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*Original Research Article*

# Determination of selected physical properties of tiger nuts (*Cyperus Esculentus*)

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**Abstract**

**The brown and yellow varieties of tiger nut seed were purchased from Uchi market Auchi, Edo State. Nigeria. They were prepared and taken to the laboratory to determine their physical properties. The moisture content was found to range from 10.1 to 28.6% (wb). The length, width, thickness, sphericity, geometric mean diameter, arithmetic mean diameter, surface area, volume, angle of repose and coefficient of friction were determined and the effect of moisture content on the physical properties of the seed was also determined. All properties studied were found to have a response to moisture content increase within the moisture content range studied. The seed volume and the seed surface area of tiger nut increased from 236.68 $mm^3$ to 737.01 $mm^3$ and 209.38 $mm^2$ to 303.22 $mm^2$respectively. Aspect ratio and sphericity of tiger nuts varied with increase in the moisture content. Angle of repose increased from 23$^o$ to 34$^o$ while static coefficient of friction increased from 0.15 to 2.24 (plywood), 0.15 to 0.1.59 (mild steel), 0.15 to 2.24 (glass).**

**Keywords:** Tiger nuts, Tiger Milk, Physical properties, design, extraction machine

## INTRODUCTION

Tigernut (*Cyperusesculentus*) is a perennial grass-like plant with spheroid tubers, pale yellow cream kernel surrounded by a fibrous sheath. It is also known as yellow nut sedge, earth or ground almonds, "souchet" in French, "ermandeln" in German and "chufa" in Spanish. Grossman and Thomas (1998) reported that chufa came to Spain from Africa. Tigernut is found wild and cultivated in Africa, South America, Europe and Asia. Tigernuts grow in the wild, along rivers and are cultivated on a small scale by rural farmers mostly in the northern states of Nigeria. It is locally called "aya" in Hausa; "akiawusa" in Igbo; "ofio" in Yoruba and "isipaccara" in Effik.

Tigernuts are edible, sweet, nutty, flavoured tubers which contain protein, carbohydrate, sugars, and lots of oil and fiber (FAO, 1988). Grossman and Thomas (1998) showed that tigernuts have been cultivated for food and drink for men and planted for hogs for many years in Spain and that the lovely milky elixir is served in health Spas, Pubs, and Restaurants as a refreshing beverage (competing successfully with other soft drinks). Unfortunately, despite these potentials in tigernuts it has been a neglected crop in Nigeria. Tigernut could provide a basis for rural industries in Africa. It is an important food crop for certain tribes in Africa, often collected and eaten raw, baked as a vegetable, roasted or dried and ground to flour. The ground flour is mixed with sorghum to make porridge, ice-cream, sherbet or milky drink. It is mostly consumed raw as snack without knowledge of the food and nutritional quality (FAO, 1988). It has also been found to possess good therapeutic quality (Moore, 2004). Moore stated that "the expansion of tigernut milky drinks will significantly help the research linking tigernut milk to healthier cholesterol levels and other non-dairy manufacturers. This could also gain a boost from an increased consumer interest in health foods".

Variety of food products can be derived from tiger nut tubers though there is little documentation at large. Various food processing techniques can be applied to

**Plate 1.** Tiger nuts

tiger nut processing to modify its appearance, develop its natural flavour, stimulate the digestive juices, add variety to the menu, make it easily digestible and bio-available, destroy harmful microorganisms, improve its nutritional quality and prevent decomposition.

The physical properties of Tigernut tubers, like those of other agricultural materials such as fruits and vegetables are essential for the design of equipment for handling, harvesting and storing the tubers or determining the behavior of the tubers for its handling. Various types of cleaning, grading and separation equipment are designed on the basis of the physical properties of the agricultural materials. Physical properties affect the converting characteristics of solid materials by air or water and cooling and heating load of food products (Sahay and Singh, 1994).

Food insecurity continues to threaten large proportions of households in Nigeria. Tigernut has been for many years one of the underutilized food crops in Nigeria. It is mostly eaten raw as snack and un-identified as a very important food crop that has great potential in managing, preventing and eliminating malnutrition (macronutrient and micronutrient deficiencies) or food insecurity problems. It has been demonstrated by nutritionist that the major nutritional problems could be solved through exploitation of the nutrition and economic potentials of the local food resources (Stoller, 2003). All though, Tiger nut has divers nutritional and health benefits yet the post-harvest operations on Tiger nut has not yet been fully mechanized, an attempt towards the mechanization of agricultural processing of produce begins with the knowledge of their physical, mechanical, thermal, chemical, rheological and frictional properties.

