

Physicochemical Characterization of *Aduwa* (*Balanites Aegyptiaca*) Seed Oil Extracted Using Soxhlet and Wet Extraction Methods

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Abstract

Balanites aegyptiaca is a dicotyledonous flowering plant species found commonly in sub Saharan region of Africa, Asia and Arab nations. It is recognized as a tree of the desert with severe tolerance of harsh weather conditions and dwell in moderate climatic zones; in countries such as Nigeria. This research article aimed at extracting oil from Aduwa (*Balanites aegyptiaca*) seeds using two selected extraction methods; soxhlet and wet extraction methods. The physical and chemical properties of the extracted oil samples were analyzed. The samples were taken in triplicate measurement are analyzed statistically for mean $\pm$ standard deviation using sample T-test' and the mean significant difference were accepted at ($P < 0.05$). The physicochemical, phytochemical, antioxidant, vitamins content of the oil were determined. The results of physiochemical properties obtained showed that Refractive index had a mean value ranging from 1.35 to 1.40, peroxide value 0.35 to 0.43 meq/kg and iodine value 28.4 to 29.4 g/100g. Phenolic content ranged from 0.21 to 2.33 $\mu\text{gGAE/ml}$ and flavonoid had a mean value of 2.05 to 2.08 $\mu\text{g/ml}$. Antioxidants content determined includes; FRAP with a mean value of 33.63 to 65.54 $\mu\text{molTE/g}$ and DPPH IC₅₀ 0.612 to 97.571 $\mu\text{g/ml}$. The Aduwa oil is found to be a good source of retinol with a mean value of 613.35 to 856.76 $\mu\text{g/dl}$ and carotenoid 9693.1 to 12188 $\mu\text{g/dl}$. Results obtained revealed that both method used for the extraction yield similar results although, samples extracted using wet extraction method are more efficient

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and palatable with high antioxidants and mineral content compared with the soxhlet method. Samples obtained from both methods possess a characteristic bitter taste and there is reduction in oil yield in wet extraction method due to informal processing procedures.

Keywords: Aduwa, extraction, wet extraction, soxhlet extraction method, oil content

INTRODUCTION

The African continent is blessed with abundant species of plants that are considered to contain significant quantities of compounds which are well known to promote human health and possibly eradicate hunger. Many of these plant species remain undiscovered or underutilized by the western society and some locals (Bamalli, *et al.*, 2014). *Balanites aegyptiaca* L. (Delile Aduwa in Hausa) is one of such plants found in the African continent. The taxonomical profile of the *Aduwa* plant is that the plant is a *dicotyledonous* flowering plant that belongs to the kingdom *Plantae*, Class: *Magnoliopsida*, Order: *Sapindales* from the family *Zygophyllaceae*, (Ogala, *et al.*, 2018). In the dry regions of Africa; the *Aduwa* plant grows well in the Sahel parts of Nigeria, and other part of Africa (Tula, *et al.*, 2014). Manji, *et al.*, (2013) reported that *Aduwa* plant is found in South Asia and in the Arabian Peninsula. Murthy, *et al.*, (2021) *Aduwa* plant grow in some part of the Middle East such as Saudis, Iran, Oman, Syria, Palestine and India. The *Aduwa* plant is well known by a very large number of local names such as Desert dates in English, *Aduwa* in Hausa, *Utaz* in Igbo, *Teji* in Yoruba, *Tanni* in fulfulde and *Heglig* in Arabic (Tula, *et al.*, 2014).

