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Effect of heat treatments on the drying behaviour, moisture content and oil yield of *Balanite aegyptiaca* Kernels

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ABSTRACT

The influence of different heat treatments, including oven drying at 40, 50, 60 and 70 °C for 60, 120 and 180 minutes at each temperature, roasting, boiling for 5, 10, and 15 minutes, sun and solar drying for 480 and 720 minutes, on the drying behaviour, moisture content and oil yield of *Balanite aegyptiaca* kernels (BaKs) was investigated.
The moisture contents on wet basis were determined by the oven drying method at 105 °C for 4 hours and calculated from both weight loss data and dry solid weight of the kernel samples, while oil was extracted with n-hexane using Soxhlet apparatus. The experiments were conducted in triplicates.
Low moisture contents of 2.726 and 2.426 % at drying times of 60 and 120 minutes were obtained in *Balanites aegyptiaca* kernels dried at 70 °C, while drying at 40, 50 and 60 °C for 180 minutes gave low moisture contents of 3.973, 3.861 and 3.779 %, respectively. The drying of *Balanite aegyptiaca* kernels occured in the falling rate period. The moisture contents of *Balanites aegyptiaca* kernels oven-dried at 40, 50, 60 and 70 °C decreased with increasing drying time when compared to the raw kernels. Similarly, the average oil yield of *Balanite aegyptiaca* kernels decreased with increasing temperature in the following order: raw>40 °C>50 °C>60 °C>70 °C. The highest oil yield (45.345 %) was obtained in the boiled kernels and the least oil yield (37.790 %) in those kernels dried at 70 °C. Results from this study justify the use of boiling in traditional Balanite kernel oil extraction process as it gave the highest oil yield.

Introduction

Generally, grains are classified into cereals (maize, wheat, millet, rice, etc), pulses (beans, peas, cowpeas, etc) and oil seeds (soyabeans, sunflower, linseed etc). Oil seeds are a source of fibre, phosphorus, iron and magnesium, vitamin E, niacin and folate. They also contain phytoestrogens, a group of substances including legnins and flavones. According to Soltani et al. (2014), edible plant oils are the main source of energy and essential fatty acid for human body and also play an important role in edible oil production and trade. Cultivated oilseeds in the world include sesame, soybean, canola, sunflower, safflower, mustard, rapeseed, cottonseed, peanut, castor, flax, coconut, palm, olive, soybean, canola, sunflower. Groundnut oil (*Arachis hypogoea*) and oil palm (*Elvesis guineensis*) are major sources of edible oils in Nigeria which are mainly utilized for cooking, production of soap, margarine and cosmetics (Aremu et al., 2015). Despite the abundant plant resources for oil production, rapid increase in population growth led to the importation of cooking oils due to increasing demand. This has necessitated the need to seek for local oil-bearing fruits as cheap and

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alternative sources for production of oils, both for consumption and industrial applications.