In recent years, the need to increase the production and utilization of locally available food resources has been highlighted at different national and international level. Tigernuts, one of the underutilized food crops locally available in Nigeria could be demonstrated to aid in solving major nutritional problems through exploitation of its nutritional and economic potentials. The results of this study will provide a baseline data on tigernut mechanization and post-harvest operations. This will go a long way to diversify its use and in turn lead to its increased production both at household and national levels ultimately to ensure food security.

The objective of this paper is to determine the physical properties of Tiger nut with specific objectives are to: compare the physical properties of two common varieties of Tiger nut, the brown and yellow type and to determine the effect of moisture content on the selected physical properties. (Plate 1)

## Botany of Tigernuts

*Cyperusesculentus* (tigernut sedge / chufa sedge / yellow nut sedge / earth almond) is a species of sedge, native to warm temperate to subtropical regions of the Northern Hemisphere. Tigernut is a highly adaptable crop and grows well under a wide range of climatic and soil conditions. The tuber grows 50- 250 tubers per plant and weighs 2 – 26 g per tuber (FAO, 1988). The leaves of tigernut (*Cyperusesculentusleptostachyus*) are long, narrow, shiny, light green, arranged in 3 rows around the triangular stem often with characteristic pointed tip separated from the rest of the leaf by a distinct shoulder (FAO, 1988). In West Africa the plant often grows in great concentration and is gathered from the wild. It is interesting to note that esculentus, means edible in latin (Negbi, 1992). Tigernut tubers are of different varieties, the notable ones are black yellow and brown with various sizes (Barminas *et al.,* 2001).The most common varieties are long and round. The varieties are:

- Cyperusesculentus var. esculentus.
- Cyperusesculentus var. hermannii.
- Cyperusesculentus var. leptostachyus.
- Cyperusesculentus var. macrostachyus.
- Cyperusesculentus var. sativus
- Cyperusesculentus var. rotundus

## Nutritional Composition of Tigernutsand its Products

Tigernut oil is 80% unsaturated fatty acid, mainly oleic (64.2 – 68.8 %) and this shows that tigernut oil has a good potential as a substitute for imported olive oil (Deatra, 1999). Fat in diets provide twice much energy as carbohydrate or protein, thus low fat diets are recommended to aid weight control. Different types of fat (fatty acids) have different effects on health and the risk of diseases states such as coronary heart disease (CHD). Saturated fatty acids (SFA) increase levels of blood cholesterol and should be avoided whenever possible. There is evidence that the replacement of SFA with monounsaturated fatty acid (MUFA) may have a favorable effect on the risk of CHD. Venho *et al.* (2000) investigated types of fat intake in relation to CHD risk in women and reported that for every increase of 5% in energy from MUFA there is a decrease in CHD relative risk of 0.81%. Tigernut is a good source of phosphorous, potassium and iron. It also contains magnesium, calcium, zinc, copper, sodium and manganese. It is involved in many enzyme reactions including those involved in energy generation from carbohydrate, fat and protein.

## Nutritional and Health Importance

Tigernuts and its products are rich in carbohydrates, mono-, di-, and polysaccharides (Moore, 2004). They contain relatively high levels of protein, oleic acid (monounsaturated fatty acid which has a bigger resistance to chemical decomposition) and fat. Tigernuts have excellent nutritional quality with a fat composition similar to olive oil and rich mineral content, especially phosphorus and potassium (FAO, 1988; Moore, 2004). Tigernut oil has a mild, pleasant flavour and is considered as food oil similar but superior in quality to olive oil. The polyunsaturated fatty acid content (linoleic acid and linolenic acid) is enough to cover daily minimum needs of about 10 g oil has high content of Vitamin E (alpha-tocopherol), and thus higher oxidative stability than other oils, due to its content of polyunsaturated fatty acids and gamma-tocopherol.

Tiger nuts may need to rely significantly on its health benefits, promoting a rich monounsaturated fatty acid content, high vitamin E levels and prebiotic qualities (Moore, 2004). Vitamin E, an antioxidant which protects the body form free radical attack, is vital for the maintenance of cell membranes. It may also play an important role in delaying cells from aging thereby improving the elasticity of skin. Vitamin E is good for treatment of acne and other skin “alterations". It is particularly important in areas of the body exposed to oxidative stress such as the lungs and the red blood cells. Vitamin E may reduce the risk of cancer and CHD due to its role as anti-oxidant, however research in this area is currently inconclusive (Moore, 2004). It can also reduce levels of triglycerides in blood, reduce risk of formation of bloody clots, produce dilatation in veins and prevent arteriosclerosis. Tigernuts may play an important role in the prevention and nutritional therapy for cardiac pathologies, due to its high content of monounsaturated fatty acids (Oleic acid) to improve metabolism and health (Moore, 2004).

