INVESTIGATION ON THE EFFECT OF MOISTURE CONTENT ON PHYSICAL AND THERMAL PROPERTIES OF OFADA RICE (*ORYZA SATIVA* L.) RELEVANT TO POST-HARVEST HANDLING

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ABSTRACT

Knowledge of the physical and thermal properties of agricultural products is essential in order to design equipment for processing, sorting, sizing and other post-harvest equipments. Some engineering properties of ofada rice were investigated as a function of moisture content in the moisture range of 9.14 to 25.36% wet basis (w.b.). The increase in moisture content was found to increase the length, width, thickness, arithmetic mean, geometric mean, surface area, volume, sphericity and aspect ratio of the rice grain respectively. Thousand grain mass, bulk density and angle of repose also increased from 19.53 to 25.83 g, 789.33 to 865.33 kg/m^3, 35.41 to 42.90º as moisture content increases. Static coefficient of friction carried out on different surfaces include plywood, mild steel, galvanized iron, glass and stainless steel were also found to increase with an increase in moisture content, the values ranged from 0.4951 to 0.5703, 0.5024 to 0.5970, 0.5511 to 0.6371, 0.4350 to 0.5170 and 0.4417 to 0.5206, respectively. The specific heat capacity, thermal conductivity and thermal diffusivity ranged from 1.46 to 1.77 kJ/kgK, 0.137 to 0.198 W/mK and 0.9 to 0.12 × 10^{-7} m^2/s, respectively. The thermal properties were observed to increase as moisture content increases. This study consequently asserts that physical and thermal properties of ofada rice are moisture content dependent and that the results could be exploited by rice processors in the post-harvest processing of rice.

Keywords: Physical properties, thermal properties, ofada rice, moisture content, static coefficient of friction

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most consumed cereals and staple food for more than half of the world's population (Rathna Priya *et al.,* 2019). It is an important source of energy, vitamins, mineral elements and rare amino acids (Sadeghi *et al.,* 2010). Rice is the agricultural commodity with the third highest worldwide production, after sugarcane and maize (FAOSTAT, 2012). Production of rice in Nigeria was reported to have risen by 19% between year 2015 and 2019 cropping seasons (Oduntan, 2019). Rice provides 20% of the world's dietary energy supply, while wheat supplies 19% and maize 5% (FAO, 2004). Ofada rice is a generic name used to describe some rice varieties cultivated and processed in a group of communities in Ogun State and some rice producing clusters in South-West Nigeria (Danbaba *et al*., 2012).

The investigation of physical properties provides important and essential engineering data in the design of machines for processing as well as storage structures and conditions. This fundamental information is beneficial to engineers and even to food scientists, processing companies and other fields of science who may be interested in these properties and for some other probable uses (Isik, 2007). In the design of equipment for handling, conveying, separation, drying, aeration, processing and storage of seeds, it is important to determine the physical properties as a function of moisture content (Sobukola and Onwuka, 2011). The principal dimensions of ofada rice grains are useful in choosing sieve for separating the grains from extraneous materials and in the calculation of required milling power. The surface area and volume of the grains can also be calculated from it which is useful in considering aeration, drying, cooling and heating (Zareiforoush *et al*., 2009). Thousand grain mass of grain is used for calculating the head rice yield which is the mass percentage of rice that remains up to three quarter or more of the whole grain milled separated from the total milled rice (USDA, 1990). Physical properties such as bulk density, true density and porosity are considered majorly in designing mechanisms for drying, aeration, grain hoppers and storage equipment. These properties dictate how easily air and water vapour moves during grain drying (Zareiforoush *et al*., 2009; Amin *et al*., 2004). Flow ability of agricultural grains is usually determined using the angle of repose (Mahmud et al., 2009). It determines the internal friction between grains and is useful in the design of hoppers; the angle at which the hopper walls will be inclined should be greater than the angle of repose for effortless flow of the grains by gravitational pull. The coefficient of friction is important for the design of equipment for moving grains, processing and storage (Amin *et al.*, 2004; Lawson, 1980).