Desert date (*Balanites aegyptiaca* (L.) Del.), of the family *Balanitaceae*, is one of the prevailing natural trees in Sudan and many tropical countries in Africa and Asia (Vogt, 1995; El Ghazali et al., 2004). It is an important tree crop of the Sudan savannah zone and semi-arid tropical region of Africa, adapted to various climatic conditions, especially in arid regions with extremely high temperatures and scarce water. Thus, it is promoted for combating desertification (Gour and Kant, 2012). It is also considered an important oilseed crop in Northeastern Nigeria. The mesocarp covers a shell enclosing an oil-bearing kernel with other valuable nutrients. The leaves, bark, and the wood are used as food, a substance for fishing and yoke for draught animals and hand implements, respectively. The fleshy plump of the fruit can be an extremely useful edible product and it is consumed as a street food in the Northern part of Nigeria. The kernel has got oil and protein contents ranging from 20–60 % and 20–37 %, respectively (Aviara et al., 2005; Elfeel, 2010). According to El badawi (2017), raw *B. aegyptiaca* kernels contained 3.72 % moisture, 2.88 % ash, 42.41 % crude protein, 39.98 % crude fat and 10.99 % total carbohydrate. These values fall within the range of those previously reported by Hussain et al. (1949); Nour et al. (1985); Chapagain et al. (2009) and Mnaji et al. (2013). The oil content which ranges from 20 – 50 % contains linoleic, oleic, stearic and palmitic acids which are known as four major fatty acids. More so, the level of unsaturated fats (65 %) is higher than that of saturated (34.4 %) with the oil similar to sesame and groundnuts oils in quality and quantity (Abu-Al-Futuh, 1983). However, no serious safety concerns have been reported (Obidah et al., 2009). In addition, numerous uses of various parts of *Balanite aegiptiaca* have been reported. Al Ashaal et al. (2010) and Chapagain (2009) reported on the use of *B. aegyptiaca* oil as food, biodiesel, antimicrobial and antiulcer agents. Obidah et al. (2009) also reported that oil extracted from the kernel of *B. aegytiaca* kernels can be used as a substitute to groundnut oil in the preparation of local foods, to fry food and add flavour to tea and the kernel cake as animal feed. No toxicological concerns were reported in rats after dietary exposure to *Balanites aegyptiaca* seed oil for four weeks. However, only subtle hepatotoxic effects in 5 % of the treated group were observed (Obidah et al. 2009; Wilson et al. 2009). According to ethno-botanical survey, all parts (fruits, seeds, barks and roots) of *Balanites aegyptiaca* have medicinal uses. Diosgenin from steroidal saponins has been used as a source of steroidal drugs such as corticosteroids, contraceptives and sex hormones (Ojo et al. 2015; Neuwinger, 2004; Farid et al. 2002; FAO, 1985). According to Obidah et al. (2009), the seed oil has been used for treatment of skin disease and rheumatism in Nigeria. Mamman et al. (2012) reported on the effects of heating temperature and time on some mechanical properties of *Balanites aegyptiaca* kernels. El badawi et al. (2017) and Ogori et al. (2017) reported on the effects of thermal processing on physicochemical properties and oxidative stability of *Balanities aegyptiaca* kernels and extracted oil as well as thermal effect on physiochemical and phytochemical qualities of pre-treated *Balanites aeqyptiaca* seed oil, respectively.

The determination of moisture levels in oilseeds is a crucial operation for harvesting and virtually all postharvest processing such as handling, storage, milling and oil extraction. It has great influence on seed quality, oil yield and stability of its intrinsic qualities during processing and storage and thus influences their utilization. Akinoso et al. (2006) reported that moisture content had the highest influence on sesame seed oil yield and expression, with optimum condition achieved at 4.6 % (wet basis) moisture content. Olayanju et al. (2006) studied the effect of moisture content on oil recovery from expelled sesame seed and obtained maximum oil recovery of 79.63 % with a 5.3 % moisture content and a minimum of 32.47 % with a 10.32 % moisture content from expelled sesame seed. Hence, for effective extraction of oil from seeds, it is important to control the moisture content with appropriate treatments to improve the oil yield and quality. Many studies have been conducted on the drying characteristic of different kinds of seeds such as soybean (Rafiee et al., 2009), candle nuts (Tarigan et al., 2007), rapeseeds (Duc et al., 2011) and castor seed (Ojediran and Raji, 2011), but data on the drying characteristics and oil yield of *Balanite aegyptiaca* kernel is still scarce for engineering design and drying models. In addition, the quality of *B. aegyptiaca* kernel oil was reported to be affected by exposure of kernels to water, prolonged time in the processing of kernels into oil after the nuts recovery, burning of kernels due to over-roasting, the use of inappropriate ratio of water to paste during boiling, inadequate stirring while mixing kernel paste with boiling water, poor pounding (failure to change into powder or paste), poor decanting (water droplets remaining in the oil), prolonged boiling and repeated decanting.