## Economic Importance of Tiger Nuts

In some parts of Africa, Europe and Asia, tigernut is grown for its edible tubers. Tigernuts may be regarded as an obnoxious weed that has been used historically as food and medicine by the Egyptians and Native Americans. Even today the Egyptians cultivate tigernuts in moist soils or sandy shores for their edible tubers. Tigernut tubers may be consumed raw, roasted, or ground into flour as well as being used to produce vegetable oil, and cellulose (FAO, 1988). Tigernut is a representative crop of the Spanish Mediterranean region, where tubers are used to make horchata. The milky-looking aqueous extract of tiger nuts has a pleasant and characteristic flavor of vanilla and almonds and could be sold in Pubs. Unfortunately, popularity of tigernut milk extract or “horchata” has not extended to Nigeria. In Maradi state, Eastern Niger, tigernut is cultivated for export to Nigeria. Revenues from this exceed those from the typical cash crops such as cowpea and groundnut. Nowadays, tigernut is cultivated in Northern Nigeria, Ghana and Togo where it is made into a sweet meat or used uncooked as a side dish.

## Products Obtained from Tigernuts

### Tiger Nut Milk

The origin of the use of this tuber for making milk is exclusive to the Spaniards to which it may have been introduced by the Arabs. Tiger nut milk/beverage/ drink commonly called ‘kunnuaya’ in northern Nigeria is a healthy drink with many nutrients. It is a nourishing and energetic product recommended by experts to be taken during any season of the year, especially in dry season when the sun is hot (Stoller, 2003).

### Tiger Nut Flour

Tiger nut flour has a unique sweet taste, which is ideal for different uses. It is a good alternative to many other flours like wheat flour, as it is gluten free and good for people who cannot take gluten in their diets. It is also used in the confectionery industry. It is considered good flour or additive for the bakery industry, as its natural sugar content is fairly high, avoiding the necessity of adding too much extra sugar (Stoller, 2003).

## Tiger Nut Oil

The edible and stable oil obtained from the tuber is said to be superior oil that compares favourably with olive oil. The oil is golden brown in colour and has a rich, nutty taste. The oil remains in a uniform liquid form at refrigeration temperature. This makes the oil suitable for salad making. It has a high oleic acid and low polyunsaturated fatty acid (linoleic acid and linolenic acid), enough to cover daily minimum needs for an adult (around 10 g) and low acidity, and so is excellent for the skin. It also has higher oxidative stability than other oils, due to the presence of polyunsaturated fatty acids and gamma-tocoferol.

## Production of Local Beverage (Kunnu)

It is also used for the production of nougat, jam, beer, and as a flavoring agent in ice cream and in the preparation of kunnu (a local beverage in Nigeria). Kunnu is a nonalcoholic beverage prepared mainly from cereals (such as millet or sorghum) by heating and mixing with spices (dandelion, alligator pepper, ginger, licorice) and sugar (Stoller, 2003).

## Used as Fishing Bait

The boiled nuts are used in the UK as a bait for carp. The nuts have to be prepared in a prescribed manner to prevent harm to the fish. The nuts are soaked in water for 24 hours and then boiled for 20 minutes or longer until fully expanded. Some anglers then leave the boiled nuts to ferment for 24–48 hours, which can enhance their effectiveness (Stoller, 2003).

## Physical Properties of Agricultural Materials

Physical characteristics of raw, unprocessed, as well as processed food materials include particle size and shape, particle and bulk density, porosity, and surface area. The study of food engineering focuses on the analysis of equipment and systems used to process food on a commercial production scale. Engineering of systems for food materials can be more thorough if there is an understanding of the changes that occur in food as it is processed by the system. Raw food materials are biological in nature and as such have certain unique characteristics which distinguish them from other manufactured products.

Knowledge of a food's physical properties is necessary for:

- Defining and quantifying a description of the food material,
- Providing basic data for food engineering and unit operations, and
- Predicting behavior of new food materials.

It is common for the physical properties of a food to change during processing operations. Not recognizing these changes can lead to potential processing failures. Physical properties are an important aspect of food quality and relate to food safety. They are the basis for instruments and sensors. A few examples of select physical properties of foods are presented in this unit.

Various methods are used to measure or characterize the shape and size characteristics of foods and food products. In several cases, actual measurements are made to estimate the major dimensions and cross sections of the product. Tracings or projections are made to compare the shapes to listed standards (Mohsenin, 1970).

