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Effects of Drying Conditions on Fuel Property of Physic Nut (Jatropha Curcas)

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Abstract

Physic nut (*Jatropha curcas*) is a bio-material that requires effective drying for easy extraction to produce oil and biofuel. Temperature and air velocity had effect on drying characteristics of physic nut which determined its fuel property. The study of drying kinetics is necessary to give information about the time required for drying physic nut and the effects of temperature on the fuel property. The drying kinetics of physic nut were investigated in a locally made electric crop dryer. The drying kinetics of physic nut was conducted at selected temperatures of 40, 50, 60, 70 and 80 °C and air flow of 1.0 and 2.0 m/s. Proximate analysis carried out were volatile matter, ash and fixed carbon contents at selected temperatures of 40, 50, 60, 70 and 80 °C. Temperature had significant effect on the fuel property of physic nut. The ash content increased, fixed carbon content and volatile matter content decreased as temperature increased from 40 to 80 ^{o}C. The drying time to achieve desired products' quality was achieved and effects of temperature and air velocity on the fuel properties of physic nut have been established.

Keywords: physic nut; drying kinetics; fuel property; temperature and air velocity.

1. Introduction

Conventional (air) drying is mostly used for dehydration operation in food and chemical industry [1] and [2] because drying occurs under controllable conditions and partially depend on climatic conditions [3] and also reduce drying time.

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Climate change is caused by the rate at which energy is received from the sun and the rate at which it is lost to space determines the equilibrium temperature and climate of Earth. This energy is distributed around the globe by winds, ocean currents, and other mechanisms to affect the climates of different regions USEPA. Consequently, the use of conventional drying for agricultural materials must be adapted to revolutionize the climate to reduce the rate of energy received from the sun and greenhouse gas emissions as reported by [4]. One important aim of drying is to reduce crop losses and improve quality of dried products [5].

Drying of produce is a vital operation in the chain of crop handling and it is known as one of the best methods to use in the preservation and storage of produce like physic nuts. Water is removed by drying, preventing microorganism growth and harmful chemical reactions consequently leading to longer storage life [6] normally regarded as the "safe storage period" as stated by [7]. Practically, drying in its ordinary application is a simultaneous heat and mass transfer process, involving vapourisation of water in the liquid state, mixing water the vapour with the drying air and removing the vapour naturally or mechanically from agricultural materials [8]. Drying processes are very important for easy extraction of oil; dried seeds with low moisture content give higher quantity of oil than the wet seeds. Utilization of heat energy of the hot air is by far the most common means of drying [9].

Thin layer drying is the process of removal of moisture from a porous media by evaporation, in which excess drying air is passed through a thin layer of the material until equilibrium moisture content is reached [10]. Drying kinetics is experimentally evaluated by measuring the weight of a drying sample as a function of time. Kinetic curves may be represented in different ways; averaged moisture content versus time, drying rate versus time, or drying rate versus averaged moisture content [11]. Drying curves are derived from the measurement of the material moisture content as a function of time under constant drying air conditions.

Physic nut (*Jatropha curcas*) is a non-edible bio-material which is considered as one of the promising energy crops [12], for future biodiesel production. The seeds contain 27-40 % oil with an average of 34.4% [13] that requires effective drying for easy extraction of oil and improve quantity of oil. But the effects of temperature on this bio-material determine the quality of the product to be obtained. Physic nut has been identified as an oil bearing plant capable of thriving in arid regions. Sokoto State's semi-arid climate is therefore very suitable for the growing of the crop. The seeds sap and leaves of fresh fruits have medicinal qualities [14]. Dried seeds are extracted to produce oil for biofuel. The cakes remaining after the oil has been pressed out can be used for cooking, fertilizer and animal fodder. Oil from physic nut can be used to make candles, soap and widely used to stop desertification. Seed husks can be used as biomass.

Proximate composition becomes imperative in order to determine the fuel property to know how combustible the dried kernels will be and investigate the effect of heat on the products. Proximate analysis which is considered as fuel property in this work; so it is a method of partitioning compounds in agricultural products based on the chemical properties of the compounds [15] and [4]. It is important to remember that proximate analysis is not a nutrient analysis, rather it is a partitioning of both nutrients and non-nutrients into categories based on common chemical properties. Recently, a total of 30 plant species producing edible fruits, seeds and leaves in south-eastern Nigeria rainforest have been reported as endangered [16] and [17]. Moreover, within the rainforest, 115 plant species whose uses were not classified have also been reported as endangered [17]. There is therefore, the need to understand their suitability for food, fodder and fuel. A proper understanding of their proximate, phytochemical and nutrient compositions will determine the dependence of many communities and industries on few known crops [17]. Proximate analysis is used to determine the proximate principles of any substance, as contrasted with an ultimate analysis. The proximate analysis of food refers to the analysis of the total content of a food component, not taking account of the individual compounds making up that food component [15]. Proximate composition is commonly determined when investigating agricultural residues as a biomass to develop renewable energy. The volatile matter, ash and fixed carbon contents of palm shell were analyzed to determine the quality or fuel property of oil to be obtained from palm shell [18].