Therefore, this research investigated the effect of various thermal treatment methods (oven drying at different temperatures, roasting, boiling, sun and solar drying) applicable in the traditional industry in order to examine the drying behaviour, moisture content and oil yield of *Balanite aegyptiaca* kernels and to determine optimum oil yield and product quality.

Materials and methods

Materials

Collection of Balanite aegyptiaca Fruits

Balanites aegyptiaca fruits, purchased from the local market in Nasarawa State, North Central Nigeria, was transported to the Biochemistry/Chemistry Laboratory of the Nigerian Stored Products Research Institute (NSPRI) Headquarters, Ilorin, Kwara State, Nigeria where they were sorted and manually processed by breaking the hard shells to release the kernels. Afterwards, they were stored in an air-tight polythene container prior to analyses. All chemicals and reagents used were of analytical grade. Temperatures for ambient and within the solar tent dryer were taken with the aid of EasyLog, EL-USB-2-LCD temperature data logger during the drying experiment. This study was carried out in June, 2018. The balanite fruits and kernels are shown in Figs. 1 a and b.

Fig. 1. *Balanite aegyptiaca* fruits with mesocarp (a); *Balanite aegyptiaca* kernels (b)

Methods

Processing of Balanite aegyptiaca kernels (BaKs) by thermal treatments

Whole *Balanite aegyptiaca* fruits were manually processed by breaking the hard shells to release the kernels. Afterwards, 1.5 kg were used for oven drying, 0.1kg for sun and solar drying and 0.3 kg for roasting and boiling. The kernels were then subjected to various thermal treatments as follows:

a. Oven drying on aluminum sheet in an electric oven (Model, DHG-9240A Drying Oven) for 3 hours at 40, 50, 60, 70 °C each and samples were taken at 20, 40, 60, 80, 100, 120, 140, 160 and 180 minutes and ground to powder in a mortar and pestle prior to analyses.

b. Sun drying: Kernels were arranged on an aluminum sheet and dried in the sun for about 20 hours during which samples were taken at 8 and 12 hours and ground in a mortar and pestle prior to analyses. On the first day, drying was conducted in the day time for 8 hours and sample was taken while the remaining kernels were left at room temperature overnight and drying continued the next day for 4 more hours then moisture content was determined. Average day temperature and relative humidity readings were 34.07±1.50 °C and 54.07±1.50 % and at night, 26.50±1.50 °C and 75.50±1.50 %.

c. Solar tent drying: Kernels were arranged on an aluminum sheet and dried in NSPRI solar tent dryer which has got a collector underlayed with thick polyurethane insulator for heat sink prevention and a concrete wall painted with food grade black paint for the absorption of heat energy, as well as roof covered with transparent film on wooden framed members to trap solar radiation. Its wooden rack of 18 trays is made of galvanised mesh constructed with a double layer of fine chicken mesh wire with fair openings for air passage through the produce during drying. It also consists of three inlet vents on each side of the dwarf walls for airflow in the system and it is fitted with a wind powered extractor fan on the top for moisture removal. Kernels were dried for about 20 hours during which samples was taken at 8 and 12 hours and ground in a mortar and pestle

prior to analyses. Average temperature obtained within the solar tent dryer was about 38.86 ± 0.15 °C.
d. Roasting: Kernels were roasted in a pan on an electric stove (with homogeneous heat distribution) for 15 minutes. The pan was set on the stove and allowed to be hot such that the kernels began to fry immediately they were placed inside it. Samples were taken at 5, 10 and 15 minutes interval and ground in a mortar and pestle prior to analyses as described by Mariod et al. (2012) with modifications.
e. Boiling: Kernels were immersed in boiling water at 100 °C in a ratio of 1:4 kernel/water for 15 minutes with continuous heating and stirring and samples were taken at intervals of 5, 10 and 15 minutes. The boiled sample was drained, dried in the solar tent dryer and ground in a mortar and pestle prior to analyses following the method adopted by Ndidi et al. (2014) with some modifications.
Drying rate behaviour of drying kernels was determined and illustrated graphically. The moisture contents of dried *Balanite aegyptiaca* kernels by all the heat treatments were determined on wet basis as; % moisture content equals difference between weight (g) of sample before drying and weight (g) of sample after drying divided by sample weight (g) before drying, multiplied by 100 in triplicates by the oven drying method at 105°C for 4 hours while the oil yield was extracted with n-hexane using the Soxhlet apparatus according to the method described by Association of Official Analytical Chemists (AOAC) 2005 and % yield equals weight (g) of oil obtained divided by weight (g) of sample before extraction multiplied by 100.

