficient of friction

The static coefficient of friction increased linearly with moisture level for all three surfaces. The linear regression equation for static coefficients of friction for all the surfaces can be represented by Equation 12:

$$\mu = AM + B' \tag{12}$$

where μ is the static coefficient of friction (dimensionless); A is the slope and B' is the intercept of the regression equation; and M is the moisture content of cassia (% d.b.).

The values of A, B' and R^2 is given in Table 1. The value of friction ranged from 0.59 to 0.67 ($p \leq 0.05$), 0.50 to 0.66 ($P \leq 0.05$) and 0.48 to 0.56 ($p \leq 0.05$) for mild steel, plywood and aluminium surfaces, respectively as the moisture content increased from 6 to 14% d.b. as shown in Figure 3. The linear increase in the static coefficient of friction may be due to the fact that at higher moisture content, the cassia barks become rougher as well as little cohesive for which sliding characteristics diminished. It was found that the mild steel as a surface for sliding offered the maximum friction followed by plywood and aluminium. This may be owing to the smoother and polished surface of the aluminium sheet compared to those of other test surfaces used. Similar results were reported for lentil seed (Amin et al., 2004).

3.8. Hardness

The hardness of cassia bark along the three orthogonal axes namely major, intermediate and minor axis of the bark showed a linear decrease with increase in moisture content. It may be due to the lower resistance offered to cracking by the sample at the higher moisture content. Hence, the lesser rupturing force was required to rupture the cassia bark at higher moisture. Hardness for all three orthogonal axes can be represented by a linear regression equation (Equation 13):

$$H = CM + E \tag{13}$$

where H is the hardness (N), C is the slope and E is the intercept of the regression equation, and M is the moisture content of cassia (% d.b.).

Table 1. Slope and intercept values of linear regression equation for static coefficients of friction on various friction surfaces

Surface	Slope (A)	Intercept (B')	Coefficient of determination (R^2)
Mild steel	0.02	0.38	0.94
Plywood	0.01	0.53	0.95
Aluminium	0.01	0.42	0.99

Note: Values of slope and intercept are significant ($p \leq 0.05$).

Figure 3. Variation in static coefficient of friction with moisture content on various friction surfaces.
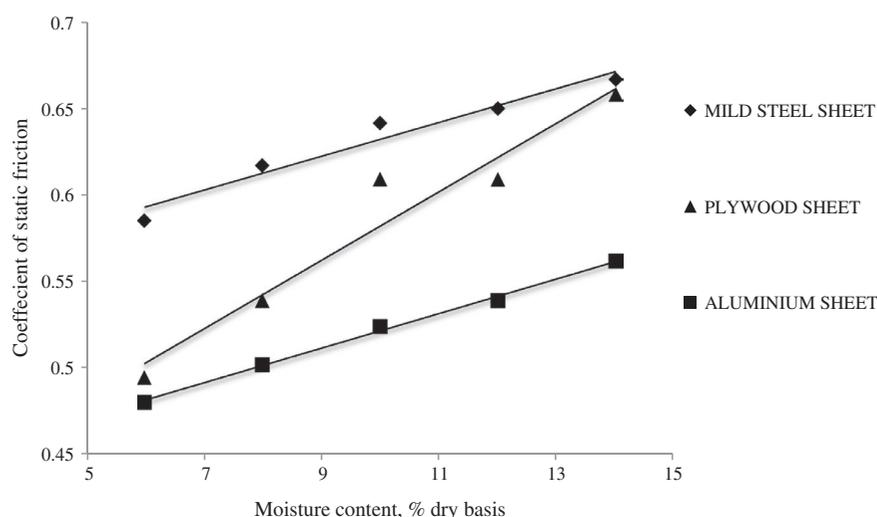

The values of C, E, and R^2 (coefficient of determination) is given in Table 2. Hardness value was found to be highest along the minor axis as compared to the other two directions for all the moisture content. Further, the hardness varies from 148 to 48 N ($p \leq 0.05$), 160 to 75 N ($p \leq 0.05$) and 211 to 79 N ($p \leq 0.05$) along major, intermediate and minor axis of cassia bark, respectively with an increase in moisture content from 6 to 14% d.b. as shown in Figure 4. The results are consistent with the report for date flesh (Rahman & Al-Farsi, 2005) and pomegranate seeds (Kingsly, Singh, Manikantan, & Jain, 2006).

Table 2. Slope and intercept values of linear regression equation for hardness along the three orthogonal axes of cassia			
Position	**Slope (*C*)**	**Intercept (*E*)**	**Coefficient of determination (*R²*)**
Minor axis (along the thickness)	−15.15	292.50	0.96
Intermediate axis (along the width)	−10.75	230.90	0.97
Major axis (along the length)	−12.10	230.60	0.93

Note: Values of slope and intercept are significant ($p \leq 0.05$).

