A comparative study on engineering properties of three varieties of shallots

Y R Kurniawan*, D D Hidayat*, R Luthfiyanti, R C E Andriansyah and A Indriati

Research Centre of Appropriate Technology, Indonesian Institute of Sciences
K.S. Tubun Road, Subang, West Java, Indonesia 41213

*Corresponding author’s email: yorizk1@gmail.com; zehidayat@gmail.com

Abstract. Shallot is one of the essential vegetables in Indonesia. Besides being consumed by the household, shallots are also potentially usable for industries. Many researchers have done a study on engineering properties of onions, but not in shallots. The information about the physical and mechanical properties of shallots related to handling and processing is still lacking. Therefore, this study conducted to provide the database on physical and mechanical properties of three different varieties of shallots and to find out the similarities and differences among them. Results of the study showed that physically, each type had a typical characteristic which was different from other varieties. The weight of Tuktuk variety was about three times of Bima Brebes variety and nearly six times of Sumenep variety. The similarity showed in the case of particle and bulk densities. Regarding the texture profile, there was a significant difference in skin strength among the three varieties. Otherwise, there was no significant difference in their elasticities. The varieties of shallots and the type of surface material affected the emptying angle of repose and static friction.

1. Introduction
There are many kinds of shallots (Allium ascalonicum) that have been cultivated by farmers in Indonesia. The Center for Assessment Quality of Seeds of Food Crops and Horticulture reported that shallot crops in six provinces contained at least 18 kinds of shallot which were classified into seven varieties [1]. Shallot farming is preferred by farmers because it brings far greater profit compared to rice or corn commodity farming. This is inseparable from the status of shallot as one of the high-value horticultural commodities [2].

There is a tendency of abundant shallot production at harvest season causes the price of it is relatively low on the contrary in the off-season the rate is quite high. In a production state abundant, the farmer tries to keep it as long as possible nevertheless tubers of shallot cannot stand to be stored long due to the tunicated bulb of shallot can be decayed or early germinated. To avoid the decay of tunicated bulb of shallot as it has no long life, hence the post-harvest technology of shallot is necessary to be developed whether it is in processing or equipment technology. To improve both processing and equipment, knowledge of physical and mechanical properties is necessarily required. Many researchers studied the engineering properties of various agricultural products, such as soybean [3][4][5] and sugar beet seed [6]. The physical and mechanical properties of crops are beneficial in providing the engineering properties of shallots. The engineering properties are indispensable in processing, designing, and manufacturing of equipment.
Some researchers had conducted the study on physical and mechanical properties of different varieties of onion (*Allium cepa*). Results of the studied geometrical and physical properties of CO 4 onion bulb (*Allium cepa var. Aggregatum don*) showed that the moisture content affected the physical properties [7]. A study on physiomechanical properties of onion varieties showed that each type had a different characteristic [8]; the condition of the storeroom affected the puncture resistance and firmness of mature Giza 20 onions [9]; the various surfaces of material influenced the angle of repose [10-12] and friction [13, 14]. Results of the study on physicochemical characteristics of shallot New-Superior Varieties (NSV) consisted of ten varieties from Indonesia showed that there were significant by the effect the physical parameters, such as diameter, length, and weight [15]. The base data on the physical and mechanical properties of shallots are still rare. Therefore this study aimed to characterize and evaluate the physical and mechanical properties of three different shallot varieties which commonly cultivated by Indonesian farmers. Those popular shallots were Tuktuk, Bima Brebes and Sumenep. Tuktuk is a superior variety [16], Bima Brebes is an adaptive variety in all regions of Indonesia [1], and Sumenep is a variety that has the highest dissolved solid content so that it is widely used as raw material for fried onions [17].

2. Materials and methods
Three popular shallots (*Allium ascalonicum*) varieties chosen as samples are showed in figure 1. Tuktuk variety was the recombination of 5607 (F) with 5607 (M) produced by Ltd. East-West Seed, while Bima Brebes and Sumenep were the local varieties.