Statistical analyses

Data obtained from the experiment were subjected to Statistical Analysis of Variance (ANOVA) using SPSS 16.0 Statistical computer software package. The results obtained are represented as Means ± Standard Error of Mean (SEM) of triplicates while the significance between the raw and thermally processed samples and the level of significance was set at $p< 0.05$.

Results and discussion

Drying behaviour of Balanite aegyptiaca kernels

In this study, drying of *Balanite aegyptiaca* kernels to optimum moisture content suitable for oil expression was investigated. Graphical illustrations of the drying behaviour of *B. aegyptiaca* kernels oven,dried at 40, 50, 60 and 70 °C, are shown in Figs. 2, 3, 4 and 5.
At the initial stage of drying, the curves show the drying rates to be very high as the moisture drops from 7 – 4 %, which occurs with increase in temperature having a significant effect on the moisture. However, the effect of treatments at temperature levels between 20 – 100 minutes shows a falling drying rate. Beyond 100 minutes at temperatures more than 50 °C, the drying rate shows to rise when moisture content in the kernels approached equilibrium. According to Gürlek et al. (2009), it has been reported that the whole drying process of foods mostly occurs in falling rate. Similarly, the drying of *Balanite aegyptiaca* kernels in this study follows both constant and falling drying rate periods which occured during oven drying of kernels at 50, 60 and 70 °C for a longer period as in generalized drying rate curve. Ndukwe (2009) also showed that the drying of cocoa bean follows a falling rate characteristic which is an important design consideration. At the constant drying rate period, moisture on the product is freely available at the kernel surface for evaporation into the drying medium while during the falling drying rate period occurs when the moisture has reduced within the kernel hence, low moisture transported to the surface increased resistance to both heat and mass transfer. This shows that hydrophobic layer exists within the *Balanite aegyptiaca* kernel.
From the curves, the falling drying rate period of *B. aegyptiaca* kernels suggests that the surface of the kernels is no longer saturated with water. This is similar to the report by Sultoni (2015) who dried Jatropha seed and kernels at 40, 50 and 60 °C. More so, Erbay and Tcier (2009) stated that drying process of agricultural materials mostly occurs in the falling rate period.
Fig. 2 shows that drying the kernels at a temperature of ≤40 °C may cause reduction in kernel moisture content to follow a zig-zag wave manner at constant temperature between 20-180 minutes. This implies that adsorption and absorption process taking place on the *B. aegyptiaca* kernels may be due to its thermal properties and its resistance to heat energy by radiation in the drying medium.
Graphical results show a linear decrease in the trend of moisture content of kernel samples dried between 20 to 100 minutes at temperatures of 50 to 70 °C. Dehydration of the kernel beyond 100 minutes shows a non-uniform relationship which implies that adsorption-reabsorption may have taken place as a result of release of oil (mixed with water) present in the kernel to the pericarp. At 70 °C, the kernel dries to moisture contents of low values of 2.726 and 2.426 % (on wet basis) in shorter times (60 and 120 minutes) than drying at 40, 50 and 60 °C for 180 minutes which gave low moisture contents of 3.973, 3.861 and 3.779 % (wet basis), respectively. This shows that increased temperature may cause the nut to further lose moisture at a faster rate. But, on the contrary, the nut reabsorbs moisture as the drying time increases from 100 to 180 minutes at 70 °C. This can be attributed to the increase in diameter of the kernel pores which may also

