Some physical and mechanical properties of fermented Keluwak (Pangium edule Reinw) seed

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Abstract. Fermented seed of the tropical tree Pangium edule Reinw., locally known as Keluwak, have been used as spices in Asian and especially Indonesia cuisine. For further processing and postharvest handling, physical and mechanical properties of the seed are needed. Some physical properties, i.e. length, width, thickness, geometric mean diameter, sphericity, surface area, unit mass and 100-mass of seeds, fraction by weight, true volume, true density, bulk density, porosity, and coefficient of static friction at five different surface (cardboard, stainless steel, iron plate, glass, and plywood) of Keluwak seeds were evaluated at the market moisture content. Also, some mechanical properties, i.e. rupture force, strain, stress and Young modulus at three dimensions axis have been measured. The average length, width, thickness, geometric mean diameter, unit mass and per 100 seeds were 44.94±5.6 mm, 43.35±5.2 mm, 27.40±3.4 mm, 37.36±3.2 mm, 11.47±3.7 g and 1693.39±483.85 g. In the market moisture content, the results indicated 0.87±0.07, 4413.99±733.22 mm², 1.01±0.01 g/cm³, 0.42±0.03 g/cm³, 58.21±3.37% and 69.10±13.84% for average sphericity, surface area, true density, bulk density, porosity and peel ratio of the seed, respectively. Angle of friction for respective cardboard, stainless steel, iron plate, glass, and plywood were 25.52±6.9 deg, 17.40±3.92 deg, 21.40±5.2 deg, 12.27±42 deg, and 24.8±7.45 deg. The average compressive force needed to break the seed at length, width, and thick axis were 295.34±87.95 N, 283.87±83.90 N, and 215.71±65.53 N. The strain, stress, and Young modulus were 0.095±0.03, 2.10±0.71 N/mm², and 23.16±7.20 N/mm² at length axis; 0.069±0.03, 2.66±0.88 N/mm², and 45.44±20.95 N/mm² at width axis; 0.05±0.02, 2.05±0.63 N/mm², and 48.12±22.61 N/mm² at thick axis, respectively.

1. Introduction

Pangium edule Reinw. (Keluwak) is a tropical tree that grows indigenously in Indonesia. The tree produces seeds that are poisonous due to the presence of cyanogenic glucosides [1]. The seed considered as prospective commodity since it has various uses and benefits, but lack of exposures of research. In renewable energy research, the seed is considered has huge potential as 2nd generation source of biodiesel due to non-edible source and can hinder problem of food-energy dilemma [2-4]. However, in other part of the world, especially in its native, i.e. South East Asia, the fermented seed, locally known as Keluwak, is considered as food material and edible following treatment and the cyanogenic glucoside removal. Various Indonesian local cuisines are made using Pangium edule Reinw. seed kernels as main ingredients or spices, e.g. dage, kecap pangi, konro soup, and rawon black soup.
For spice utilisation, the seed is fermented in specific method. According to Andarwulan et al. [5], fermentation process begin with the harvested fruit are placed in the field for about ten days until the fruit is tainted. The seeds are then removed, washed, and boiled for 3 hours. The seeds are then cooled and placed in the indoor ground hole and covered by ash. After about 40 days, the fermented seeds are cleaned and ready to be used as spices. The seed also has been studied for anti-obesity-related bioactivities [6].

Considering its huge utilisation potential and the absence of its properties in the literatures, the objectives of present study is to quantify some physical and mechanical properties of Keluwak, namely, length, width, thickness, geometric mean diameter, sphericity, surface area, unit mass and 100-mass of seeds, fraction by weight, true volume, true density, bulk density, porosity, coefficient of static friction, rupture force, strain, stress and Young modulus at three dimensions axis have been measured. The physical and mechanical properties are needed for further research and development of postharvest handling and processing equipment and machinery, e.g. for cleaning, grading, separation, storage, and transportation process of Keluwak.