## MATERIALS AND METHODS

### Sample Preparation

One thousand samples of the brown and yellow variety of Tigernuts were used for this study, it was purchased from Uchi market Auchi, Edo state Nigeria, and it was randomly selected and taken to the Department of Agricultural Engineering laboratory, the seed were divided into two parts and one part was soaked in water to absorb moisture and the other was sun dried for 24 hours making a total of four different samples designated as follows: Brown sun dried variety (A), Yellow sun dried variety (B), Brown soaked variety (C) and Yellow variety soaked (D). The initial moisture content was obtained by keeping a sample of 10 g in the oven at a temperature of 105°C for 24 h as shown in the Plate 2. The moisture content was calculated using the relation:

$$MC_{wb} = \frac{W_w}{W_w + W_d} \times \frac{100}{1} \qquad Eq. 1$$

### Determination of Physical Properties of Tigernut

### Dimension and Size

The length, width and thickness of the tubers were determined using a Vernier calliper with 0.01 mm accuracy. 20 tubers each was randomly selected from the sun dried and soaked tuber of the brown and yellow varieties. The three principal dimensions of the selected tubers were measured and their averages were taken.

**Plate 2.** Tiger nut seeds in the Oven

### Determination of Sphericity

The results of length, width and thickness obtained were used to calculate the sphericity, geometric mean diameter and other parameters. According to Abano and Amoah (2011), the degree of sphericity, ø, can be expressed as follows:

$$\varnothing = \frac{(WTL)^{0.333}}{L} \quad (2)$$

Where L, W and T are the tuber major (length), intermediate (width) and minor (thickness) diameters.

### Determination of Arithmetic Mean Diameter

The arithmetic mean diameter, Da is given by:

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

### Determination of Geometric Mean Diameter

The geometric mean diameter, Dg is given as:

$$D_g = (WTL)^{0.333} \quad (4)$$

### Determination of Surface Area

The surface area, S was determined by using the formula:

$$S = \pi {D_g}^2 \quad (5)$$

### Determination of Volume

The volume V is given by:

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (6)$$

Where, B = $(WT)^{0.5}$ (7)

### Determination of Aspect Ratio

The aspect ratio was calculated using the relation:

$$R_a = \frac{W}{L} \quad (8)$$

### Angle of Repose and Coefficient of Friction

To determine the angle of repose, plywood, glass, and sheet metal were used. The tubers were allowed to fall from a height of 15 cm to form a natural heap was shown in Plate 3. The angle of repose is taken to be the arctangent of the ratio of height of the conical heap to the diameter of the cone.

The coefficient of static friction was obtained using a device developed in the Department of Agricultural and Bio-Environmental Engineering Technology, Auchi Polytechnic Auchi for determining coefficient of friction. A cylinder was pulled up slightly, and the angle at which the tubers just began to slide down was recorded from the attached protractor as the static angle of friction between the tubers and the friction surface. The coefficient of

**Plate 3.** Determination of Angle of Repose

**Table 1.** Moisture Content

| Variety | Moisture Content of the Sun Dried Seed (%) | Moisture Content of the Soaked Seed (%) |
|---|---|---|
| Brown | 10.1 | 26.4 |
| Yellow | 11.2 | 28.6 |

**Table 2.** Geometric properties of Tiger nut seed

| Sample | L(mm) | W(mm) | T(mm) | Ø(%) | Da(mm) | Dg(mm) | S ($mm^2$) | V ($mm^3$) | Ra |
|---|---|---|---|---|---|---|---|---|---|
| A | 10.03 | 8.47 | 6.57 | 81.56 | 8.35 | 8.13 | 209.38 | 236.68 | 0.85 |
| B | 8.72 | 10.85 | 6.57 | 77.74 | 8.71 | 8.42 | 224.92 | 502.05 | 1.30 |
| C | 9.85 | 10.56 | 6.88 | 84.71 | 9.09 | 8.86 | 248.30 | 564.35 | 1.10 |
| D | 10.66 | 11.55 | 7.75 | 84.68 | 9.99 | 9.77 | 303.22 | 737.01 | 1.11 |

static friction was determined on three structural surfaces of plywood, metal and glass.

### Density Determination

The density of the kernel was determined using the ratio of weight to the volume method (Mohsenin, 1970):

$$Density\ (\rho) = \frac{Weight\ (g)}{Volume\ (mm^3)} \qquad (9)$$

## RESULTS AND DISCUSSION

### Results

### Moisture Content

The moisture content of the brown and yellow variety was determined as presented in Table 1. The above result was determine to give room for comparison of the effect of moisture content on the physical properties of Tiger nut seed, especially properties like angle of repose and angle of internal friction that affects their handling and processing.

### Dimension and Size

The average of the geometric dimension of twenty (20) tubers chosen from each samples are shown in Table 2. The complete results of the twenty (20) are presented in Apendex A – D of this work.