give high tendency of moisture increase in the kernel owing to the effect of energy and mass transfer within the oven as the pores in the kernel samples increased. At higher temperatures, drying rate was faster, hence the time needed to reach specified constant moisture content decreased. This result is in agreement with studies reported by Sacilik et al. (2007) for pumpkin kernel and Kashaninejad et al. (2007) for pistachio nuts. According to Subroto et al. (2015), who studied the drying behaviour of Jatropha seed and kernel, at air temperatures of 40, 50 and 60 °C and relative humidity of 85 %, the seeds and kernels were dried to a moisture content of 5.9 % wet basis and 4 % dry basis, respectively. Thus, the moisture content decreased continuously with the drying time until it reached constant level. More so, Sirimboson and Kitchaiya (2009) stated that drying of the kernels without shell needs less energy (and time) compared to drying the complete seed.

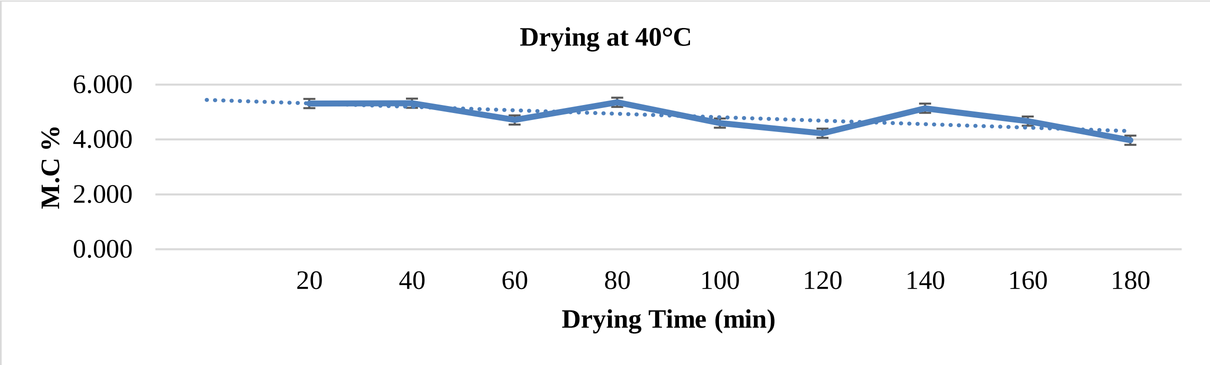

Fig. 2. Drying rate curve of *B. aegyptiaca* kernels dried at 40 °C

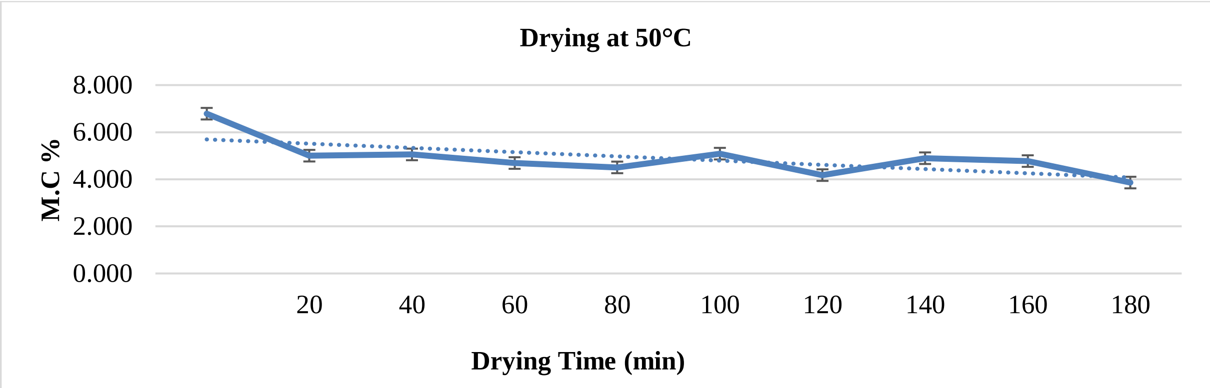

Fig. 3. Drying rate curve of *B. aegyptiaca* kernels dried at 50 °C

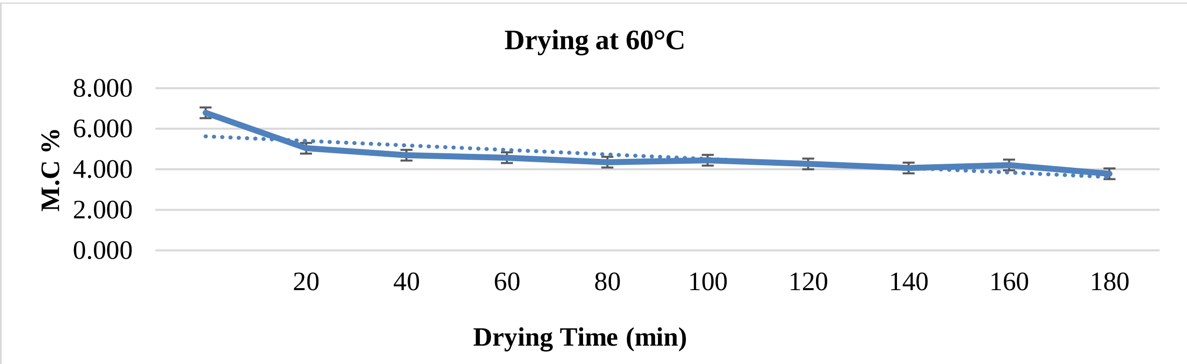

Fig. 4. Drying rate curve of *B. aegyptiaca* kernels dried at 60 °C

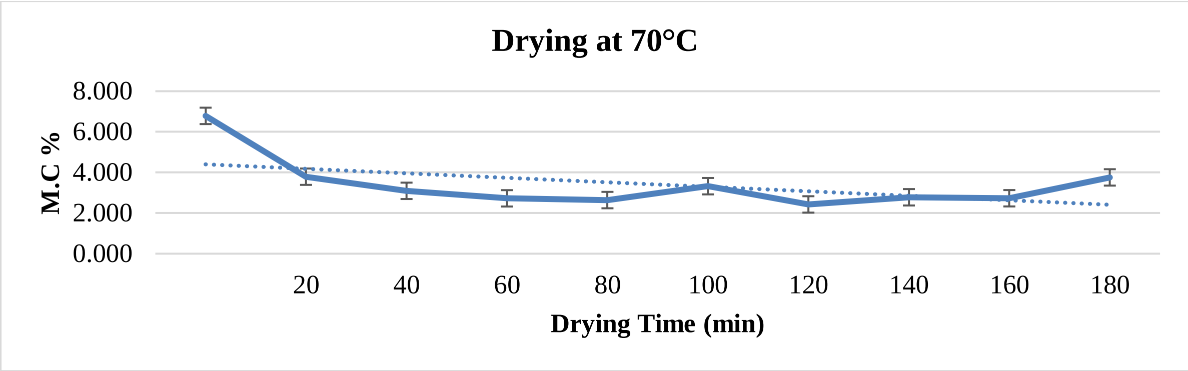

Fig. 5. Drying rate curve of *B. aegyptiaca* kernels dried at 70 °C

Moisture contents and oil yield from Balanite aegyptiaca kernels

During the drying process, the constituents of seeds undergo undesirable reactions changing the quality state, especially due to lipid peroxidation and lipid hydrolysis. Thus, information on oil quality and the effect of heat during the drying of *Balanite aegyptiaca* kernel is imperative for optimum oil extraction and kernel quality. As the kernel dries, it releases its moisture into the drying air and consequently loses weight, thus controlling the moisture content of the kernels.