2. Materials and Method

2.1. Materials
Keluwak (Pangium edule Reinw) seeds were purchased from local traditional market in Malang, East Java Province, Indonesia, in fermented condition. The fermentation process was previously conducted by the farmers according to method previously mentioned by Andarwulan et al. [5]. The moisture content of the seed shells and kernels (endosperm) then measured according to standard gravimetric method proposed by AOAC [7]. Ten randomly selected Keluwak were used for the measurement.

2.2. Physical properties
2.2.1. Length, width and thickness measurement
The length, width and thickness of Keluwak were measured by a digital caliper (Mitutoyo, Japan) to an accuracy of 0.01 mm. The length, width, and thickness measurement of the seed were measured in randomly selected 50 Keluwak as depicted in Figure 1. The measurement of seed dimensions was conducted in three replications.

![Figure 1. Measurement of Keluwak dimension: (a) length; (b) width; and (c) thickness](image)

According to Mohsenin [8], the geometric mean diameter in mm \((d_g)\), the sphericity \((\phi)\), and surface area in mm\(^2\) \((S)\) of the seed were calculated using Eq. 1, 2 and 3, respectively, where \(a\) in mm represent length, \(b\) in mm is width, and \(c\) in mm is thickness (Fig. 1).

\[
d_g = (abc)^{\frac{1}{3}}\tag{1}
\]

\[
\phi = \frac{(abc)^{\frac{1}{3}}}{a} = \frac{d_g}{a}\tag{2}
\]

\[
S = \pi d_g^2\tag{3}
\]
2.2.2. Unit mass and hundred mass of seed
Unit mass in g and 100-mass in g of seed are measured using electronic balance with 0.01 g of accuracy. In total, randomly selected 50 Keluwak samples with three replications were used for unit mass measurement. Randomly selected 100 Keluwak samples with three replications were used for 100-mass measurement.

2.2.3. Fraction by weight
The fraction by weight of seed shell and kernel (endosperm) in % of keluwak is the ratio of the weight of seed part, to the weight of whole seed. Randomly selected 100 Keluwak seeds samples with three replications were used for fraction by weight measurement.

2.2.4. True volume, true density, bulk density, and porosity
The true volume and true density of Keluwak were measured according to method previously used by Razavi and Parvar [9]. The volume of seed was measured using liquid displacement method with water. The true volume \( V_t \) in cm\(^3\) and true density \( \rho_t \) in g/cm\(^3\) of the fermented seed were calculated using Eq. 4 and 5, respectively, where \( M_w \) in g is the mass of sample in water, \( M_a \) in g represents mass of sample in air, and \( \rho_w \) in 1 g/cm\(^3\) is density of water.

\[
V_t = \frac{M_w - M_a}{\rho_w} \tag{4}
\]
\[
\rho_t = \frac{M_a}{V_t} \tag{5}
\]

Bulk density and porosity of Keluwak were measured according to method previously used by Sirisomboon et al. [10]. Bulk of fermented seeds was put into a container with known weight and volume and was weighed. Bulk density \( \rho_b \) in g/cm\(^3\) and porosity \( \varepsilon \) in % of the fermented seed were calculated using Eq. 6 and 7, respectively, where \( v \) in cm\(^3\) is occupied volume of container. All parameters, i.e. true volume, true density, bulk density, and porosity were measured using 10 randomly selected samples with three replications.

\[
\rho_b = \frac{M_a}{v} \tag{6}
\]
\[
\varepsilon = \left[ 1 - \frac{\rho_b}{\rho_t} \right] \times 100 \tag{7}
\]

2.2.5. Coefficient of static friction
Coefficient of static friction of Keluwak was determined against surface of cardboard, stainless steel, iron plate, glass, and plywood. The coefficient of static friction measurement was conducted according to inclined plane method previously used by Mahawar et al. [11] using inclined plane method. The custom-made apparatus of adjustable tilting plate was made specifically for measurement. The coefficient of static friction \( \mu \) of Keluwak was calculated using Eq. 8, where \( \alpha \) represents the angle at which the material just started to move downward.

\[
\mu = \tan \alpha \tag{8}
\]

2.3. Mechanical properties
The mechanical properties of kluwak were expressed in terms of rupture force, stress, strain, and Young modulus. Flat plate compression test was carried out using universal testing machine (WDW 1-E series, Time Group, Inc., China). Each sample was compressed at three dimensions axis, i.e. length, width,
thickness (Fig. 1). The test was conducted in 10 randomly selected keluwak with three replications at each axis.