Sun drying method leads to low quality control and prolongs drying time of agricultural materials [19] and [20]. Due to erratic or irregular supply of solar energy from the sun, materials are not uniformly dried and become deteriorated, so this leads to product loss. The temperature at which the materials are being dried is uncontrollable, this causes under-drying of the produce and insect infestation thereby, valuable kernels of physic nut are destroyed. The weather is independent for drying, the technique seems very strenuous to most farmers and causes drudgery. The aforementioned problems affected the fuel property, that is, the volatile matter and ash content will be relatively low.

There is need for a non-convectional source of energy that will be very affordable and readily available for domestic and industrial needs, due to high price of kerosene, refilled gas and irregular supply of electricity and physic nut oil or biofuel is an alternative. From previous research efforts, it has been established that biofuel can be obtained from a biomaterial called physic nut (*Jatropha* c*urcas),* as reported by [12] and [21]. Efficiency of the drying process is an important factor in the assessment and selection of the optimum dryer for a particular task. Drying characteristics of physic nut will give information that is very essential in the handling of the kernels, this protects the products from deterioration and the shelf life is increased. Proximate composition helps to identify the poisonous or volatile chemicals and assess their cumulative adverse effects on consumers [17] and [18]. Energy utilized in the drying process also makes the extraction of oil from the kernels easier; the biomaterials, that contain low moisture, yield high quantity of oil.

In this study, the objective is to investigate effects of drying conditions on drying behavior and fuel property of physic nut.

2. Research Methodology

2.1 Sample Preparation

Physic nuts (*Jatropha curcas)* used for the research were collected from bushes in the rural areas near Ogbomoso town, Nigeria. The experiments were performed in the Laboratory of the Department of Agricultural Engineering, LAUTECH, Ogbomoso. Fresh matured fruits were harvested, peeled and washed with clean water. This preparation was done to remove the stalks, leaves, stains, stones and dirty objects harvested with the fruits. The physic nuts were placed on sieve trays to drain the surface water and then 20 kg of whole fruits was uniformly spread in four wire mesh baskets in a single layer and placed in the dryer. The initial weight of the sample was measured using an electronic weighing balance; Mettler Toledo P.B 153 with an accuracy of 0.01g.The drying experiment was conducted at five temperature levels of 40, 50, 60, 70 and 80 °C with three replications. A locally made crop dryer was used for the experimental work. The dryer consists of a fan, heaters, a drying chamber and instruments for various measurements. The dryer was adjusted to a preset temperature for about half an hour prior to achieve the steady state. During the course of the drying process, the whole fruits were weighed hourly using the digital balance. The drying process was continued until equilibrium moisture content was reached. The data obtained from drying process were used to construct drying curves. Proximate composition (% volatile matter, ash and carbon contents) was analyzed for samples dried at temperatures 40, 50, 60 70 and 80 ^{o}C. This test was carried out in line with [22] and each experiment was done with three replications.

Figure 1: Fresh matured physic nuts (Jatropha curcas)

2.2 Determination of moisture content

The moisture content of physic nut was determined by two methods. The sample was placed in an electronic moisture analyzer of model MAC 50/NH RADWAG with accuracy of 0.1g which was operated for 1h 13 minutes, using infra-red ray to dry the sample (5.0 g) placed on it. The final moisture content of the sample automatically showed on the equipment.

Oven method was also used; the sample was weighed and dried to a constant weight (bone dry) in a Uniscope SM 9053 laboratory oven set at 65 ^{o}C for 24 h, by the procedure described by [23]. The sample was removed and allowed to cool using natural current air. The weight of the dry material was determined using an electronic scale balance. The % moisture content on wet basis (%) by the formula was computed using equation (1), as determined by [23, 24,25].

$$\% MC_{wb} = \frac{W_w}{W_w + W_d}.100 \quad (1)$$

$$\% MC_{db} = \frac{W_w}{W_d}.100 \quad (2)$$

$$\% MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}}.100 \quad (3)$$

where% MC_{db} = % moisture content (in dry basis) of the fruits, W_w= initial weight of the sample, W_d = final weight of the dried sample.