Aduwa plant produces single seeded fruit having a characteristic bitter taste. Acceptability of *Aduwa* fruits may be greatly hindered by the characteristic bitter taste it possesses and by the dizziness effect it brings (especially when consumed in large amounts). The kernel seeds have almost 49% oil which is edible oil (Murthy, *et al.*, 2021) due to the fatty acid composition it possesses. However, the oil also tends to have bitter taste after extraction by mechanical means, which also prevents its maximum utilization as cooking oil. The local communities extract the seed oil and use it for various purposes, such as in food preparations and traditional medicine. *Aduwa* seed oil contains important phytochemicals components such as flavonoids, phenolics, tannins, saponins and alkaloids, these compounds possess anti-microbial, anti-oxidant, anti-inflammatory, anti-cancer, and steroidal effects (Selouka *et al.*, 2020; Hashmi *et al.*, 2021). However, the seeds of the *Aduwa* are not fully utilized. Attention on the *Aduwa* plant has always been on the fruit pulp, but the seeds have always been over looked despite the high mono and polyunsaturated fatty acid and antioxidant present in the oil from the seeds. Both quality and quantity of *Aduwa* seed oil is an aspect of great concern in food insecurity in countries like Nigeria (Selouka *et al.*, 2020). Studying the physical and chemical, as well as the functional properties of the oil extracted will be a step forward in incorporating the oil into our food system. This article therefore, aimed at extracting oil using soxhlet and wet extraction method to compare the efficiency and characteristics of the oil from *Aduwa* (*Balanites aegyptiaca*) seed.

MATERIALS AND METHODS

Sample Collection

The sample of freshly harvested *Aduwa* fruits were purchased from Awaya village, in Sumaila Local Government Area, Kano, Nigeria.

Sample Preparation

The freshly harvested *Aduwa* (*Balanites aegyptiaca*) seeds were obtained, sorted and then soaked in water overnight to dissolved the flesh then washed off to obtain fruit stone, i.e. the seeds used for oil extraction. The stones were cracked manually to obtain the oily nut. Then further subjected to oil extraction from the seeds using Solvent and Wet extraction methods. The sample preparation, oil extraction and laboratory analysis were conducted in Pollution Controlled Laboratory, Kano State Ministry of Environment.

Extraction of Oil

Soxhlet Extraction Method

Soxhlet extraction method as described by Bayisa and Bullo (2021) was used to extract the oil from grounded *Aduwa* seeds with N-Hexane as solvent. Soxhlet extraction was carried out for 8 hours in 2 L Soxhlet apparatus set with each extraction using 150 g of grounded seed and 400 ml hexane at boiling point of 60 °C as described by AOAC, (2012). After extraction, a rotary evaporator was used to evaporate off the solvent while the residual solvent was removed by drying the oil in an oven at 60 °C for 1 hour. The oil samples were weighed to obtain the yield (% oil/100 g seed), pooled, gently mixed, sealed after flushing with N₂ and then stored at -20 °C prior to analysis.

Wet Extraction Method

About 3.1 kg of grounded *Aduwa* (*Balanites aegyptiaca*) seeds was added to a pot of boiling water (30 liters), continued boiling (almost 3 hours) until oil emerged completely covering the water in the pot. Heating was stopped and oil was collected by scooping with a ladle into a smaller pot. Boiling was resumed (7 minutes) for further water removal. Then oil was subjected to oven drying to further remove moisture. The oil was weighed and oil yield was determined as; oil recovered /3.1 Kg X 100% (Onwuka, 2018).

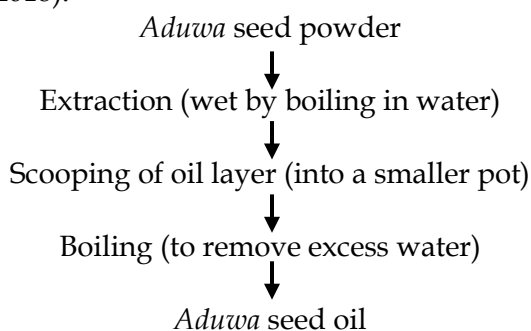


Figure 1: Flowchart for the extraction of *Aduwa* Seed Oil using Wet Extraction.
Sources: (Selouka *et al.*, 2020)

Physical Analysis of Oil Sample

The refractive index of the oil extracted using soxhlet and wet extraction method were analysed following a method of Bayisa and Bullo, (2021). The density of the oil samples were determined according to the method described by Ogala *et al.*, (2018). where 25 ml of oil sample were measured in a known volume of measuring cylinder, and the weight of the cylinder and oil content were taken; the net weight of the oil was obtained by subtracting the weight of the cylinder from the initial weight of the oil as specific density using the following formulae;

$$S. D = \frac{W1 - W0}{V}$$

Where:

W1 = weight of empty measuring cylinder + oil; W_o = weight of measuring cylinder; V = volume of oil.