From this study, a light-yellow oil was obtained from *Balanites aegyptiaca* kernels after extraction with n-hexane. Moisture contents of all the kernels decreased with increasing time of drying when compared to the raw kernels at four oven temperatures (40, 50, 60 and 70 °C). A similar trend was observed for sun-dried and solar-dried kernel samples.

However, the moisture content of boileddried *Balanites aegyptiaca* kernels increased from 6.239 to 7.731 % wet basis (at 5 to 10 minutes of boiling) and then decreased at 15 minutes boiling time to 6.517 % wet basis when compared to raw samples. This could be due to the reabsorption of water by the kernels as a result of the properties of carbohydrates and protein contents of the kernels which are known practically have absorptive property with exception of oils. The high % oil yield in boiled kernels could be attributed to the disruption of the cell structures and membrane partitions of the kernels by heat during cooking, causing the fat (oil) to melt and be easily released from it and this explains the use of boiling in the extraction of oil from *Balanites aegyptiaca* kernels by local oil processors.

Most oil seeds and nuts are heattreated by roasting to liquefy the oil in the plant cells and facilitate its release during extraction, except for palm fruits where "sterilization" replaces this operation. In roasted kernels, the low % moisture contents (2.493 %) obtained could be attributed to the effect of roasting which facilitates oil extraction by decreasing its viscosity, releasing oil from intact cells and removing moisture (Alenyorege, 2015). El badawi et al. (2017) reported a low moisture content of 2.18 % in *B. aegyptiaca* kernels roasted for 15 minutes. This is similar to the result in this study for kernels roasted for 15 minutes. Moisture contents of *Balanite aegyptiaca* kernels dried under the sun and solar tent decreased with increasing drying time (from 480 to 720 minutes) when compared to the raw kernels. It is observed that oil yields of *Balanite aegyptiaca* kernels dried under the sun and in solar tent for 720 minutes did not differ and were significantly lower than raw kernels. Oil yield of BaKs dried under solar tent for 480 minutes did not differ from raw kernels, however, the oil yields of BaKs dried under the sun for 480 minutes significantly decreased when compared to raw kernels.

No significant difference was observed in the % oil contents of kernels oven-dried at 40 °C for 60, 120 and 180 minutes when compared with the raw kernels. However, at 70 °C drying temperature, % oil contents of kernels significantly ($p<0.05$) decreased with increasing drying time. Thus, in the oven-dried kernel samples, average % oil yield decreased with increasing temperatures in the order; raw > 40 > 50 > 60 > 70 °C. This confirms the report by Ghaly et al. (1984) which states that safe drying of oilseeds should be below 70 °C. Oil yield, in general, increases with increasing temperature and decreasing moisture content. The highest % oil yield from this study is 45.345 %, obtained from *Balanites aegyptiaca* kernels boiled for 5 minutes with a moisture content of 6.239 % while the least oil yield of 33.340 % was obtained in *Balanites aegyptiaca* kernels oven-dried at 70 °C for 180 minutes with a moisture content of 3.757 %. The high oil contents of *B. aegyptiaca* kernels were obtained as 45.345 and 44.230 % for boiled and roasted kernels, respectively, and this is comparable to those obtained from rich oilseeds such as sesame seed (beniseed) (which is 44 %) (Tunde-Akintunde and Akintunde, 2004) and canola seed oil ≈ 40% (Razani et al., 2003). The cooking process coagulates the proteins (albuminoids) present in the seed causing coalescence of oil droplets and making the seed permeable to the flow of oil. The process also decreases the affinity of oil for the solid surfaces of seed, because of which the best possible yields of oil are obtained on expression/extraction of cooked seed. The cooking process also helps in imparting proper plasticity to seed mass (Shukia et al., 1992). This result is in good agreement with result by El-Badrawy et al. (2017) who reported that the oil and protein content of raw peanut increased as a result of roasting process, thus the increase in oil and protein content in safflower seed could be due to temperature of roasting and boiling techniques (Mariod et al., 2012). The roasting of seeds prior to oil extraction has been reported by Wijesundera et al. (2008) and Abou-Gharbia et al. (1996) to enhance the oxidative stability of oils. Although Mariod et al. (2012) and Anjum et al. (2006) reported that roasting has got a negative effect on the oxidative stability of oils extracted from roasted seeds. This may be for prolonged time and at temperatures above 70 °C. This confirms the report by Ghaly et al. (1984) which states that the safe drying of oilseeds should be below 70 °C.