2.3 Determination of the percentage volatile matter content

The volatile matter content was carried out to determine the combustibility of the dried products. The procedure adopted was in accordance with [22]. 10 g of the dried sample was put in crucible and heated in a muffle furnace of model CARBOLITE-ELF 11/6B at 250 ^{o}C for 7 minutes. The crucible was retrieved and kept to cool in a dessicator to a room temperature of the original weight to obtain the percentage volatile matter content and calculated using Eq. (4) as determined by [26].

$$\% V_m = \frac{100\,(w_1 - w_2)}{w_2} \quad (4)$$

where, % *Vm*= % volatile matter content, w_1 = initial weight of the dried sample, w_2 = final weight of the sample after being subjected to 250 ^{o}C for 7 minutes.

2.4 Determination of the ash content

The ash content experiment was carried out to determine the effect of heat on the dried seeds. This was done in accordance with [22]. About 10 g of finely ground sample of physic nut was placed in a crucible and heated in a muffle furnace CARBOLITE-ELF 11/6B at 250 ^{o}C for 10 minutes. After cooling it in a desiccator, the final weight was measured. The ratio of the initial weight to the final was expressed as a percentage to obtain the % ash content of the residue samples using Equation (5) as stated by [26].

$$\% Ash = \frac{100 w_4}{w_3} \quad (5)$$

where, w_3 = initial weight of the oven-dried sample (g), w_4 = final weight, g.

2.5 Determination of fixed carbon content

This experiment was carried out to determine the fixed carbon content in the dried seed that would be needed to tackle the growing carbon emissions in the atmosphere with a goal to becoming carbon neutral. The fixed carbon content was obtained by using [22], as found by [26]. The percentage fixed carbon was deduced from the ash content.

$$\% FCC = 100 - \% Ash \quad (6)$$

Where % C = the % amount of the fixed carbon,

% Ash = % Ash content of dried sample.

3. Results and Discussions

3.1 Drying kinetics

The results of the moisture content of fresh physic nuts obtained from moisture analyzer and oven-method were 84.3 % and 83.5 % respectively. There is no significant difference (p>0.05) in the moisture content using both methods. But the actual or optimum drying time was found to be 27.50 hours using design expert analysis. Figure 2 shows the dried sample of physic nuts after the drying experiment. Figure 3 presents the drying curves showing reduction in weight of physic nut as a function of drying time at different temperatures of 40, 50, 60, 70 and 80 ^oC. At 40 ^oC, the drying period was longer (28 hours) while at 50, 60, 70 and 80^oC , the samples dried for 26, 24 and 22 hours respectively. The drying time was shortest (20 hours) at 80^oC. This was because the rate of evaporation in the product was faster when the temperature was higher. The time to reach 16.5 % moisture content (dry basis) from the initial moisture content at the various drying air temperature of physic nut was found to be between 20 and 28 hours. This result indicates that the rate of moisture loss decreased as the drying time increased due to variation in temperature until finally, the fruits reached equilibrium moisture content. This occurs as a result of increase in the drying rate. This increase is due to the increased heat transfer potential between the air and physic nut, which enhances evaporation of water from physic nut. The effect of temperature on the condition of drying is well documented in the literature [27,5]. Hence, the shelf life of physic nut is prolonged and the phenomenon in this drying kinetics helps in the storage ability of the products.

Table 1 shows the summary of Two-way ANOVA on effect of the drying temperatures as a function of time in drying of physic nuts. The effect of temperature was highly significant (p<0. 05) and the model F value 38.85 implies that the model is significant. Also, the effect of drying time was not significant as p>0.05. This indicated that temperature is a dependent factor while weight loss and drying time are the response variables. It is obvious that the drying process was enhanced substantially with the increment of the temperature. Similar behavior was reported by several authors; Akendo *et al.* [28] observed the behavior in dewatering and drying process of water hyacinth petiole. Similar behavior was observed by [29,30,31] as they investigated the drying kinetics of aromatic plants, date palm fruits and garlic slices respectively.