Having an understanding of the mechanisms of heat transfer in ofada rice allows the food engineers to design better equipment and processes like drying. Heat transfer is relatively described by three important engineering properties which are specific heat capacity, thermal conductivity and thermal diffusivity (Yang *et al*., 2002; Carson *et al*., 2015). The thermal properties of some food grains/seeds have been reported by different researchers including minor millet grains and flour (Subramanian and Viswanathan, 2003), cowpea flours (Mahapatra *et al*., 2013), sweet sorghum bagasse (Mahaprata *et al*., 2017) and Jack bean seeds (Adeyanju *et al*., 2019).

In spite of widespread search, no published literature was available on the detailed physical and thermal properties of ofada rice and their dependency on operational parameters that would be useful for the design of processing machinery. In order to design equipment and facilities for the handling, conveying, separation, drying, aeration, storing and processing of ofada rice, it is necessary to know their thermal and physical properties as a function of moisture content. Thus, an investigation was carried out to determine moisture-dependent thermal and physical properties of ofada rice at different moisture contents.

MATERIALS AND METHODS

Material Source

Ofada rice was purchased from Waso market in Ogbomoso North Local Government area of Oyo State (located between Latitude: 8º.07¹ N and Longitude: 4º.14¹ E). The samples were manually cleaned to remove dirty and extraneous materials.

Sample Preparation

Ofada rice grain was manually cleaned to remove foreign materials such as stones and broken grains. The initial moisture content of the grain was determined using the method described by AOAC method (2010). Selected samples of the ofada rice grain were conditioned using equation 1 to elevate their moisture content to the desired different levels considered in this research work (Coskun *et al.,* 2006).

$$Q = w_i\left(\frac{mf-mi}{100-mf}\right) \quad 1$$

Where; Q, is the mass of added water (kg), w_i, is the initial mass of the sample (kg), m_i, is the initial moisture content of the sample (%, *d. b.*) and m_f, is the final moisture content of the sample (%, *d. b.*).

Five levels of 9.14, 13.26, 17.47, 21.50 and 25.36 % moisture contents were obtained for the ofada rice grain after which the samples were stored in airtight Ziploc polythene and kept in a refrigerator for uniform moisture distribution until used.

Dimensional Properties Determination

Grain dimension, surface area and grain volume

A digital vernier caliper (Model AD-5765-100) was used to measure the linear dimensions namely; length (L), width (W) and thickness (T) of ofada rice to an accuracy of 0.01 mm. The surface area (S) and grain volume (V) was calculated from the linear dimensions according to equations 2 and 3 (Jain and Bal, 1997).

$$S = \frac{\pi(\sqrt{WT})L^2}{2L-\sqrt{WT}} \quad 2$$

$$V = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T^2)\right] \quad 3$$

Arithmetic and geometric mean diameter

The arithmetic mean diameter, D_{am} and geometric mean diameter, D_{gm} of the grain were calculated by equations 4 and 5 (Mohsenin, 1986):

$$D_{am} = \frac{LWT}{3} \quad 4$$

$$D_{gm} = (LWT)^{1/3} \quad 5$$

Sphericity and aspect ratio

The sphericity (**∅**) was calculated from the linear dimensions according to equation 6 (Jain and Bal, 1997). Aspect ratio (R_a) was calculated as described by Mohsenin (1986) in equation 7.

$$\emptyset = \frac{LWT^{\frac{1}{3}}}{L} \quad 6$$

$$R_a = \frac{W}{L} \quad 7$$

Gravimetrical Properties Determination

Thousand grains mass

The mass of one thousand rice grains was determined using an electronic balance to an accuracy of 0.0 l g (Varnamkhasti *et al*., 2008).

Bulk density

The bulk density was determined using the standard test weight procedure. The total weight of grains and cylinder was recorded. It was determined as the ratio of the mass of grains only to the volume occupied by the grains (Gupta and Das, 1997).

