Physical properties of dried red chili (*Capsicum annuum*) var. Hot Beauty as a function of moisture content

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**Abstract.** Dried red chili variety of Hot Beauty from local Malang city, East Java, Indonesia were determined experimentally at various water contents of 12.009, 13.005, 15.012, 17.248, and 19.003% (wet basis) then monitoring was done based on several physical parameters. The objectives of this research are to determine physical properties of chili such as length, width, thickness, roundness, mean diameter, surface area, bulk density, true density, porosity, coefficient of static friction (towards cardboard surface, metal plate, plywood board, and stainless steel), and compressive force at different moisture content. The results showed that geometrical dimension, roundness, mean diameter, surface area, bulk density, true density, porosity, and coefficient of static friction were linearly increased following the increase of water content. Otherwise, compressive force was decreased following the increase of water contents from 12.009 to 19.003% (wet basis). This can be happened due to high water content causing the increase of internal pressure on cell wall of dry red chili in which this pressure is naturally strengthen the structure of cell wall and make it more rigid.

1. Introduction

Red chili (*Capsicum annuum*) is an essential commercial plant used in various purposes, both related to household activities, especially as food raw material. Optimal productivity of red chili cultivation can potentially reach up to 20 tons per hectare [1].

Physical characteristics of agricultural product such as red chili are mandatory for further development, i.e. product processing, packaging, and storage. In addition, the characteristics are also needed for designing tools and machinery for agricultural product handling. For instance, the size and shape characteristics of agricultural product are beneficial for electrostatic separation of foreign material and for designing machines dedicated for measurement and grading process [2]. The shape characteristic also can be used for analytical approach for its drying behavior [3]. The ambient drying and aeration system of drying process need bulk density and porosity characteristics of agricultural product due to airflow resistance [4]. Designing handling equipment such as conveyor need friction characteristic of handled agricultural material.

Measurement of the physical properties of red chili at different moisture content with a humidity range of 13 to 19%. The conditioning of the moisture content range is based on the standard moisture content of red chilli the market which is close to the equilibrium moisture content. Increased moisture content of chili skin tend to be flexible and soft. This study aims to determine physical properties of chili such as length,
width, thickness, roundness, mean diameter, surface area, bulk density, true density, porosity, coefficient of static friction (towards cardboard surface, metal plate, plywood board, and stainless steel), and compressive force at different moisture content.

2. Materials and Methods

2.1. Sample
Fresh red chili purchased from the traditional market in Malang, Indonesia. Fresh chili is dried using a convective tray dryer for 5 days at 70°C, continuously so that the water content became 11%. Water content from dried red chilies then measured using the gravimetric method during 4 hours at 105°C. All observations were repeated three times.

2.2. Physical Properties Measurement
2.2.1. Geometrical Dimension
The geometrical dimension of chili, namely length, width, and thickness of the dried red chili are measured using calipers (made in France) with a level of accuracy ± 0.01 mm to obtain a higher accuracy value. Length, width, and thickness measurements are measured in 50 randomly selected red chili seeds, as shown in Figure 1.

Figure 1. Dimensional characteristic representation of red chili: (a) length; (b) thickness; (c) width.

According to Wardani [3], the arithmetic diameter ($D_a$), geometric (mm) ($D_g$), roundness ($\Theta$) used to explain shapes. The size can be described using the dimensions of the projected area $mm^2$ ($S$). Where the axial dimension ($L$) was the length dimension, ($W$) is the width dimension, and ($T$) is the thick dimension.

2.2.2. Mass
The unit of mass (g) measured using digital scales with an accuracy of 0.01 g. In total, 15 samples were taken randomly, with three replications used to measure unit mass.