Figure 2: Dried sample of physic nuts

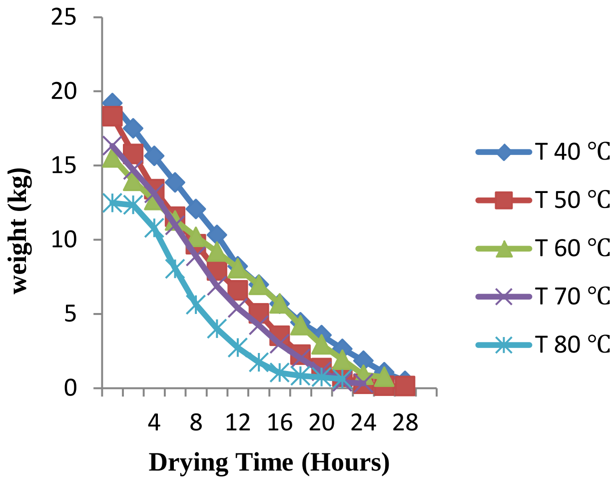

Figure 3: Drying curves of physic nut at different temperatures

Table 1: Summary of ANOVA on effect of temperatures in the drying of physic nut

Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model	0.16	2	0.053	38.85	< 0.0001
A	0.063	1	0.063	46.18	< 0.0001
B	0.000	1	0.000	0.000	1.000
Residual	0.022	11	1.36E-003		
Lack of fit	0.022	6	1.99E-003		
Pure error	0.000	5	0.000		
Cor. Total	0.18	13			

A = Temperature: highly significant at $p<0.05$

B = Drying period: not significant $p>0.05$

The drying rate curves for physic nut at five different temperatures 40, 50, 60, 70 and 80 ^{o}C are shown in Figure 4. Analysis of the drying rate data could not establish a constant rate period. The drying rate curves consist of three falling rate periods. The falling rate period is observed as behavior drying of many biological materials [32,33,34,35]. During the falling rate period, drying rate is caused by the concentration gradient of moisture inside the food matrix. The internal moisture migration results from a number of mechanisms such as liquid diffusion, capillary flow, flows due to shrinkage and pressure gradients [36]. This indicated that drying rate decreases as moisture content decreases. This is in agreement with the findings of [37] in drying process and sorption of tomato slices. It is apparent that drying rate decreases continuously as drying time progresses. This may be due to the fact that, higher temperature implies a larger water vapor pressure deficit [38,39]. It also accelerates the drying process, as the temperature provides larger driving force for heat transfer [40]. The reduction in moisture content yields low weight of physic nut, this means the material is less bulky, and this phenomenon helps in the transportation and handling of the products. This indicates that the transportation and packaging costs are reduced.

Table 2 shows the summary of Two-way ANOVA on effect of the drying temperatures and air velocity on moisture loss and drying rate in drying of physic nuts. The effect of temperature was highly significant (p<0. 05) and the model F value 28.81 implies that the model is significant. Also, the effect of temperature (A) and air velocity (B) are significant at p<0.05. This implies that A, B and interaction of AB are significant models at 95 % confidence level. Though, temperature is a major determining while moisture losses and drying rate are the response variables. It is obvious that the drying process was enhanced substantially with the increment of the temperature.

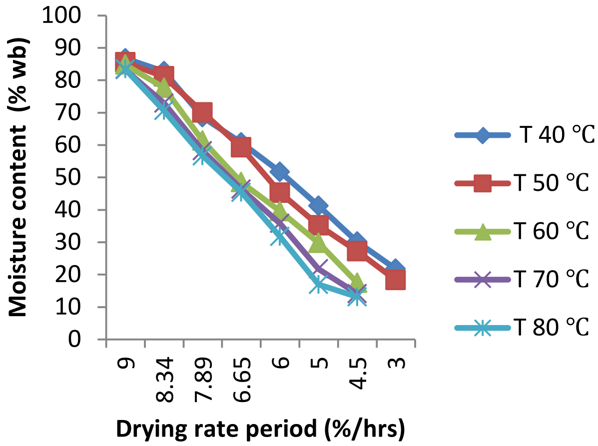

Figure 4: Drying rate curves of physic nuts at different temperatures

Table 2: Summary of ANOVA on effect of temperatures on drying rate of physic nut

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	0.10	5	0.020	28.81	0.0002
A	0.037	1	0.037	53.48	0.0002
B	0.059	1	0.059	84.20	0.0001
AB	4.402E-003	1	4.402E-003	6.31	0.0403
Residual	4.882E-003	7	6.974E-004		
Pure Error	0.000	4	0.000		
Cor Total	0.11	12			