### Angle of Repose and Coefficient of Friction

Table 3 shows the results of angle of repose and coeffi-

**Table 3.** Angle of Repose

| | Coefficient of Friction | | | Angle of Repose | | |
|---|---|---|---|---|---|---|
| **Sample** | **Plywood (°)** | **Sheet metal (°)** | **Glass (°)** | **Plywood (°)** | **Sheet metal (°)** | **Glass (°)** |
| A | 0.30 | 0.15 | 0.15 | 8 | 9 | 10 |
| B | 2.24 | 1.59 | 0.15 | 10 | 8 | 10 |
| C | 0.15 | 0.15 | 0.15 | 15 | 10 | 21 |
| D | 2.24 | 1.59 | 2.24 | 19 | 13 | 23 |

**Table 4.** Density of the Tubers

| S/N | Density of Sample A ($g/mm^3$) | Density of Sample B ($g/mm^3$) | Density of Sample C ($g/mm^3$) | Density of Sample D ($g/mm^3$) |
|---|---|---|---|---|
| 1 | 0.0018 | 0.0015 | 0.0015 | 0.0011 |
| 2 | 0.0034 | 0.0014 | 0.0012 | 0.0014 |
| 3 | 0.0051 | 0.0039 | 0.0019 | 0.0018 |
| 4 | 0.0033 | 0.0027 | 0.0012 | 0.0012 |
| 5 | 0.0049 | 0.0023 | 0.0016 | 0.0021 |
| 6 | 0.0034 | 0.0021 | 0.0023 | 0.0020 |
| 7 | 0.0041 | 0.0025 | 0.0022 | 0.0020 |
| 8 | 0.0038 | 0.0019 | 0.0017 | 0.0017 |
| 9 | 0.0056 | 0.0028 | 0.0010 | 0.0024 |
| 10 | 0.0046 | 0.0024 | 0.0027 | 0.0017 |
| 11 | 0.0040 | 0.0018 | 0.0020 | 0.0008 |
| 12 | 0.0021 | 0.0016 | 0.0013 | 0.0016 |
| 13 | 0.0055 | 0.0025 | 0.0012 | 0.0010 |
| 14 | 0.0046 | 0.0014 | 0.0013 | 0.0013 |
| 15 | 0.0045 | 0.0014 | 0.0012 | 0.0010 |
| 16 | 0.0026 | 0.0016 | 0.0016 | 0.0011 |
| 17 | 0.0028 | 0.0020 | 0.0010 | 0.0008 |
| 18 | 0.0035 | 0.0025 | 0.0020 | 0.0022 |
| 19 | 0.0026 | 0.0016 | 0.0012 | 0.0011 |
| 20 | 0.0064 | 0.0017 | 0.0016 | 0.0014 |

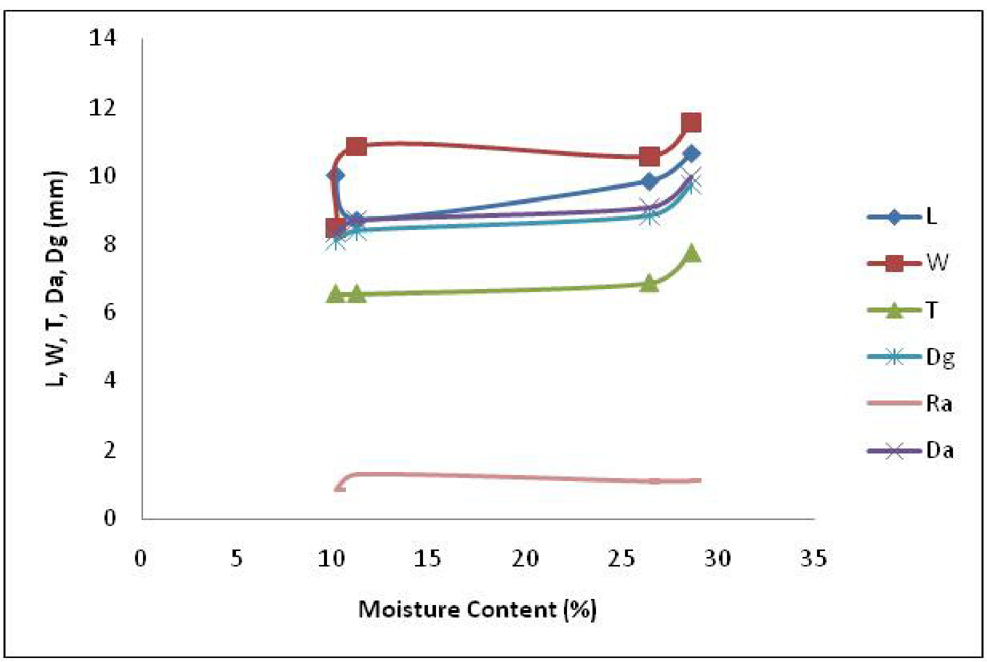


**Figure 1.** The geometric parameters against moisture content

cient of friction measured in degrees.