Figure 4. Variation in hardness of cassia bark with moisture content along three orthogonal axes of cassia bark.
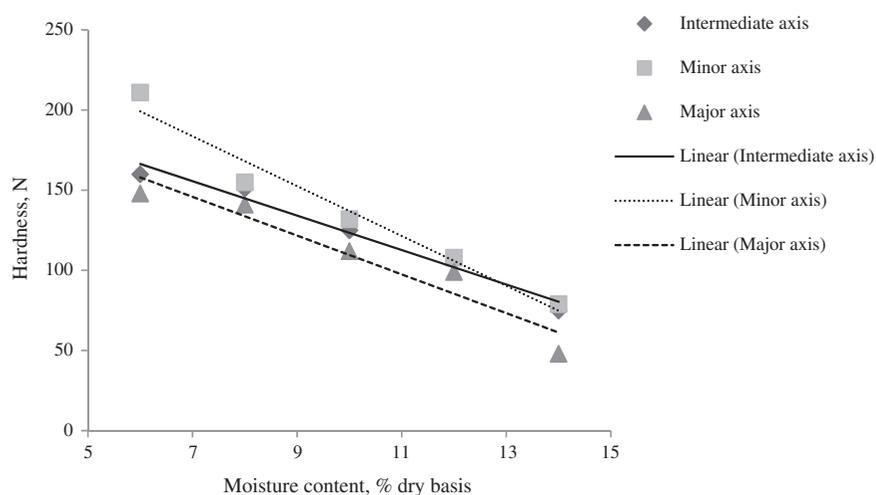
4. Conclusions

Physical properties of cassia bark viz., bulk density, true density, porosity, angle of repose, and static coefficient of friction concerning to different surfaces showed a linear increasing relationship with the rising moisture level from 6 to 14% d.b. However, hardness showed a linearly increasing trend with the decrease in moisture for all three orthogonal axes. This study provides an opportunity for the spice industry to ensure the higher quality of end product by selecting the safe and appropriate moisture for the design of bulk storage, processing, handling and transportation structures.

Competing interests
The authors declare no competing interests.

Author details
Bhupendra M. Ghodki[1]
E-mail: bhupendramghodki@gmail.com
ORCID ID: http://orcid.org/0000-0002-8879-1550
T. K. Goswami[1]
E-mail: tkg@agfe.iitkgp.ernet.in
[1] Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur 721302, India.

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References
Altuntaş, E., Özgöz, E., & Taşer, Ö. F. (2005). Some physical properties of fenugreek (Trigonella foenum-graceum L.) seeds. *Journal of Food Engineering, 71*, 37–43. http://dx.doi.org/10.1016/j.jfoodeng.2004.10.015

Altuntaş, E., & Yıldız, M. (2007). Effect of moisture content on some physical and mechanical properties of faba bean (Vicia faba L.) grains. *Journal of Food Engineering, 78*, 174–183. http://dx.doi.org/10.1016/j.jfoodeng.2005.09.013

Amin, M. N., Hossain, M. A., & Roy, K. C. (2004). Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering, 65*, 83–87. http://dx.doi.org/10.1016/j.jfoodeng.2003.12.006

Aviara, N. A., Gwandzang, M. I., & Haque, M. A. (1999). Physical properties of guna seeds. *Journal of Agricultural Engineering Research, 73*, 105–111. http://dx.doi.org/10.1006/jaer.1998.0374

Balasubramanian, S., Singh, K. K., Mohite, A. M., & Zachariah, T. J. (2012). Physical properties of cinnamon bark. *Journal of Spices and Aromatic Crops, 21*, 161–163.

Balasubramanian, S., & Viswanathan, R. (2010). Influence of moisture content on physical properties of minor millets. *Journal of Food Science and Technology, 47*, 279–284. http://dx.doi.org/10.1007/s13197-010-0043-z

Dash, A. K., Pradhan, R. C., Das, L. M., & Naik, S. N. (2008). Some physical properties of simarouba fruit and kernel. *International Agrophysics, 22*, 111–116.

Deshpande, S. D., Bal, S., & Ojha, T. P. (1993). Physical properties of soybean. *Journal of Agricultural Engineering Research, 56*, 89–98. http://dx.doi.org/10.1006/jaer.1993.1063

Dutta, S. K., Nema, V. K., & Bhardwaj, R. K. (1988). Physical properties of gram. *Journal of Agricultural Engineering Research, 39*, 259–268. http://dx.doi.org/10.1016/0021-8634(88)90147-3

Ghodki, B. M., & Goswami, T. K. (2015). Optimization of cryogenic grinding process for cassia (Cinnamomum loureirii Nees L.). *Journal of Food Process Engineering*. doi:10.1111/jfpe.12258

Ghodki, B. M., & Goswami, T. K. (2016a). Thermal and mechanical properties of black pepper at different temperatures. *Journal of Food Process Engineering*. doi:10.1111/jfpe.12342.

Ghodki, B. M., & Goswami, T. K. (2016b). Effect of grinding temperatures on particle and physicochemical characteristics of black pepper powder. *Powder Technology, 299*, 168–177.