Frictional Properties Determination

Angle of repose

Angle of repose was measured at different moisture contents using a specially constructed wooden box measuring 300 × 300 × 300 mm with a detachable front panel (Ogunjimi *et al*., 2002). The box was filled with rice grains and the front panel was removed quickly. The rice grains were allowed to flow according to their natural flow pattern. The angle of repose was calculated by measuring the distance between the end of the flow and the end of the box.

$$Angle\ of\ repose, \phi = \frac{tan^{-1}(\text{horizontal distance})}{\text{height of box}} \quad 8$$

Static coefficient of friction

The static coefficient of friction for ofada rice at different moisture contents on different structural surfaces (mild steel, galvanized iron, glass, plywood and stainless steel) was obtained by the inclined plane method which involved using a hollow metal cylinder (50 mm diameter and 50 mm height) open at both ends and filled with rice grains. The cylinder was placed on an adjustable tilting plate without allowing the metal cylinder to touch the inclined surface. The tilting surface was raised slowly and gradually until the grains started to slide down and the angle of inclination was read from the graduated scale (Dutta *et al*., 1988; Razavi and Milani, 2006).

$$\mu = tan\alpha \quad 9$$

Where; μ is static coefficient of friction, α is angle of inclination (°)

Thermal Properties Measurement

The thermal properties such as specific heat capacity, thermal conductivity and thermal diffusivity of ofada rice grains were determined using the KD2 pro thermal property analyzer (Decagon Devices, Inc., Pullman, WA) at five moisture contents (9.14, 13.26, 17.47, 21.50 and 25.36 %; w.b.). The KD2 pro thermal property analyzer is a fully portable field and lab thermal properties analyzer which uses the transient line heat source method to measure thermal conductivity, thermal diffusivity, and specific heat capacity. It has some needle sensors which measures thermal properties when in contact with the samples. The 30 mm long, 1.28 mm diameter, and 6 mm spacing dual needle SH-1 sensor measured the thermal conductivity, thermal diffusivity and specific heat (heat capacity) of the ofada rice altogether. Interval of 15 minutes was maintained between each reading to allow the probe sensor to cool down.

Statistical Analysis

Data obtained are means of triplicate determinations and data were subjected to analysis of variance (ANOVA) and means separated using Duncan multiple range test at 5% probability level using SPSS software version 21.

RESULTS AND DISCUSSION

Dimensional Properties

The result of dimensional properties of ofada rice is presented on Table 1. The length, width, thickness ranged from 6.89 to 7.48 mm, 2.27 to 2.57 mm and 1.62 to 1.89 mm, respectively. The increase in the axial dimensions may be due to the fact that as moisture content increased, the grains tend to swell as it absorbs moisture. Similar results for surface area ranging from 24.16 to 30.41 mm^2 were reported by Jain and Bal (1997) for millet; Karababa and Coskuner (2007) for sweet corn and Sobukola *et al*. (2013) for high quality maize. The surface area ranged from 24.16 to 30.41 mm^2. This increased with increasing moisture content as axial dimensions (Table 1). This is suspected to be due to the increase in the axial dimensions with increase in moisture content. The results corroborate with findings of Seifi and Alimardani (2010) on corn grains and (Milani *et al*. (2007) on cucurbit seeds of three varieties. The grain volume of ofada rice increased from 13.71 to 19.54 mm^3 as moisture content increased from 9.14% to 25.36%. Related trends were reported by Baryehe (2002) for millet; Cetin (2007) for barbunia beans and Karababa and Coşkuner (2007) for sweet corn.

The arithmetic mean diameter of ofada rice ranged from 3.60 to 3.98 mm. The value varies with increase in the moisture content. Determination of arithmetic mean and geometric mean diameter is important in the designing of sorting, grinding and other processing equipment. The result differs with the report on Soybean grains (Isik, 2007), Beniseed (Tunde-Akintunde and Akintunde, 2007) and sweet seed (Simoyan *et al*., 2009). Geometric mean diameter of ofada rice varied from 2.94 to 3.31 mm. There was increase in the geometric mean diameter of ofada rice with increase in the moisture content. Similar findings were reported by Ampah (2012) for drying of "*asontem"* cowpea variety Shoughy and Amer (2006) and Tarighi *et al*. (2011) also found geometric mean diameter to increase nonlinearly with increasing moisture for Faba bean and corn respectively. The regression equation showing relationship between length, width, thickness, arithmetic mean, geometric mean and moisture content (MC) of ofada rice are shown in Equations 10 – 14 with the value of coefficient of determination.