### Density of the Tubers

The results of the density of each of the tubers are presented in Table 4.

## DISCUSSION

Seed dimensions and geometric properties shown in Table 1 and Figure 1 clearly display the variations of mean length, width, thickness and geometric diameters of the tubers with tuber moisture content. All the linear dimensions decreased with decreasing tuber moisture content. This trend is probably due to enough air voids as they as they lose moisture and thereby making the tubers display appreciable dimensional change.

The sphericity, ø, variation with tuber moisture content is also shown in Table 1, the value of sphericity obtained suggest an elliptical shape. Change in moisture content also lead to a slight change in the sphericity of the tubers. This results indicate that the tuber is has shape of a sphere and that the moisture content does not greatly affect the sphericity. This means that a sieving or separating machine with circular holes will easily let tubers through its holes. During unloading the tubers will roll on their own accord. The surface area decreases with decreasing moisture content for both varieties.

The angle of repose decreased non-linearly with tuber moisture content from. The coefficient of friction also decreased with decreasing moisture content for plywood structural surface. The result of the density presented in Table 4.4 shows that the yellow variety had higher values of moisture content and also the tubers with higher moisture content showed a clearly higher densities.

## CONCLUSION

1. All properties studied were found to have a response to moisture content increase within the moisture content range studied.
2. The seed volume and the seed surface area of tiger nut increased from 236.68 $mm^3$ to 737.01 $mm^3$ and 209.38 $mm^2$ to 303.22 $mm^2$ within the range of moisture content tested. Aspect ratio and sphericity tiger nuts varied with increase in the tested moisture content.
3. Angle of repose increased from $23^o$ to $34^o$while static coefficient of friction increased from 0.15 to 2.24 (plywood), 0.15 to 0.1.59 (mild steel), 0.15 to 2.24 (glass).

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## APPENDICES

### Appendix A: Brown variety sun dried

| L (mm) | W (mm) | T (mm) | ϕ (%) | Da (mm) | Dg (mm) | S ($mm^2$) | V ($mm^3$) | Ra |
|---|---|---|---|---|---|---|---|---|
| 9.90 | 10.20 | 9.60 | 99.7 | 9.90 | 9.87 | 31.03 | 507.41 | 1.03 |
| 11.60 | 11.20 | 5.50 | 76.9 | 9.43 | 8.92 | 28.03 | 282.75 | 0.97 |
| 10.20 | 5.50 | 8.80 | 77.3 | 8.17 | 7.89 | 24.78 | 196.16 | 0.54 |
| 9.00 | 6.70 | 7.10 | 83.6 | 7.60 | 7.52 | 23.63 | 181.73 | 0.74 |
| 10.00 | 8.60 | 4.40 | 72.2 | 7.67 | 7.22 | 22.68 | 143.09 | 0.86 |
| 9.70 | 9.80 | 5.60 | 83.4 | 8.37 | 8.09 | 25.41 | 225.49 | 1.01 |
| 11.20 | 5.80 | 7.70 | 70.7 | 8.23 | 7.92 | 24.89 | 186.65 | 0.52 |
| 8.90 | 9.30 | 6.10 | 89.3 | 8.10 | 7.95 | 24.97 | 229.17 | 1.04 |
| 9.90 | 8.40 | 3.90 | 69.3 | 7.40 | 6.86 | 21.55 | 119.45 | 0.85 |
| 10.10 | 7.90 | 6.70 | 80.2 | 8.23 | 8.10 | 25.45 | 218.77 | 0.78 |
| 8.00 | 8.80 | 7.00 | 98.5 | 7.93 | 7.88 | 24.77 | 253.27 | 1.10 |
| 11.00 | 9.80 | 8.00 | 86.3 | 9.60 | 9.50 | 29.84 | 377.90 | 0.89 |
| 8.40 | 7.60 | 6.00 | 86.3 | 7.33 | 7.25 | 22.77 | 167.70 | 0.90 |
| 11.00 | 9.00 | 5.00 | 71.8 | 8.33 | 7.89 | 24.80 | 186.46 | 0.82 |
| 9.00 | 8.00 | 6.00 | 83.8 | 7.67 | 7.54 | 23.70 | 183.89 | 0.89 |
| 11.10 | 10.00 | 7.00 | 82.6 | 9.37 | 9.17 | 28.82 | 326.49 | 0.90 |
| 12.00 | 6.80 | 8.00 | 72.1 | 8.93 | 8.66 | 27.20 | 246.76 | 0.57 |
| 9.90 | 9.00 | 6.60 | 84.4 | 8.50 | 8.36 | 26.27 | 252.11 | 0.91 |
| 9.70 | 9.20 | 7.50 | 90.0 | 8.80 | 8.73 | 27.42 | 306.47 | 0.95 |
| 9.90 | 7.70 | 4.90 | 72.6 | 7.50 | 7.19 | 22.58 | 141.79 | 0.78 |