The viscosity of the oil was determined by suspension sphere method as described by Sahasrabudhe *et al.*, (2014) and the value obtained was expressed in mega pascal (Pa.s).

The smoke point was determined using method described by Onwuka, (2018). Fifty mills (50 ml) of oil sample was used and a thermometer was dipped inside the oil without touching the bottom of the beaker and the bulb area with a gradually rise in temperature of oil using electric stove. The cloud point was determined using heated oil sample at 100 °C and rapidly cooled in water bath followed by steady stirring to prevent super-cooling and solidification of fat crystals on the surface of the bottle, the bottle were observed for the presence of cloudiness as described by Norhayati *et al.*, (2015). The pH was determined using 10 ml of the oil samples by homogenizing in 50 ml distilled water and pH determined using a standardized pH meter with standard buffer of pH 7.0 as described by Onwuka, (2018).

Chemical Analysis of the Oil Sample

Free fatty acid (FFA), was determined using 2 g of samples and 2.5 mL of methanol was added with constant stirring followed by 3 drops of phenolphthalein indicator then titrated against 0.14 M potassium hydroxide solution with vigorous shaking until a light pink color persisted for 1 min as described by Datti *et al.*, (2020).

The peroxide value (PV), iodine value, P-anisidine value was determined using spectrophotometer (UV 6705, JENWEY) according to the method described by Pardeshi, (2020). Whereas, saponifiable and unaponifiable values was measured following a method of (AOAS, 2000; Manji *et al.*, 2013). The FFA and PV was determined using titration method, while, AV was measured using (5 ml) iodine solution into 5 ml of 10 % KI solution reported by Manji *et al.*, (2013). Two grams (2 g) of oil sample was measured into a 250 ml conical flask and 25 ml 10 % alcoholic KOH was added, for saponifiable matter. One (1) ml phenolphthalein indicator were added and the solution were titrated with 0.5 M HCL as described by (AOAC, 2000). The unsaponifiable matter was determined according to the method of Onwuka, (2018) using a titration of the saponification value, neutralized liquid and then adding alkaline again with 1 ml of aqueous 3M KOH solution. Alkaline phenolphthalein followed by evaporating off the dried residue at 80 °C was weighed to a constant weight as % unsaponifiable matter.

Quantitative Analysis of total Phenolic and total flavonoid Content

The phenolic and flavonoid content was determined quantitatively following a method of Habarakada *et al.*, (2021), using UV visible spectrophotometer and the results were expressed in µg gallic acid equivalents per ml of oil (µgGAE/ml) at 765 nm wavelength for the determination of phenolic and total flavonoids content using aluminium chloride.

Determination of Antioxidant Activity

One milliliter of the sample was measured into a test tube and 3 ml of DPPH solution was added and the solution was made to 10 mL volume with 99 % methanol. the samples was incubated in a dark place for 30 minutes, and then ran at 517 nm against blank using a UV visible

spectrophotometer (MHLI-295, MediRay) as described by Habarakada, (2021). The DPPH radical scavenging activity percentage was calculated as follows:

$$\text{DPPH (\%)} = 100 \times \frac{\text{Blank absorbance} - \text{Sample absorbance}}{\text{Blank absorbance}}$$

The FRAP assay was measured according to method described by Niyukuri *et al.*, (2020). The reducing agents in the extracts induce a reduction of ferric ions (Fe^{+3}) to ferrous ions (Fe^{+2}). Absorbance was measured using a spectrophotometer (MHLI-295, MediRay) at a wavelength of 593 nm.