![Figure 1. Three varieties of shallot (a) Tuktuk var., (b) Bima Brebes var. and (c) Sumenep var.](image)

2.1. Physical properties
The properties of 20 samples were assessed at an average moisture content of 79.28 ± 0.06 % (wb) for Tuktuk variety, 81.74 ± 1.20 % (wb) for Bima Brebes variety, and 77.36 ± 0.15 % (wb) for Sumenep variety; the moisture content was measured referring to AOAC [18]. The physical properties observed in this study consisted of polar diameter, equatorial diameter, thickness, geometric diameter, surface area, sphericity, aspect ratio, shape index, mass, volume, particle density, bulk density and porosity. The primary dimension of shallot samples such as polar diameter, equatorial diameter and thickness were measured by digital vernier alipers with accuracy of 0.01 mm. Figure 2 showed the measurement position of the polar diameter, equatorial diameter and a thickness of the sample. An electronic balance with an accuracy of 0.01 gram weighed samples, while the water displacement method determined the volume of samples.

![Figure 2. The position of polar diameter (Dp), equatorial diameter (De) and thickness of shallots (T).](image)
The following equations determined the derived physical properties which were consisted of geometric diameter, surface area, porosity, sphericity, aspect ratio, shape index, particle and bulk densities [7, 19-25].

\[
D_{gm} = \sqrt[3]{D_p D_r T} \tag{1}
\]

\[
A_s = 3.14 \left( D_{gm} \right)^2 \tag{2}
\]

\[
\rho_p = \frac{M}{V} \tag{3}
\]

\[
\rho_b = \frac{M_{250}}{V_{250}} \tag{4}
\]

\[
\varepsilon = \frac{\rho_p - \rho_b}{\rho_p} \tag{5}
\]

\[
\psi = \frac{D_{gm}}{D_p} \times 100 \% \tag{6}
\]

\[
R_a = \frac{D_e}{D_p} \times 100 \% \tag{7}
\]

\[
I_s = \frac{D_e}{2D_p \times T} \tag{8}
\]

2.2. Mechanical Properties

![Figure 3. An apparatus for measuring an emptying angle of repose.](image)

The skin strength and elasticity of 15 samples were measured by using Texture Analyzer Stable Micro System- Probe: P2. An angle of repose was measured by using the apparatus of a moving metal plate equipped with sensors and will show the magnitude of the angle when the sample started rolling down. The angle of repose was the angle where the bulb of shallot started rolling down. Figure 3 showed the apparatus to determine the emptying angle of repose. The static friction was the value of the tangent of the emptying angle of repose.

2.3. Statistical Analysis

All data obtained from measurement were analyzed statistically to find out the range of physical and mechanical properties of each variety of shallots. Paired t-test sample was used to determine the similarities and differences between the types of shallots.
3. Results and discussions

3.1. Physical properties

Table 1 showed the main physical properties of three different shallot varieties. In general, the Tuktuk variety was prominent than other types, except for polar diameter, the Bima Brebes variety had the longest ones. Regarding volume and mass, the Tuktuk variety had a size of about three times of that of the Bima Brebes and nearly six times that of the Sumenep variety. Results of paired t-test analysis showed that there were significant differences among the three different types (t(1,19); p<0.05).

Table 1. The statistic description of the main physical properties of three varieties of shallots.

| Physical Properties | Tuktuk | Bima Brebes | Sumenep |
|---------------------|--------|-------------|---------|
| Dp                  | Mean   | 37.83       | 34.27   | 44.16   |
|                     | Std. Deviation | 4.34       | 3.62    | 4.03    |
| Dv                  | Mean   | 32.46       | 24.92   | 22.74   |
|                     | Std. Deviation | 6.04       | 3       | 2.31    |
| T                   | Mean   | 28.56       | 22.14   | 19.58   |
|                     | Std. Deviation | 2.31       | 1.82    | 1.72    |
| V                   | Mean   | 27.08       | 8.95    | 1.47    |
|                     | Std. Deviation | 8.89       | 1.55    | 1.02    |
| M                   | Mean   | 26.67       | 8.84    | 4.13    |
|                     | Std. Deviation | 8.92       | 1.55    | 0.88    |

Table 2. Derived physical properties of three different varieties of shallots.