### Appendix B: Yellow variety sun dried

| L (mm) | W (mm) | T (mm) | ϕ (%) | Da (mm) | Dg (mm) | S ($mm^2$) | V ($mm^3$) | Ra |
|---|---|---|---|---|---|---|---|---|
| 10.20 | 11.40 | 9.60 | 90.8 | 10.40 | 10.35 | 336.53 | 658.77 | 1.12 |
| 11.20 | 11.60 | 5.50 | 76.9 | 9.43 | 8.92 | 250.03 | 775.72 | 1.04 |
| 5.50 | 10.20 | 8.80 | 77.3 | 8.17 | 7.89 | 195.45 | 253.18 | 1.85 |
| 6.70 | 11.00 | 7.10 | 73.1 | 8.27 | 8.04 | 203.18 | 359.80 | 1.64 |
| 8.60 | 10.00 | 4.40 | 72.2 | 7.67 | 7.22 | 163.73 | 420.22 | 1.16 |
| 9.80 | 9.70 | 5.60 | 83.4 | 8.37 | 8.09 | 205.52 | 485.36 | 0.99 |
| 5.80 | 12.30 | 7.70 | 66.4 | 8.60 | 8.17 | 209.86 | 398.50 | 2.12 |
| 9.30 | 11.60 | 6.10 | 74.8 | 9.00 | 8.68 | 236.69 | 594.89 | 1.25 |
| 8.40 | 9.90 | 3.90 | 69.3 | 7.40 | 6.86 | 147.75 | 400.06 | 1.18 |
| 7.90 | 10.10 | 6.70 | 80.2 | 8.23 | 8.10 | 206.10 | 379.72 | 1.28 |
| 8.80 | 10.20 | 7.00 | 83.8 | 8.67 | 8.55 | 229.51 | 447.96 | 1.16 |
| 9.80 | 11.00 | 8.00 | 86.3 | 9.60 | 9.50 | 283.39 | 588.19 | 1.12 |
| 7.60 | 10.00 | 6.00 | 76.8 | 7.87 | 7.68 | 185.39 | 354.63 | 1.32 |
| 11.00 | 11.00 | 5.00 | 76.7 | 9.00 | 8.44 | 223.80 | 697.00 | 1.00 |
| 11.00 | 11.20 | 6.00 | 80.6 | 9.40 | 9.02 | 255.74 | 716.15 | 1.02 |
| 10.00 | 11.10 | 7.00 | 82.6 | 9.37 | 9.17 | 264.38 | 614.17 | 1.11 |
| 6.80 | 12.00 | 8.00 | 72.1 | 8.93 | 8.66 | 235.42 | 432.67 | 1.76 |
| 9.00 | 9.90 | 6.60 | 84.4 | 8.50 | 8.36 | 219.60 | 441.48 | 1.10 |
| 9.20 | 11.90 | 7.50 | 78.5 | 9.53 | 9.34 | 274.28 | 611.40 | 1.29 |
| 7.70 | 10.80 | 4.90 | 68.5 | 7.80 | 7.40 | 172.00 | 411.09 | 1.40 |