$L = 0.0414MC + 6.6157, (R^2 = 0.9066)$ 10

$W = 0.0165MC + 2.154, (R^2 = 0.9147)$ 11

$T = 0.0156MC + 1.5342, (R^2 = 0.8186)$ 12

$D_{am} = 0.023MC + 3.4594, (R^2 = 0.8562)$ 13

$D_{gm} = 0.0217MC + 2.8052, (R^2 = 0.8768)$ 14

Table 1. Influence of moisture content on length, width, thickness, arithmetic and geometric mean diameter of ofada rice

Moisture content (%)	Length (mm)	Width (mm)	Thickness (mm)	Arithmetic mean (mm)	Geometric mean (mm)
9.14	6.89±0.21^a	2.27±0.09^a	1.62±0.04^a	3.60±0.09^a	2.94±0.06^a
13.26	7.26±0.31^b	2.41±0.05^b	1.80±0.05^b	3.82±0.09^b	3.15±0.03^b
17.47	7.42±0.30^b	2.47±0.07^b	1.82±0.03^b	3.90±0.13^c	3.22±0.09^c
21.50	7.48±0.15^b	2.48±0.04^b	1.89±0.02^b	3.99±0.07^c	3.29±0.05^c
25.36	7.62±0.16^c	2.57±0.02^c	1.89±0.06^b	3.98±0.11^c	3.31±0.10^c

Values are mean ± standard deviation of triplicate determinations. Means with the same superscripts within the same column are not significantly different (p>0.05).

Sphericity and Aspect Ratio

Table 2 shows the variation of moisture content on dimensional parameters of ofada rice. The values of sphericity ranged from 0.43% to 0.45%. It was found to increase as moisture content increased from 9.14% to 25.36%. According to (Dutta *et al*., 1988), a grain is considered not to be spherical when the value for sphericity is less than 70%. From the results obtained, ofada rice grains should not be considered spherical when calculating the surface area. Similar finding was reported for paddy (Ravi and Venkatachalam, 2015).

It was also observed from Table 2 that the aspect ratio increased with increase in moisture content from 0.33 to 0.34 as moisture content increased. The values of the aspect ratio are low, this means that it will be difficult to get the rice grains to roll, they will rather slide on their flat surface as explained by Ghadge and Prasad (2012). The relationship between sphericity (Q), surface area (S), grain volume (V), aspect ratio (R_a) and the moisture content can be represented as shown In Equations 15 – 18:

$Q = 0.0002MC^2 - 0.0051MC + 0.4624, (R^2 = 0.8434)$ 15

$S = 0.3678MC + 21.859, (R^2 = 0.8797)$ 16

$V = 0.2415MC + 13.594, (R^2 = 0.992)$ 17

$R_a = 0.00009MC^2 - 0.0025MC + 0.3467, (R^2 = 0.8434)$ 18

Table 2. Influence of moisture content on sphericity, surface area, volume and aspect ratio of ofada rice

Moisture content (%)	Sphericity (%)	Surface area (mm^2)	Grain volume (mm^3)	Aspect ratio
9.14	0.43±0.01[a]	24.16±1.03[a]	15.71±0.88[a]	0.33±0.01[a]
13.26	0.43±0.02[a]	27.71±0.65[b]	16.82±0.41[b]	0.33±0.02[a]
17.47	0.43±0.01[a]	28.80±1.67[c]	17.87±1.50[c]	0.33±0.01[a]
21.50	0.43±0.00[a]	30.11±0.96[d]	18.97±0.87[d]	0.33±0.01[a]
25.36	0.45±0.01[a]	30.41±1.78[d]	19.54±1.82[e]	0.34±0.01[a]

Values are mean ± standard deviation of triplicate determinations. Means with the same superscripts within the same column are not significantly different ($p>0.05$).