| Physical Properties | Tuktuk | Bima Brebes | Sumenep |
|---------------------|--------|-------------|---------|
| Dp,man              | Mean   | 32.66       | 26.59   | 26.92   |
|                     | Std. Deviation | 3.86       | 2.20    | 1.59    |
| Spa                 | Mean   | 3393.69     | 2235.00 | 2283.46 |
|                     | Std. Deviation | 774.70     | 387.27  | 270.98  |
| ψ                   | Mean   | 86.39       | 77.92   | 61.26   |
|                     | Std. Deviation | 4.43       | 5.29    | 4.31    |
| Ra                  | Mean   | 85.37       | 73.15   | 51.83   |
|                     | Std. Deviation | 10.14      | 9.25    | 6.90    |
| Ia                  | Mean   | 0.98        | 0.91    | 0.77    |
|                     | Std. Deviation | 0.12       | 0.09    | 0.08    |
| ρp                  | Mean   | 0.99        | 0.99    | 0.97    |
|                     | Std. Deviation | 0.05       | 0.06    | 0.08    |
| ρb                  | Mean   | 0.45        | 0.50    | 0.43    |
|                     | Std. Deviation | 0.00       | 0.00    | 0.00    |
| ε                   | Mean   | 0.54        | 0.49    | 0.55    |
|                     | Std. Deviation | 0.02       | 0.03    | 0.04    |

Table 2 showed the derived physical properties of three different varieties of shallots. Regarding the sphericity, the three varieties were spherical (ψ<1.5) [26]. According to [27], the shape of Tuktuk and Bima Brebes were spherical, and Sumenep was the rod. Results of paired t-test analysis showed that in general there were significant differences among the three varieties of the sample (t(1,19); p<0.05), except for the surface area of Bima Brebes and Sumenep varieties (t(1,19); p>0.05). The similarity of the properties also happened on the particle and bulk densities of the three different types, and the porosity of Tuktuk and Sumenep varieties (t(1,19); p>0.05).

Physical characteristics such as shape, size, volume, frontal surface area, density, porosity and colour are essential in designing related machines or analysing the behaviour of products in material handling. Two main parameters have to be first defined to calculate other parameters such as terminal velocity, drag coefficient, and Reynolds numbers needed in designing related equipment and material analysis behaviour namely shape and size; the required parameters were calculated using a typical empirical formula depending on shape and size. There is a limited reference on physical properties of shallot; most of the existing literature is oriented on that of Onion (Allium cepa L.). However, compared to the weight of CO4 Onion (Allium cepa L.) [7], Tuktuk, Bima and Brebes varieties (Allium ascalonicum) were heavier. The weight per dm$^3$ (bulk density) of CO4 Onion was 0.42 kg/dm$^3$, while that of Tuktuk, Bima and Brebes shallot was 0.45, 0.50, and 0.43 kg/dm$^3$. In comparison to the weight of Talaja Red Onion [10], Tuktuk, Bima and Brebes shallot were relatively lighter; the
weight of Talaja Red Onion was 0.548 kg/dm³. In term of shape, CO 4 and Talaja Red Onion were considered oval (Shape Index >1.5) while Tuktuk, Bima and Brebes shallot were spherical (Shape Index <1.5).

3.2. Mechanical Properties

3.2.1. Texture Profile. Table 3 showed the skin strength and elasticity of three different varieties of shallots. Bima Brebes variety had the highest skin strength; otherwise, the lowest ones were Tuktuk variety. The highest elasticity occurred in Sumenep variety. Otherwise, the lowest ones happened in Tuktuk variety. Results of paired t-test analysis indicated that there was not any significant difference between the skin strength of Tuktuk and Sumenep and between Bima Brebes and Sumenep (t(1,14); p>0.05). Otherwise, there was a significant difference between skin strength of Tuktuk and Bima (t(1,14); p<0.05). Regarding the elasticity, three varieties showed similarity among them.

| Texture Profile | Tuktuk        | Bima Brebes  | Sumenep      |
|-----------------|---------------|--------------|--------------|
| Mean            | 1398.44       | 1704.88      | 1670.01      |
| Std. Deviation  | 125.68        | 62.75        | 64.60        |
| Skin strength   |               |              |              |
| Elasticity      | 56.84         |              | 64.60        |
| Std. Deviation  | 1.90          | 1.43         | 2.97         |

There is minimal information on shallot and onion skin strength; however, as an illustration, earlier published paper [28] stated that the hardness of Onion Cv. N-53 is 5.60 kg/cm². The hardness is able to increase due to the advancement of storage period. Shoba, H. [8] reported that crushing load of Ballari red, Arka Kalyan, Satara, and Kalasa has grown in Koppal District – India, vary depending on varieties and size of the onion. The range of crushing load of Ballari red, Arka Kalyan, Satara, and Kalasa are 425.70 – 842.52, 415.60 – 832.4, 405.12 – 821.32, and 398.40 – 819.70 kg/cm², respectively. Predicted by skin strength value, the hardness of Tuktuk, Bima Brebes and Sumenep shallots was in between the value of that of earlier published papers [8] and [28].