2.2.3. Mean diameter
According to [1], the average diameter of red chili is calculated by the arithmetic ($D_a$) and geometric ($D_g$) averages of the three axillary dimensions. In addition, there is a square diameter ($D_k$), and an equivalent diameter ($D_{eq}$) which can describe the material size using equations 1, 2, 3, and 4.

$$D_a = \left(\frac{L+W+T}{3}\right)$$  \hspace{1cm} (1)
$$D_g = \left(\frac{LW+LT+WT}{3}\right)^{1/3}$$  \hspace{1cm} (2)
$$D_k = \left(\frac{(L+T+W)^2}{3}\right)^{1/2}$$  \hspace{1cm} (3)
$$D_{eq} = \frac{D_a + D_g + D_k}{3}$$  \hspace{1cm} (4)
2.2.4. Roundness
According to Sinaga [5], roundness is a relationship between each part with other parts of various diameter variations (length, width, and thickness) of an object, especially the degree of sharpness in which the shape of the object is near or spherical. The round back value can be calculated using equation 5.

$$\Phi = \frac{(lwT)^{1/3}}{t}$$  \hspace{1cm} (5)

2.2.5. Surface area
According to [5], the surface area of fruit can usually be determined based on measurements and weight. The surface area is one of the test methods commonly used to determine the physical properties of a material. The surface area can be calculated using equation 6.

$$S = \pi D g^2$$  \hspace{1cm} (6)

2.2.6. Bulk density, true density, porosity
The true density of red chili is measured using the liquid displacement method, which is the method of fluid transfer with toluene. Bulk density ($\rho_b$) in g/cm$^3$ in red chili is calculated using equation 7 and 8.

$$\rho_b = \frac{M_a}{V_a}$$  \hspace{1cm} (7)

$$\rho_t = \rho_{toluene} \times \frac{M_a}{V_t}$$  \hspace{1cm} (8)

Porosity is measured according to the Kallemullah method [1]. A vessel with certain weight and volume was filled with material then weighed. Porosity ($\varepsilon$) in % of the chili was determined using equation 9. All parameters, namely true density, bulk density, and porosity, were determined in 10 random samples.

$$\% \varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$$  \hspace{1cm} (9)

2.2.7. Coefficient of static friction
The coefficient of static friction is the angle formed when the fruit begin to slide on the friction surface. The coefficient of static friction measurement through the sloping surface on cardboard, stainless steel, iron plate, glass, and wood. The measurement mechanism for the coefficient of static friction, namely the surface of tool that has been coated with the friction surface, is gradually increased until the material begins to slip, which is shown as a static friction angle [6]. The coefficient of static friction ($\mu$) is calculated using equation 10.

$$\mu = \tan \alpha$$  \hspace{1cm} (10)

2.3. Compressive force
The mechanical properties of red chili are shown in the form of compressive force. Compressive force tests used a GY-4 model penetrometer, where each sample was compressed on a three-dimensional axis of length, width, and thickness (Figure 1). The compressive force test carried out on ten random samples.

3. Results and Discussion

3.1 Moisture content condition
The samples at selected moisture content were prepared by adding a calculated amount of water to the product and stored in an ambient environment for 7 days at 5°C to equilibrated the water content throughout the sample using equation 11 [7]. Where; $W_i$, initial mass (kg), $M_i$, initial moisture content (% d.b.), and $M_f$, final moisture content (% d.b.). The moisture content condition of red chilli is shown in Table 1.

$$Q = \frac{W_i (M_f - M_i)}{(100 - M_f)}$$  \hspace{1cm} (11)
Table 1. Moisture content condition of red chili.

| Number of samples | Moisture content measurement (%) | Standard deviation |
|-------------------|----------------------------------|-------------------|
|                   | Min     | Mean | Max    |                       |
| 15                | 12.285  | 13.005 | 14.727  | 0.785  |
| 15                | 14.056  | 15.012 | 16.788  | 0.770  |
| 15                | 16.024  | 17.248 | 19.339  | 0.890  |
| 15                | 16.232  | 19.033 | 22.531  | 0.165  |

3.2. Physical properties

![Figure 2. Relationship of dimension with moisture content.](image1)

![Figure 3. Relationship of average dimensions with moisture content.](image2)

![Figure 4. Relationship of roundness with moisture content.](image3)