3.3 Gravimetrical Properties

As the moisture content increased from 9.14% to 25.36%, the mass of thousand grains of ofada rice increased invariably from 19.53 to 25.83 g (Table 3). This trend was also observed by Sacilik *et al*. (2003) for hemp seed and Garnayak *et al*. (2008) for *Jatropha* seed. The bulk density of ofada rice determined experimentally is shown in Table 3. It was observed that as the moisture content increased from 9.14 to 25.36 %, the bulk density increased from 789.33 to 865.33 kg/m^3. This is due to the fact that the increase in mass is higher than the corresponding increase in volume. Similar results were found by Simoyan *et al*. (2009) for sweet seeds and Ahemen and Raji (2017) for *Tacca involucrata* tuber. The experimental results for the angle of repose for ofada rice at moisture (9.14 to 25.36 %) are shown in Table 4. The values ranged from 35.41° to 42.90° and found to increase with increasing moisture content. This is because at higher moisture content, there is greater tendency for the grains to be more cohesive thereby resisting flows. Comparable results were reported by Garnayak *et al*. (2008) for jatropha seeds and Sobukola *et al*. (2013) for high quality maize seeds. The relationship existing between moisture content and thousand grain mass (TGM), bulk density (ρ_b) and angle of repose (ϕ) appears to be linear for ofada rice as seen in the regression equations 19, 20 and 21:

$$TGM = 0.3803MC + 15.821, (R^2 = 0.9862) \quad 19$$

$$\rho_b = 4.7789MC + 749.51, (R^2 = 0.9804) \quad 20$$

$$\phi = 0.4665MC + 31, (R^2 = 0.9953) \quad 21$$

Table 3. Influence of moisture content on mass, bulk density and angle of repose of ofada rice

Moisture content (%)	Thousand Grain Mass (g)	Bulk Density (kg/m^3)	Angle of repose (°)
9.14	19.53±0.42[a]	789.33±6.43[a]	35.41±0.77[a]
13.26	20.80±0.20[b]	814.67±5.03[b]	37.17±0.27[b]
17.47	22.23±0.40[c]	836.00±4.00[c]	38.80±0.25[c]
21.50	23.70±0.30[d]	856.67±3.06[d]	41.18±0.41[d]
25.36	25.83±0.25[e]	865.33±1.15[e]	42.90±0.21[e]

Values are mean ± standard deviation of triplicate determinations. Means with the same superscripts within the same column are not significantly different ($p>0.05$).

Frictional Properties

Static coefficient of friction

The static coefficient of friction for ofada rice at moisture content from 9.14 to 25.36% was determined for different surfaces namely plywood, mild steel, galvanized iron, glass and stainless steel. The values are presented in Table 4. It is observed that the values for each surface increased as the moisture content increased. For plywood, the values ranged from 0.4951 to 0.5703, for mild steel, the values ranged from 0.5024 to 0.5970. Galvanized steel has it values between 0.5511 and 0.6371 and the values for glass surface ranged from 0.4350 to 0.5170. For stainless steel surface, the values ranged from 0.4417 to 0.5206. It is observed that glass and stainless steel surfaces have the least values for static coefficient of friction, this is suspected to be because of their smoothness while the higher values of plywood, galvanized iron and mild steel can be attributed to their roughness. Similar trends were reported by Ghadge and Prasad (2012) for rice kernels and (Sobukola *et al*., 2013) for high quality maize seeds and Amin *et al*., 2004) reported that there was no significant variation between plywood and galvanized iron for pulse grains. Aydin, (2002) reported that as moisture level of hazel nut increased, the static coefficient of friction increased. This is because the seed may become rough and static coefficient of friction is increased. The relationships between these coefficients against various surfaces and moisture contents of ofada rice are shown in the regression equations 22 - 26:

Plywood, $\mu_P = 0.0046MC + 0.4477, (R^2 = 0.9607)$ 22

Mild steel, $\mu_{MS} = 0.0058MC + 0.4376, (R^2 = 0.8332)$ 23

Galvanized iron, $\mu_{GI} = 0.0054MC + 0.4913, (R^2 = 0.9158)$ 24

Glass, $\mu_G = 0.0059MC + 0.3701, (R^2 = 0.9081)$ 25

Stainless steel, $\mu_{SS} = 0.005MC + 0.3935, (R^2 = 0.9797)$ 26

Table 4. Frictional properties of ofada rice on plywood, mild steel, galvanized iron, glass and stainless