Goswami, T. K, & Ghodki, B. M. (2015, March). Cryogenic grinding of cassia. In *International Conference on Advances in Chemical, Biological & Environmental Engineering (ACBEE)* (pp. 242–249). http://urst.org/siteadmin/upload/5499UE0315204.pdf

Gupta, R. K., & Das, S. K. (1997). Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research, 66*(1), 1–8. http://dx.doi.org/10.1006/jaer.1996.0111

Iqbal, M. (1993). International trade in non-wood forest products: An overview. Retrieved from http://www.fao.org/docrep/x5326e/x5326e00.htm

Joshi, D. C., Das, S. K., & Mukherjee, R. K. (1993). Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research, 54*, 219–229. http://dx.doi.org/10.1006/jaer.1993.1016

Kashaninejad, M., Mortazavi, A., Safekordi, A., & Tabil, L. G. (2006). Some physical properties of Pistachio (Pistacia vera L.) nut and its kernel. *Journal of Food Engineering, 72*, 30–38. http://dx.doi.org/10.1016/j.jfoodeng.2004.11.016

Kingsly, A. R. P., Singh, D. B., Manikantan, M. R., & Jain, R. K. (2006). Moisture dependent physical properties of dried pomegranate seeds (Anardana). *Journal of Food Engineering, 75*, 492–496. http://dx.doi.org/10.1016/j.jfoodeng.2005.04.033

Manuwa, S. I., & Muhammad, H. A. (2011). Effects of moisture content and compression axis on mechanical properties of shea kernel. *Journal of Food Engineering, 105*, 144–148. http://dx.doi.org/10.1016/j.jfoodeng.2011.02.017

Mohsenin, N. N. (1970). Physical properties of plant and animial materials. *Structure, Physical Characterisitics and Mechanical properties,1*, New York, NY: Gordon & Breach Science Publishers Inc.

Murthy, C. T., & Bhattacharya, S. (1998). Moisture dependant physical and uniaxial compression properties of black pepper. *Journal of Food Engineering, 37*, 193–205. http://dx.doi.org/10.1016/S0260-8774(98)00083-1

Nimkar, P. M., & Chattopadhyay, P. K. (2001). PH—Postharvest Technology: Some physical properties of green gram. *Journal of Agricultural Engineering Research, 80*, 183–189. http://dx.doi.org/10.1006/jaer.2000.0664

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Oje, K., & Ugbor, E. C. (1991). Some physical properties of oilbean seed. *Journal of Agricultural Engineering Research, 50*, 305–313.
http://dx.doi.org/10.1016/S0021-8634(05)80022-8

Paksoy, M., & Aydin, C. (2004). Some physical properties of edible squash (Cucurbita pepo L.) seeds. *Journal of Food Engineering, 65*, 225–231.
http://dx.doi.org/10.1016/j.jfoodeng.2004.01.019

Peter, K. V. (Ed.). (2006). *Handbook of herbs and spices* (Vol. 3). Cambridge: Woodhead publishing.

Rahman, M. S., & Al-Farsi, S. A. (2005). Instrumental texture profile analysis (TPA) of date flesh as a function of moisture content. *Journal of Food Engineering, 66*, 505–511.
http://dx.doi.org/10.1016/j.jfoodeng.2004.04.022

Ranganna, S. (1986). *Handbook of analysis and quality control for fruit and vegetable products*. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Razavi, S. M., Rafe, A., Moghaddam, T. M., & Amini, A. M. (2007). Physical properties of pistachio nut and its kernel as a function of moisture content and variety. Part II. Gravimetrical properties. *Journal of Food Engineering, 81*, 218–225.
http://dx.doi.org/10.1016/j.jfoodeng.2006.10.024

Sessiz, A., Esgici, R., & Kızıl, S. (2007). Moisture-dependent physical properties of caper (Capparis ssp.) fruit. *Journal of Food Engineering, 79*, 1426–1431.
http://dx.doi.org/10.1016/j.jfoodeng.2006.04.033

Shepherd, H., & Bhardwaj, R. K. (1986). Moisture-dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research, 35*, 227–234.
http://dx.doi.org/10.1016/S0021-8634(86)80060-9

Singh, K. K., & Goswami, T. K. (1996). Physical properties of cumin seed. *Journal of Agricultural Engineering Research, 64*, 93–98. http://dx.doi.org/10.1006/jaer.1996.0049

Singh, K. K., & Goswami, T. K. (1998). Mechanical properties of cumin seed (Cuminum cyminum linn.) under compressive loading. *Journal of Food Engineering, 36*, 311–321.
http://dx.doi.org/10.1016/S0260-8774(98)00056-9

Suthar, S. H., & Das, S. K. (1996). Some physical properties of karingda [Citrullus lanatus (Thumb) Mansf] Seeds. *Journal of Agricultural Engineering Research, 65*, 15–22.
http://dx.doi.org/10.1006/jaer.1996.0075

Tainter, D. R., & Grenis, A. T. (2001). *Spices and seasonings: A food technology handbook*. Hoboken, NJ: Wiley.

Vilche, C., Gely, M., & Santalla, E. (2003). Physical properties of quinoa seeds. *Biosystems Engineering, 86*, 59–65.
http://dx.doi.org/10.1016/S1537-5110(03)00114-4

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