**Appendix C: Brown variety soaked**

| L (mm) | W (mm) | T (mm) | ϕ (%) | Da (mm) | Dg (mm) | S ($mm^2$) | V ($mm^3$) | Ra |
|---|---|---|---|---|---|---|---|---|
| 11.00 | 10.00 | 9.40 | 100.9 | 10.13 | 10.09 | 319.80 | 605.46 | 0.91 |
| 11.20 | 11.60 | 6.60 | 81.7 | 9.80 | 9.48 | 282.31 | 775.72 | 1.04 |
| 9.00 | 11.00 | 8.80 | 86.6 | 9.60 | 9.53 | 285.32 | 521.64 | 1.22 |
| 10.00 | 9.90 | 6.40 | 86.6 | 8.77 | 8.57 | 230.79 | 515.84 | 0.99 |
| 8.90 | 10.00 | 5.20 | 77.2 | 8.03 | 7.72 | 187.22 | 441.27 | 1.12 |
| 11.00 | 6.60 | 5.60 | 112.0 | 7.73 | 7.39 | 171.74 | 341.28 | 0.60 |
| 6.00 | 11.40 | 7.80 | 71.0 | 8.40 | 8.09 | 205.82 | 345.74 | 1.90 |
| 9.30 | 10.60 | 8.40 | 88.4 | 9.43 | 9.37 | 275.83 | 514.91 | 1.14 |
| 12.00 | 9.70 | 5.50 | 88.7 | 9.07 | 8.60 | 232.39 | 664.40 | 0.81 |
| 8.00 | 10.00 | 6.80 | 81.5 | 8.27 | 8.15 | 208.50 | 380.00 | 1.25 |
| 10.00 | 9.80 | 6.00 | 85.3 | 8.60 | 8.36 | 219.59 | 508.09 | 0.98 |
| 9.80 | 11.10 | 7.00 | 82.1 | 9.30 | 9.11 | 260.85 | 596.59 | 1.13 |
| 12.00 | 10.90 | 7.00 | 88.9 | 9.97 | 9.69 | 294.92 | 785.10 | 0.91 |
| 9.90 | 11.50 | 6.00 | 76.4 | 9.13 | 8.79 | 242.65 | 640.01 | 1.16 |
| 10.10 | 12.00 | 6.90 | 78.3 | 9.67 | 9.40 | 277.65 | 704.44 | 1.19 |
| 10.00 | 10.30 | 7.10 | 87.3 | 9.13 | 8.99 | 253.92 | 547.53 | 1.03 |
| 9.90 | 12.00 | 7.50 | 80.0 | 9.80 | 9.60 | 289.62 | 685.06 | 1.21 |
| 9.00 | 10.00 | 6.80 | 84.7 | 8.60 | 8.47 | 225.52 | 448.43 | 1.11 |
| 10.00 | 11.90 | 7.50 | 80.7 | 9.80 | 9.61 | 289.94 | 685.45 | 1.19 |
| 9.90 | 10.80 | 5.20 | 76.0 | 8.63 | 8.21 | 211.55 | 580.10 | 1.09 |

**Appendix D: Yellow variety soaked**

| L (mm) | W (mm) | T (mm) | ϕ (%) | Da (mm) | Dg (mm) | S ($mm^2$) | V ($mm^3$) | Ra |
|---|---|---|---|---|---|---|---|---|
| 12.30 | 12.10 | 10.00 | 94.1 | 11.47 | 11.39 | 407.58 | 950.87 | 0.98 |
| 11.60 | 11.60 | 6.60 | 82.7 | 9.93 | 9.59 | 288.99 | 817.39 | 1.00 |
| 7.70 | 13.00 | 8.90 | 73.8 | 9.87 | 9.60 | 289.59 | 576.07 | 1.69 |
| 12.10 | 11.00 | 9.90 | 99.4 | 11.00 | 10.94 | 375.84 | 805.87 | 0.91 |
| 9.00 | 10.20 | 5.60 | 78.4 | 8.27 | 7.99 | 200.79 | 462.52 | 1.13 |
| 10.00 | 9.70 | 7.00 | 90.4 | 8.90 | 8.77 | 241.67 | 500.39 | 0.97 |
| 7.60 | 12.30 | 7.70 | 72.7 | 9.20 | 8.94 | 251.25 | 511.16 | 1.62 |
| 10.00 | 11.60 | 8.00 | 83.9 | 9.87 | 9.73 | 297.57 | 658.15 | 1.16 |
| 9.00 | 10.40 | 5.00 | 74.5 | 8.13 | 7.75 | 188.62 | 476.89 | 1.16 |
| 8.80 | 11.60 | 7.00 | 76.9 | 9.13 | 8.92 | 250.03 | 552.21 | 1.32 |
| 13.20 | 12.10 | 7.00 | 85.6 | 10.77 | 10.35 | 336.88 | 1058.97 | 0.92 |
| 10.00 | 11.00 | 8.00 | 86.9 | 9.67 | 9.56 | 287.23 | 605.59 | 1.10 |
| 12.00 | 12.00 | 8.30 | 88.2 | 10.77 | 10.59 | 352.19 | 904.90 | 1.00 |
| 12.00 | 11.00 | 6.60 | 86.6 | 9.87 | 9.53 | 285.32 | 795.62 | 0.92 |
| 12.00 | 13.00 | 9.00 | 85.9 | 11.33 | 11.17 | 392.06 | 1022.04 | 1.08 |
| 13.00 | 11.10 | 9.00 | 98.1 | 11.03 | 10.88 | 372.22 | 912.99 | 0.85 |
| 13.10 | 12.90 | 8.00 | 85.5 | 11.33 | 11.03 | 382.31 | 1150.46 | 0.98 |
| 9.00 | 10.90 | 9.30 | 88.8 | 9.73 | 9.68 | 294.22 | 514.01 | 1.21 |
| 12.00 | 12.40 | 7.50 | 83.5 | 10.63 | 10.35 | 336.47 | 950.78 | 1.03 |
| 8.80 | 11.10 | 6.60 | 77.7 | 8.83 | 8.62 | 233.47 | 513.33 | 1.26 |