Moisture content (%)	Plywood	Mild steel	Galvanized iron	Glass	Stainless
9.14	0.4951±0.024^a	0.5024±0.0254^a	0.5511±0.046^a	0.4350±0.0276^a	0.4417±0.0060^a
13.26	0.5043±0.043^b	0.5169±0.0128^a	0.5581±0.006^a	0.4348±0.0104^a	0.4599±0.0530^a
17.47	0.5243±0.006^b	0.5104±0.0576^a	0.5706±0.058^a	0.4628±0.0162^a	0.4734±0.0124^a
21.50	0.5398±0.046^b	0.5658±0.0116^b	0.6055±0.048^b	0.5096±0.0220^b	0.5059±0.0167^b
25.36	0.5703±0.048^b	0.5970±0.0180^b	0.6371±0.012^b	0.5170±0.0254^c	0.5206±0.0111^c

Values are mean ± standard deviation of triplicate determinations. Means with the same superscripts within the same column are not significantly different (p>0.05).

Thermal Properties

The moisture effects on the specific heat, thermal conductivity and thermal diffusivity of ofada rice are shown on Table 5. The specific heat of ofada rice ranged from 1.46 to 1.77 kJ/kgK with moisture at 9.14% having the lowest value and moisture at 25.36% had the highest value. The specific heat of ofada rice increased with increase in moisture content. The result is related to the report by Hsu *et al*. (1991) for pistachios, Dutta *et al*. (1988) for gram, Subramanian and Viswanathan (2003) for minor millet, Bamgboye and Adejumo (2010) for roselle seeds that showed increases in their products.

Table 5. Thermal properties of ofada rice at different moisture content

Moisture content (%)	Specific heat capacity (kJ/kgK)	Thermal conductivity (W/mK)	Thermal diffusivity (mm^2/s)
9.14	1.46±0.02[a]	0.137±0.001[a]	0.09±0.02[a]
13.26	1.56±0.06[b]	0.165±0.021[b]	0.10±0.01[b]
17.47	1.64±0.20[c]	0.171±0.014[b]	0.11±0.00[b]
21.50	1.73±0.02[d]	0.190±0.020[c]	0.13±0.01[a]
25.36	1.77±0.02[d]	0.198±0.007[c]	0.15±0.01[c]

Values are mean ± standard deviation of triplicate determinations. Means with the same superscripts within the same column are not significantly different (p>0.05).

The thermal conductivity of ofada rice ranged from 0.1367 to 0.1977 W/mK. Moisture content significantly affects the thermal conductivity which varies with the increase in the moisture content. The result is similar to the report of Yang *et al*. (2002) for minor millet grains and flour. Subramanian and Viswanathan (2003) also reported that the thermal conductivity of six types of millet and their flour increased linearly with the increase in the moisture content in the range of 10–30%.

The thermal diffusivity of the ofada rice ranged from 0.9 to 0.12 × 10^{-7} m^2/s with increasing moisture content from 9.14% to 25.36%. Aviara and Haque (2001) observed the thermal diffusivity of sheanut kernel to increase with moisture content. Thermal diffusivity decreased with the increase in moisture content for six varieties of millet seeds and their flour as reported by Subramanian and Viswanathan (2003), borage seeds by Yang *et al*. (2002) and cumin seeds by Singh and Goswami, (2000). The relationship existing between moisture content and thermal properties appears to be linear and are as expressed in Equations 27, 28 and 29:

$$C_p = 0.0195MC + 1.2946, (R^2 = 0.9865) \quad (27)$$

$$k = 0.0036MC + 0.1094, (R^2 = 0.9523) \quad (28)$$

$$\alpha = 0.0037MC + 0.0522, (R^2 = 0.9646) \quad (29)$$

CONCLUSION

Physical and thermal properties of ofada rice which may influence the design, fabrication and development of postharvest handling and processing equipment were studied. The findings revealed that the physical and thermal of ofada rice understudied vary significantly with moisture content. The information gathered is important in designing storage equipment, optimization of milling operations and processing machinery which makes the ofada rice grains more relevant to postharvest processors.

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