A = Temperature: highly significant at p<0.05

B = Air velocity: significant p<0.05

3.2 Results of fuel property of physic nut

The proximate composition determined were moisture content, ash, % volatile matter and % fixed carbon contents to investigate the fuel properties of the dried kernels. Table 3 presents the constituent values of samples dried at different drying temperatures of 40, 50, 60, 70 and 80 ^oC. The samples dried at 40 ^oC had the highest volatile matter content (VMC), 22 % while the samples dried at 80 ^oC had lowest value of 4.0 %. The volatile matter content (VMC) values of physic nuts dried at 50, 60 and 70 ^oC were 14, 8.7 and 6.9 % respectively. The values of VMC decreased as drying temperature increased. This result showed that materials dried at lower temperature had the tendency to yield products that could be highly volatile or combustible which could cause explosion or fire hazard while the materials dried at higher temperature might yield products that could be less volatile. This indicated that high temperature had absorbed some chemical constituent that could explode easily from the materials, hence made the product to be less explosive. These results indicated that the combustibility property of physic nuts decreased as drying temperature increased. ANOVA resulted that there was no significant difference ($p>0.05$) in VMC of materials dried at 40 and 50 ^oC. But the difference was statistically significant ($p<0.05$) for materials dried at 50, 60 and 70 ^oC. There was no significant difference ($p<0.05$) in the VMC value of products dried at 60 and 70 ^oC.

Table 3: Results of Fuel property of physic nut dried at different temperatures

Temperatures	**Constituent values**		
^{o}C	**VMC (%)**	**Ash %**	**FCC %**
40	22	74	26
50	14	76	24
60	8.7	87.5	12.5
70	6.9	90.2	9.8
80	4.0	93.1	6.9

VMC volatile matter content, FCC fixed carbon content, Ash content

The samples dried at 80 and 40 ^oC, had the highest, 93.1% and lowest, 74 % ash content, respectively while the values of samples dried at 50, 60 and 70 ^oC were 76, 87.5 and 90.2 % respectively. The values of ash content increased as drying temperature increased. The result indicated that materials dried at 40 ^oC, had tendency of having low ash content. This means the material contains some chemical matter that may not burn to ash. The materials dried at 80 ℃ had high ash content. This indicates that higher temperature must have weakened the chemical bond between the molecules of the samples; this will enable the material to burn to ash. The obtainable amount of percentage ash content indicates fuel property of physic nut determines the extent of burning when it is extinguished. Consequently, high ash content indicates high quality energy source (high fuel property) and vice versa. The results obtained are higher than those reported for *Jatropha curcas* seed provenances from different countries [41], this may be due to climate change factor and also higher for seeds of Mimosoidea, Annonaceae and Moraceae from eastern part of Nigeria (Dike, 2010), it may be due to the fact that the crops are not of the same family group while the ash content of Dragon fruit (*Hylecereuspolyhizus*) was also lower [15], because of low oil content. In addition, the result of VMC of rice straw, 66.89 % is higher and ash content is lower (7.56 %) than that obtained in this study as investigated by [42], it might be because rice straw particle is less dense than that of physic nut which may cause rapid burning of particle.

The values of fixed carbon content of 26 % and 6.9 % were obtained at temperature 40 and 80 ℃ respectively and fixed carbon content values were 24, 12.5 and 9.8 % at temperatures 50, 60 and 70 ℃ respectively. These results showed the effect of heat on the physic nut, the values of fixed carbon content decreased as the drying temperature increased. The result showed that FCC was high at low temperature (40 ℃) while low value of FCC was obtained at high temperature (80 ℃). This shows that fresh physic nuts will absorb more carbon content from the atmosphere (more carbon will be emitted with fresh fruits). This is one of the most promising solutions for tackling the growing carbon emissions from atmosphere [12], hence reducing the problem of ozone layer. The FCC of rice straw, reported by Ahmad [42], was lower than that obtained for physic nut at 40 ℃. This implies that physic nut has greater potential to absorb carbon emission, thereby making the atmosphere carbon neutral. This factor can be a strategy for climate change adaptation or mitigation, if more cultivation practice of physic nut is established or encouraged in different countries of the world.

4. Conclusions

The time required for drying physic nut was considerably decreased with the increment in the drying air temperature. The major factor that influenced the drying kinetics is the air temperature. The drying behavior of whole fruit of physic nut occurred in the falling rate. Also, temperature has effect on the fuel property of physic nut. The volatile matter and fixed carbon contents decreased as temperature increased, while ash content decreased. Therefore, the biomaterial is recommended to oil and fuel processing industries and for storage purposes. Also, the research gives information for strategic planning for climate change and adaptation.

5. Recommendation

Such research can be carried out on other varieties of Jatropha plant for comparison and industrial purpose.

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