Determination of fat-soluble vitamins

The fat soluble vitamins which includes; retinol, carotenoid and vitamin E content were determined as per method described by Onwuka, (2018). Where blanks sample was prepared for each vitamin separately. The samples was prepared, incubated and extracted then centrifuged at 600-1000 x g for 5 minutes. The samples were analyzed using UV-visible spectrophotometer under optical absorbance of 328 nm. Retinol content was calculated using the following:

$$\text{Retinol } (\mu \text{ g/dl}) = A^\circ (328) - A' \times 637$$

The carotenoid was analyzed using optical absorbance of 460 nm using UV visible spectrophotometer (JENWAY) and the total carotenoid content was determined as:

$$\text{Carotenes } (\mu \text{ g/dl}) = A^\circ (460) \times 480$$

Where; A° = Optical absorbance reading.

While, the vitamin E content was calculated as follows:

$$C = A / \epsilon l$$

Statistical Analysis

The analysis were carried out in triplicates measurement and all the data obtained in this study was analysed SPSS version 16 for mean and standard deviation. Sample T-test was employed to compare the means of oil characteristics analyzed with significant difference at ($p < 0.05$) using graph-Pad prism 5. All values were expressed as mean of triplicate $\pm$ standard deviation. (Okia *et al.*, 2013).

RESULTS AND DISCUSSIONS

Physical properties of Aduwa (*Balanites aegyptiaca*) oil

Table 1 shows the results of physical properties of Aduwa (*Balanites aegyptiaca*) oil samples. Sample 'WE' for wet extraction method had a mean value of 0.903 density while sample 'SE' for soxhlet extraction method had 0.740 density. Viscosity of the sample revealed that 'WE' had 0.015 Pa. s whereas, sample 'SE' had viscosity of 0.016 Pa. s. The refractive index had 1.400 and 1.350 for samples 'WE' and 'SE' respectively. The oil samples shows high acidic content with pH of 5.600 for sample 'WE' and 6.800 for sample 'SE'. The cloud point of the samples was similar; with a mean value of 36.930 °C for sample 'WE' and 36.330 °C for sample 'SE'. The smoke point for sample 'WE' and a mean value of 132.300 °C and higher than 124.700 °C for sample 'SE'.

Table 1: Physical properties of *Aduwa (Balanites aegyptiaca)* oil

S/N	Parameter	Sample 'WE'	Sample 'SE'
1	Density (g/cm ³)	0.903±0.015 ^a	0.740±0.050 ^b
2	Viscosity (Pa/s)	0.015±0.002 ^a	0.016±0.001 ^a
3	Refractive index	1.400±0.010 ^a	1.350±0.120 ^a
4	pH	5.600±0.173 ^b	6.800±0.110 ^a
5	Cloud point	36.930±0.706 ^a	36.330±0.764 ^a
6	Smoke point	132.300±0.667 ^a	124.700±2.186 ^b

Note: Values are presented as mean ± standard deviations of triplicate readings n= 3, values within same row bearing different superscripts letters are statistically (p< 0.05) different.

KEY: 'WE' = *Aduwa* oil extracted using Wet method. 'SE' = *Aduwa* oil extracted using soxhlet method.

Chemical Characteristics of *Aduwa (Balanites aegyptiaca)* oil

Table 2 present the chemical properties of *Aduwa* oil samples. The result presented showed that sample 'WE' had the highest mean saponification value of 121.000 mgKOH/g, iodine value of 28.400 g/100g, 0.430 meq/kg, peroxide value, 7.910 % for free fatty acids, but low values of 0.607% for un-saponifiable matter and 1.863 AnV for p-Anisidine value respectively, as compared with sample 'SE' which had low values of 118.200 mgKOH/g for saponification value, 29.400 g/100g iodine value, 0.350 meq/kg peroxide value content, free fatty acid content of 7.280 %, but a higher value of 0.700 % for unsaponifiable matter and 1.953 AnV for p-Anisidine.