3. Results and Discussion

3.1. Moisture content

Table 1 shows the results of moisture content of keluwak parts, i.e. shells and kernels (endosperm). The kernel of keluwak contained higher moisture content compare to seed shell. This indicated that the water inside the seed was not decreased even if prolonged fermentation process of the seed.

| Seed part | Mean | Max. | Min. | ± St. Dev. |
|-----------|------|------|------|------------|
| Shell     | 14.83| 21.28| 11.56| 2.68       |
| Kernel    | 50.86| 69.21| 13.90| 15.99      |

3.2. Physical properties

The results of Keluwak physical properties evaluation summarised in Table 2, where the dimensions, geometric mean diameters, sphericity, surface area, unit mass, 100-unit mass, fraction of seed parts, true volume, true density, bulk density, porosity, and coefficient of static friction are provided. The measurements of dimension indicated that keluwak has slightly higher dimension at length than its width. The Keluwak seed has 0.87±0.07 of sphericity, which indicated that the seed is less similar to a sphere. The seed also has 37.36±3.16 mm and 4413.99±733.22 mm² of geometric mean diameter and surface area, respectively.

| Physical properties | Samples | Mean | Max. | Min. | ± St. Dev. |
|---------------------|---------|------|------|------|------------|
| Length, mm          | 150     | 44.94| 60.97| 30.70| 5.76       |
| Width, mm           | 150     | 43.35| 55.53| 32.60| 5.23       |
| Thickness, mm       | 150     | 27.40| 36.60| 18.97| 3.44       |
| Geometric mean diameter, mm | 150 | 37.36| 43.78| 29.88| 3.17       |
| Sphericity          | 150     | 0.87 | 1.03 | 0.70 | 0.06       |
| Surface area, mm²   | 150     | 4413.99| 6017.36| 2802.45| 733.22   |
| Unit mass, g        | 150     | 19.51| 33.49| 8.22 | 13.83      |
| 100-unit mass, g    | 300     | 1693.39| 2196.72| 1231.72| 483.85   |
| Shell fraction, %   | 150     | 39.44| 48.63| 29.84| 4.66       |
| Kernel fraction, %  | 150     | 58.08| 70.02| 47.31| 5.15       |
| True volume, cm³    | 30      | 13.57| 20.01| 7.99 | 2.80       |
| True density, g/cm³ | 30      | 1.01 | 1.08 | 1.00 | 0.01       |
| Bulk density, g/cm³ | 30      | 0.42 | 0.45 | 0.37 | 0.03       |
| Porosity, %         | 30      | 58.21| 64.96| 54.64| 3.37       |
| Coef. static friction, cardboard | 30 | 0.48 | 0.73 | 0.17 | 0.15       |
| Coef. static friction, s. steel | 30 | 0.31 | 0.40 | 0.16 | 0.07       |
| Coef. static friction, iron plate | 30 | 0.39 | 0.55 | 0.17 | 0.11       |
| Coef. static friction, glass | 30 | 0.22 | 0.31 | 0.14 | 0.04       |
| Coef. static friction, plywood | 30 | 0.47 | 0.82 | 0.17 | 0.16       |

As indicated by Table 2, the mean unit mass and 100-mass of keluwak are 19.51±13.83 g and 1693.39±483.85 g, respectively. It also shows that kernel has higher fraction of weight than its shell. True volume, true density, bulk density, and porosity of Keluwak are 13.57±2.80 cm³, 1.01±0.01 g/cm³, 0.42±0.03 g/cm³, 58.21±3.37%, respectively. The true density of the seed is slightly higher the density
of water (1 g/cm³). The true density of unprocessed *Keluwak* seed may higher since fermentation process may cause shrinkage of the kernel. The high porosity of keluwak of the seed indicated that the larger room and volume are needed for storage, transportation, packaging, and various further processing and handling. Kluwak has a large surface area value so that it can be grouped into large grain types. Kluwak also has surface area values that are not too far away from other types of grains such as Chabokser walnuts by Gharibzahedi et al. [12] and candlenuts by Sinaga et al. [13]. Information about surface area can be used in designing a grading and separation machine. In addition, according to Jahromi et al. [14] measurement of surface area is important to know in the accuracy of heat transfer modeling and mass during cooling and drying of a material.