The % oil yield of *Balanite aegyptiaca* kernels from the highest to the least is shown in the following order: boiled (45.345)>solar tent-dried (44.710)>roasted (44.230)>raw (43.170)>oven-dried at 70 °C (33.340). The moisture contents and oil yield obtained from *B. aegyptiaca* kernels processed by the thermal treatments used in this study are shown in Table 1.

Table 1. Effect of Thermal Treatments on Moisture Content and Oil Yield of *B. aegyptiaca* Kernels

Sample	**Time (Minutes)**	**Moisture content % (wet basis)**	**Oil yield %**
Raw BaK	0	6.757±0.024[a]	43.170±0.070[a]
Oven-dried BaK @40 ˚C	60	4.311±0.186[b]	42.882±0.246[a]
	120	4.228±0.468[b]	42.697±0.218[a]
	180	3.973±0.319[b]	42.559±0.169[a]
Oven-dried BaK @ 50 ˚C	60	4.689±0.349[b]	39.878±0.033[c]
	120	4.177±0.312[b]	41.296±0.187[b]
	180	3.861±0.415[b]	40.239±0.495[c]
Oven-dried BaK @ 60 ˚C	60	4.571±0.143[b]	40.475±0.800[b]
	120	4.157±0.289[bc]	39.033±0.008[c]
	180	3.779±0.564[c]	40.680±0.470[b]
Oven-dried BaK @ 70 ˚C	60	2.726±0.037[c]	40.560±0.190[b]
	120	2.426±0.043[d]	37.790±0.740[c]
	180	3.757±0.063[b]	33.340±0.220[d]
Raw BaK	0	6.757±0.024[a]	43.170±0.070[b]
Boiled BaK	5	6.239±0.110[b]	45.345±0.545[a]
	10	7.731±0.575[a]	39.715±0.025[d]
	15	6.517±0.267[b]	40.990±0.340[c]
Raw BaK	0	6.757±0.024[a]	43.170±0.070[ab]
Roasted BaK	5	3.547±0.043[c]	42.505±0.475[b]
	10	3.980±0.212[b]	44.230±0.110[a]
	15	2.493±0.109[d]	42.535±0.425[b]
Raw BaK	0	6.757±0.024[a]	43.170±0.070[a]
Sun-dried BaK	480	5.788±0.070[b]	40.170±0.035[c]
	720	4.421±0.170[c]	42.080±0.055[b]
Solar tent-dried BaK	480	4.765±0.700[b]	44.710±0.490[a]
	720	4.262±0.172[c]	42.870±0.486[b]

BaK – *Balanite aegyptiaca* kernels. Results are represented as Mean±SEM of triplicate values. Test values with superscripts different from the control for each parameter are significantly different ($p<0.05$).

Conclusion

The moisture content and oil yield of *Balanite aegyptiaca* kernels decreased with increasing drying time in this order: raw>40 °C>50 °C>60 °C>70 °C for moisture content and boiled>solar tent-dried>roasted>raw>oven-dried at 70 °C for oil yield. This confirms the use of boiling in traditional processing technology in oil extraction from *B. aegptiaca* kernels among local processors. It can be deduced that optimum % moisture content for high oil yield from *Balanite aegyptiaca* kernels is within the range of 6 – 7 %. Thus, boiling as a thermal processing method could be adopted for commercial oil production for domestic and industrial applications, although, there is a need to screen the oil for the moisture content level.

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