Table 2: Chemical Characteristics of *Aduwa (Balanites aegyptiaca)* oil

S/N	Parameter	Sample 'WE'	Sample 'SE'
1	Saponification (mgKOH/g)	121.000±0.500 ^a	118.200±0.280 ^b
2	Iodine Value (g/100g)	28.400±0.506 ^a	29.400±0.416 ^a
3	Peroxide Value (meq/kg)	0.430±0.076 ^a	0.350±0.031 ^a
4	Unsaponifiable matter (%)	0.607±0.012 ^a	0.700±0.010 ^a
5	FFA (%)	7.910±1.105 ^a	7.280±0.435 ^b
6	p-Anisidine value (AnV)	1.863±0.198 ^b	1.953±0.4316 ^a

Note: Values are presented as mean ± standard deviations of triplicate readings n= 3, values within the same row bearing different superscripts letters are statistically (p< 0.05) different.

KEY: 'WE' = *Aduwa* oil extracted using Wet method. 'SE' = *Aduwa* oil extracted using Soxhlet method.

Quantitative Phytochemicals analysis of *Aduwa* oil

Table 3 shows the phytochemical contents of *Aduwa* oil samples analyzed where, total phenolic content is much lower in sample 'WE' with (0.210 µg/ml) compared to (2.330 µg/ml) in sample 'SE'. The total Flavonoid, the samples have similar results; (2.050 µg/ml) for 'WE' and (2.080 µg/ml) for 'SE'.

Table 3: Quantitative Phytochemicals analysis of *Aduwa (Balanites aegyptiaca)* oil

Sample	Total Phenolics (µg/ml)	Total Flavonoids (µg/ml)
'WE'	0.210±0.010 ^b	2.050±0.050 ^a
'SE'	2.330±0.030 ^a	2.080±0.023 ^b

Note: Values are presented as mean ± standard deviations of triplicate readings n= 3, values within the same column bearing different superscripts letters are statistically (p< 0.05) different.

KEY: 'WE' = *Aduwa* oil extracted using Wet method. 'SE' = *Aduwa* oil extracted using Soxhlet method.

Antioxidant analysis of Aduwa (*Balanites aegyptiaca*) oil

Tables 4 and 5 present antioxidant activity of Aduwa (*Balanites aegyptiaca*) oil samples. The result shows a clear significant difference for antioxidant potentials of the two samples. Sample 'SE' is shown to have greater antioxidant power with values of 3.954 µg/ml than sample 'WE' which have 97.571 µg/ml for DPPH analysis. Both samples were shown to have lower antioxidant power than the control sample (ascorbic acid) which has (0.612 µg/ml). For FRAP analysis, sample 'SE' have 65.540 µmolTE/g while sample 'WE' have 33.630 µmolTE/g.

Table 4: Antioxidant analysis of Aduwa (*Balanites aegyptiaca*) oil

Sample	FRAP (µmolTE/g)	DPPH IC50 (µg/ml)
'LE'	33.630±0.839 ^b	97.571 ± 10.496 ^a
'SE'	65.540±0.153 ^a	3.954 ± 0.589 ^b
Ascorbic acid	-	0.612 ± 0.266 ^c

Note: Values are presented as mean ± standard deviations of triplicate readings n= 3, values within the same column bearing different superscripts letters are statistically (p< 0.05) different.

KEY: 'WE' = Aduwa oil extracted using Wet method. 'SE' = Aduwa oil extracted using Soxhlet method.