3.2.2. Angle of Repose and Friction. Table 4 showed the angle of repose of three varieties of shallots performed on various surfaces. The three varieties of shallots performed similar patterns on the type of surfaces. The surface of stainless steel showed the most slippery. Otherwise, the roughest surface was infraboard. Results of paired t-test analysis indicated that in general the variety and surface types affected the magnitude of the angle of repose (t(1,14); p<0.05), except for emptying angle of repose on stainless steel, infraboard and plywood for Brebes and Sumenep varieties (t(1,14); p> 0.05).

The angle of repose of Under Koppal District Onion [8], Talaja Red Onion [10] and Iranian onion [12] performed on plywood surface is 26.3, 17.0, and 37.71 was different from that of the angle of repose found in this study. The difference was mainly due to the difference in the shape and size of the onion and shallot.

| Empting Angle of Repose | Tuktuk | Bima Brebes | Sumenep |
|-------------------------|--------|-------------|---------|
| θ_eoss                  | 14.65  | 17.15       | 17.10   |
| θ_eal                   | 15.80  | 19.60       | 17.75   |
| θ_eacry                 | 16.00  | 19.90       | 18.85   |
| θ_eplyw                 | 16.45  | 19.90       | 20.30   |
| θ_eab                   | 16.75  | 20.15       | 21.05   |

Table 3. Texture profile of three varieties of shallot samples.

Table 4. The emptying angle of repose of three varieties of shallots on different surfaces.
3.3. Static friction

Table 5. The static friction of three varieties of shallots on different surfaces.

| Static Friction | Tuktuk var. | Bima Brebes var. | Sumenep var. |
|-----------------|-------------|------------------|--------------|
| μes             | Mean        | Std. Deviation   | Mean         | Std. Deviation | Mean | Std. Deviation |
| μsl             | 0.262       | 0.07             | 0.31         | 0.095          | 0.310 | 0.072          |
| μal             | 0.287       | 0.094            | 0.358        | 0.1            | 0.321 | 0.07           |
| μacry           | 0.29        | 0.085            | 0.364        | 0.118          | 0.343 | 0.093          |
| μplyw           | 0.296       | 0.067            | 0.366        | 0.107          | 0.373 | 0.111          |
| μfib            | 0.303       | 0.085            | 0.371        | 0.117          | 0.394 | 0.158          |

Table 5 showed the static friction of three varieties shallots on different surfaces. The static friction had a tangential correlation with the angle of repose; hence, the static friction had a similar pattern with the repose angle. The more slippery surfaces the least static friction. Results of paired t-test analysis showed that in general the variety and surface types affected the magnitude of the static friction (t(1,14); p<0.05), except for static friction on stainless steel, infraboard and plywood for Brebes and Sumenep varieties (t(1,14); p>0.05).

The static friction of Talaja Red Onion [10] and Iranian onion [12] performed on plywood surface is 0.32, and 0.29 was different from that of the static friction found in this study. The difference was mainly due to the difference in the shape and size of the onion and shallot.

4. Conclusion

Shape and size are two main parameters to be defined in employing other physical parameters to design associated equipment and analysis the behaviour of materials. The shape of shallot, all of the varieties were spherical. Physically, three varieties of shallots had different characteristics, except for some derived properties such as bulk density, particle density and porosity showed similarity. There was significant difference in skin strength, but no in elasticity. Bima Brebes variety had the highest skin strength 1704.88 ± 422.84 gf and Tuktuk variety had the lowest ones of 1398.44 ± 125.68 gf. The varieties of shallot and type of surfaces affected the emptying angle of repose and static friction. The surface of stainless steel showed the most slippery, whereas the roughest surface was infraboard. Properties of shape and size can be beneficial for designing packaging equipment, texture profile can be factor for designing equipment for crushing, and friction can be very useful in conveying material.

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