![Figure 5. Relationship of surface area with moisture content.](image4)
The results of the physical properties evaluation of dried red chili are described in Figure 2-6. Dimension measurement results showed that the dimensions of red chili are increased with the increasing of water content as shown in Figure 2 and 3. Red chili had 0.462–0.466 roundness, which indicated that red chili did not have a shape similar to a ball but rather towards the oval as shown in Figure 4. The geometric diameter and surface area of the red chili were 49.076–1.160 mm, 7397.295–7708.882 mm², respectively as shown in Figure 5. The average mass unit of red chili was 2.256 – 2.427 g as shown in Figure 6. This is consistent with Moghadam’s research [8] on date palm material. The dimensions increase due to the water content so that it will affect each of the average diameter values [9]. The same was expressed by Andasuryani [10], Kakade [11], and Fathollahzadeh [12], who used cocoa beans, apricot carnelian soybeans. Diameter measurements are useful for estimating the number of fruits, disk spacing, and the number of slices [13]. Data regarding the surface area of the agricultural product can be utilized for the designing stage of a grading and separation equipment and machinery. Furthermore, according to Andasuryani [10], surface area measurement is valuable to understand in the modelling strength of heat and mass transfer during cooling and drying of material.

**Figure 6.** Relationship of mass with moisture content.

**Figure 7.** Relationship of bulk density and true density with moisture content.
As shown in Figure 5, the average mass unit of red chili is 2.256–2.427 g. True density, bulk density, and porosity are 0.8458–1.3116 g/cm³, 0.188–0.156 g/cm³, and 0.471688–0.544468%, respectively. True density and bulk density have increased due to the increased water content in the material as shown in Figure 7. True density values are in accordance with Shreelavaniya's study [13] used pepper hydam ingredients. Bulk density values are in accordance with the research of Baryeh [14] and Altuntas [15] using barley and walnuts. Red chili porosity in Figure 8 indicated that greater space and volume is required for storage, transportation, packaging, and various further processing and handling. Red chili also had a surface area that is not too far from materials such as lentil [7], and white pepper seeds [16]. This is in accordance with the research of Hossain [17], which used the same material.

On each surface used, the highest coefficient of static friction of red chili is in stainless steel and iron plate, and lowest in wood as shown in Figure 9. Chili skin has a flexible surface and is affected by the resistance of the friction surface to material that passed through the surface due to the hardness of the friction surface itself. On the stainless steel friction surface and the iron plate, the material allowed it to move easily because the friction surface was slippery, while on wood and cardboard, which was slightly rough, makes red chili more difficult to move. The relationship of the static friction coefficient showed that with increasing water content, the angles formed would increase for all surfaces but with different levels [18]. However, worth to note that the results of the static friction evaluation depend greatly on the skill of the equipment user because the equipment that can be adjusted is the simplest basic equipment for evaluating the coefficient of static friction.

3.3. Compressive force
The mechanical properties of red chili are a compressive force on the material. Identification of red chili compressive force is vital to know the different forces held by the red chili—a decrease in the value of hardness in the material, especially at high water levels. The water content strongly influences changes in the hardness of an agricultural product. This can happen due to the water content can penetrate the cell wall causing an increase in internal pressure on the cell wall where the cell wall plays a role in the toughness and hardness of a material [19]. In other materials such as shellfish, the position of the emphasis affects the opening of the outer shell quickly [20].
Figure 10. Relationship of compressive force with moisture content.

4. Conclusions

The results of this study in the form of an average value of mass with a moisture content of 13–19% of 2.256–2.427 g, dimensions including length 105.43–106.91 mm; width 23.73–24.695 mm; 52.715–53.457 mm thickness, mean diameter 47.535–50.295 mm, sphericity 0.462–0.466, surface area 7397.295–7708.882 mm², true density 0.845–1.311 g/mm², bulk density 0.188–0.516 g/mm², porosity 47.168–61.001%, and angle of friction with five types of friction surfaces including glass 0.604–0.808; iron plate 0.658–0.821; cardboard 0.684–0.813; stainless steel 0.613–0.905 and plywood boards 0.627–0.790. In addition, the measurement of the compressive force to test the hardness of the material is 1.825–1.462 KgF.

Geometrical dimensions, roundness, mean diameter, surface area, bulk density, true density, porosity, and coefficient of static friction were linearly increased following the increase of water content. Otherwise, the compressive force was decreased following the increase of water contents. Information about the physical properties of red chilli is an important parameter for machine design, processing, packaging, and storage techniques.

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