Vitamins analysis of Aduwa (*Balanites aegyptiaca*) oil

Table 5 presents the results of vitamins analysis on Aduwa seed oil samples 'WE' and 'SE'. Sample 'WE' have a lower retinol content of 613.350 µg/dl while sample 'SE' have 856.760 µg/dl. Carotenoid content of sample 'SE' 12188.000 µg/dl was also found to be higher than 9693.100 µg/dl for sample 'WE'. The result shows that both samples have the same values with regards to vitamin E content. Vitamin E content was determined to be 14286.000 mg/L for both sample 'WE' and sample 'SE'.

Table 5: Analysis of vitamins of Aduwa seed (*Balanites aegyptiaca*) oil.

S/N	Parameter	Sample 'LE'	Sample 'SE'
1.	Retinol(µg/ dl)	613.350±10.362 ^b	856.760±106.650 ^a
2.	Carotenoid (µg/dl)	9693.100±79.611 ^b	12188.000±79.611 ^a
3.	Vitamin E (mg/L)	14286.000±1.100 ^a	14286.000±1.100 ^a

Note: Values are presented as mean ± standard deviations of triplicate readings n= 3, values within the same row bearing different superscripts letters are statistically (p< 0.05) different.

KEY: 'WE' = Aduwa oil extracted using Wet method. 'SE' = Aduwa oil extracted using Soxhlet method.

DISCUSSION

Physical Characteristics Analysis

The result presented in Table 1 revealed that characteristics of oil extracted from adua using wet and soxhlet methods had a density value of 0.740 g/cm³ for SE which showed that the samples were less dense than water due to presence of water in extraction process as reported by Datti *et al.*, (2020). The result also agreed with a report by Babeker, (2013) and Manji *et al.*, (2013) within the FAO/WHO standards of (0.909 g/cm³). Density being a factor which enhances absorption of oil during frying and also affect the rate of mass transfer has been practically described to be linearly dependent on temperature (Sahasrabudhe *et al.*, 2017).

The viscosity of the oil was determined and the viscosity enables absorption and drainage during frying processes, the more viscous an oil is, the slower the rate of oil drainage Sahasrabudhe *et*

al., (2017). Rukke and Barfod, (2017) in their study on the viscosity of varieties of vegetable oil discovered a decrease with an increase in temperature as reported (Endo, 2018).

Refractive index for sample 'WE' was 1.40 and for sample 'SE' 1.35, these values were below the FAO/WHO standard of (1.4677-1.4705) as reported by Datti *et al.*, (2020). High value for the refractive index of oil reveals that the fatty acids contained in the oil had a high number of carbon atoms (Bayisa and Bulla, 2021). The pH of oil samples agreed with Alaba *et al.*, (2023) reported that pH of palm kernel oil is 6.800, this was found to be the same with the pH of sample 'SE' as reported by Chizoo *et al.*, (2017). This shows that pH can be affected by extraction procedure being used as in the case with samples 'WE' and 'SE'. Smoke point of sample may be high due the presence of volatile materials such as free fatty acids and residual extracting solvent in an oil sample Nwakodo *et al.*, (2018). The results shows that the smoke point decrease with prolong storage of the oil as reported by Chizoo *et al.*, (2017) and therefore they are much lower than smoke points determined for both sample 'WE' and 'SE'. The cloud point of oil is related to the level of unsaturation, meaning that highly unsaturated oil will have lower cloud point compared to their saturated counterparts (Nwakodo *et al.*, 2018). Norhayaty *et al.*, (2015) stated that cloud point can be seen as a factor of melting point where saturated fats are characterized with having high melting point and of course a high cloud point, while on the other hand unsaturated fats are known to have lower melting point and lower cloud point as well as reported by Usman *et al.*, (2022). Palm oil have cloud point temperature of 10.7 °C (Norhayaty *et al.*, 2015; Nwakodo *et al.*, (2018).