On all surface studied, i.e. cardboard, stainless steel, iron plate, glass, and plywood, the coefficient of static friction of kluwak was highest on cardboard and plywood, and lowest on glass. The seed shells have slightly rough surface and their hardness enabled them to move easily on slippery surface of glass, while slightly rough surface of cardboard and plywood make the seed more difficult to move. However, it must be noticed that the result of the coefficient of static friction evaluation was highly dependent on the skill of the apparatus user, due to adjustable tilting plate apparatus is the simplest basic apparatus to evaluate coefficient of static friction.

3.3. Mechanical properties

The mechanical properties of keluwak, including rupture force, stress, strain, and Young modulus are presented in Table 3. The force needed to rupture a keluwak shell, from highest to lowest is at length (a), width (b), and thickness (c) axis, consecutively. The relatively higher force needed to rupture keluwak shell because keluwak has considerably hard shell. The rupture force property is beneficial information to design crusher machine for *Keluwak*. Young modulus data give information that keluwak is easy to deform at length (a) axis. The highest strain average value in the study was obtained at the perpendicular to the length and smallest dimensions in perpendicular thick dimensions. This is because the greater the force given to break the shell of *Keluwak*, the greater the strain value. In this case it means that the force is directly proportional to the strain value. The statement was also strengthened by research conducted by Sari et al. [15] which states that the stronger the force is given, the greater the deformation and the greater the strain that occurs. In designing *Keluwak* crusher it takes physical quantities that can determine the elasticity of a material such as strain.

| Physical properties                                      | Samples | Mean   | Max.   | Min.  | ±St. Dev. |
|----------------------------------------------------------|---------|--------|--------|-------|-----------|
| Rupture force, length axis, N                            | 30      | 295.34 | 446.20 | 64.72 | 87.95     |
| Rupture force, width axis, N                             | 30      | 283.87 | 447.18 | 44.13 | 83.90     |
| Rupture force, thickness axis, N                         | 30      | 215.71 | 359.90 | 109.83| 65.53     |
| Stress, length axis, N/mm²                               | 30      | 2.10   | 3.43   | 0.41  | 0.71      |
| Stress, width axis, N/mm²                                | 30      | 2.66   | 4.27   | 0.47  | 0.88      |
| Stress, thickness axis, N/mm²                            | 30      | 2.05   | 3.56   | 1.17  | 0.63      |
| Strain, length axis                                      | 30      | 0.09   | 0.17   | 0.04  | 0.71      |
| Strain, width axis                                       | 30      | 0.07   | 0.15   | 0.02  | 0.03      |
| Strain, thickness axis                                   | 30      | 0.05   | 0.11   | 0.01  | 0.02      |
| Young modulus, length axis, N/mm²                        | 30      | 23.16  | 36.92  | 7.57  | 7.20      |
| Young modulus, width axis, N/mm²                         | 30      | 45.44  | 120.45 | 18.10 | 20.95     |
| Young modulus, thickness axis, N/mm²                     | 30      | 48.12  | 113.75 | 18.01 | 22.61     |

4. Conclusions

*Pangium edule* Reinw. seed has great potential as spices for traditional dishes. For utilisation of the spices, the seed must be fermented and the seed shells must be shelled, as well as should be stored in long period. To design and fabricate the tools and equipments related to the process, the physical and
mechanical properties of the seed are important design parameters. The physical and mechanical properties of fermented Keluwak seed at market moisture content including length, width, thickness, geometric mean diameter, sphericity, surface area, unit mass and 100-mass of seeds, fraction by weight, true volume, true density, bulk density, porosity, coefficient of static friction, rupture force, strain, stress and Young modulus were investigated and reported, and application was also discussed.

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