Chemical Characteristics Analysis

The FFA for sample 'WE' from Table 2 shows 7.910 % and for sample 'SE' is 7.280 %, there is significant difference between the samples. Adam *et al.*, (2021) in their study reported that the free fatty acid content of Aduwa (*Balanites aegyptiaca*) seed oil is 12.500 - 12.700 %, and Ogala *et al.*, (2018) also reported similar result, the values are higher than the ones obtained in this study which agreed with Manji *et al.*, (2013), 1.270 % by Datti *et al.*, (2020) and 0.260 % by Habarakada *et al.*, (2021). Famurewa *et al.*, (2021) reported that FFA of palm oil ranged from 1.730 to 2.210 mg KOH g⁻¹ and Bayisa and Bulla (2021) reported FFA of *Croton macrostachyus* seed oil as (1.750 mgKOH/g) and these were lower than the result of FFA obtained in sample 'WE' and 'SE'. Although, sample 'SE' met the FAO/WHO standard limits of (5.780-7.280 %) while that of sample 'WE' was little higher. Lower free fatty acid make oil more palatable (Famurewa *et al.*, 2021).

The saponification value for Aduwa (*Balanites aegyptiaca*) seed oil sample 'WE' was determined as 121.000 mgKOH/g and for sample 'SE' as 118.200 mgKOH/g. Saponification value were used to measure the oxidation level during storage and also indicates degradation of effect on quality of cooking oil Famurewa *et al.*, (2021). Saponification values is a measure of average molecular weight of fatty acid in the oil sample Al-Hilfi and Al-Fekaik, (2016) and it is also directly proportional to the shorter chain fatty acids on the glycerol backbone (Nivya *et al.*, 2023). Kibiya and Adam, (2020) report that the saponification value of Aduwa (*Balanites aegyptiaca*) seed oil were 134 mgKOH/g and suggested would be used in soap making. Very high saponification value in Aduwa (*Balanites aegyptiaca*) seed oil was reported to be 194.33 mgKOH/g by Habarakada *et al.*, (2021).

The unsaponifiable matter determined in Aduwa (*Balanites aegyptiaca*) seed oil revealed that sample 'WE' had 0.607 % and sample 'SE' had (0.700 %). The results shows that Sample 'SE' have the highest unsaponifiable matter than sample 'WE', but there is no significant difference between the samples. Un-saponifiable matter was found to be 3.080 % by Habarakada *et al.*, (2021) for the Aduwa (*Balanites aegyptiaca*) seed oil in their study. This is considerably higher than what was obtained in this study for both samples 'WE' and 'SE'. The variation could be attributed due to difference in extraction method. Datti, *et al.*, (1994) described that saponification value of Soya bean oil was between 0.660 - 0.710 % and palm oil 0.720 - 0.760 %. It can be seen that these values was closely related to results obtained in this findings.

Iodine value is used as a measure of the level of unsaturation present in fats and oils. It is calculated as the grams of iodine that 100 g oil absorbs during the test. Non-drying oils are those with iodine value below 100 (Akinola and Adeyinka, 2022) and they are liquid at room temperature (Kibiya and Adam, 2020). Iodine value (58.98 g/100g) was obtained by Akinola and Adeyinka, (2022) for almond oil found to be higher than what was obtained in this study. The iodine value in sample 'SE' and 'WE' was significantly lower compared with that in literature as reported by Asouzu *et al.*, (2023). In this study, it is noted that iodine value of cooking oils decreases with increasing frying time and temperature. Low level of iodine value ensures resistance of fat and oil to oxidative rancidity (Nivya *et al.*, 2023).

Table 2 show that 4.3, 0.43 meqO/kg were recorded in peroxide value for adua seed oil coded 'WE' and 0.35 meqO/kg for sample 'SE', the period value was effective and sensitive approach towards early detection of oxidative deterioration. Low peroxide values in fats and oils is an indication of strong presence and levels of antioxidants because certain antioxidants are well known to reduce rancidity Al-hilfi and Alfekaik, (2016).

The p-anisidine value for sample 'WE' and SE were 1.863 AnV and 1.953 AnV respectively, there was significant difference between the samples. Pardeshi, (2020) reports a similar result of p-anisidine value for a branded vegetable oil 1.820 AnV. P-anisidine values obtained for both samples are within normal range of 10 AnV (Giufere *et al.*, 2018). P-anisidine index were used to detect the presence of non-volatile and aldehyde compounds produced during decomposition of hydrogen peroxides (Gagour *et al.*, 2022). Determination of p-anisidine value is a method used for evaluation of secondary products of lipid oxidation that are related to the formation of non-volatile aldehydes and ketones which are responsible for the rancid odour and taste in fats and oils. The importance of p-anisidine value in refined oil revealed oxidative damage that occurred which cannot be neutralized by deodorization process (Giufere *et al.*, 2018).

Quantitative Phytochemical Analysis.

Total phenolic content determined in adua samples had a mean value of 0.210 and 2.330 µg/ml, there was significant difference between the samples compared with study conducted by Nivya *et al.*, (2022) on virgin coconut oil, it was revealed that the oil has phenolic content of 8.820 to 9.970 µg/mg which is higher than the phenolic contents of samples 'WE' and 'SE'. According to Pardeshi *et al.*, (2020) it was observed that the total phenolic content of oil from cold extraction method was high compared to phenolic content of other oil seeds from hot process extraction method. Hashmi *et al.*, (2021) points out that heating process can lead to the destruction of phenolics in the oil. The total flavonoid content determined ranged between (2.050 µg/ml and

2.08 µg/ml). These values were higher than 0.600-1.770 µg/ml obtained by Abdel-farid and El-sayed (2021) for Aduwa (*Balanites aegyptiaca*) tree parts extracts but lower than 6.400-47.400 mgQE/100g and 112.830 mgQE/g reported by Selouka *et al.*, (2020) respectively. Anti-oxidant properties of most medicinal plants are related to presence of flavonoids / phenolic compounds they contain (Selouka *et al.*, 2020).

Antioxidant Activity Analysis

Table 6 shows the results of DPPH analysis on *Balanites aegyptiaca* seeds oil samples, where sample 'WE' had the antioxidant activity of 97.571 µg/ml and sample 'SE' had activities of 3.954 µg/ml. A lower value of IC₅₀ represents higher antioxidant activity and vice versa as described by Mokoroane *et al.*, (2020) and Lahmadi *et al.*, (2022). Ascorbic acid was used as control sample and it shown higher antioxidant potential than the oil samples with value of 0.612 µg/ml. There is a significant difference between the DPPH potential of samples 'SE' and 'WE'. Various researches have demonstrated that the anti-oxidant activity of seeds and / or seed oils is greatly affected by their phenolic and flavonoid contents (Gagour *et al.*, 2022). The extent of anti-oxidant activity can be hindered by thermal treatment, the heating process during extraction of oil seeds were responsible for decreasing antioxidant scavenging activity of the oil, with total phenolic content of the same oil sample (Nivya *et al.*, 2022). Lahmadi *et al.*, (2022) in their study on a medicinal plant (*Euphorbia retusa*) parts, found the seeds to have anti-oxidant activity of 50. 790 µg/ml.

FRAP sample 'WE' determined showed a mean value of 33.630 µmolTE/g and that of sample 'SE' 65.540 µmolTE/g, were found to be higher than that of samples 'SE'. The ferric reduction antioxidant power (FRAP) is a test carried out to determine antioxidant capacity of a test sample by which the antioxidant presented in the samples were able to reduce an oxidant, that changes colour when reduced (Fe³ to Fe²). The extent of colour change degree is proportional to the antioxidant capacity of the test sample (Murthy *et al.*, 2021). Niyukuri, *et al.*, (2020) observed that the total phenols content correlated with antioxidant potential (FRAP) of some autochthonous wild plants of Burundi. *P. curatellifolia* had oxidant reducing capacity of 16.813 mg/100 g and *S. tragacantha* had 16.133 mg /100 g (Niyukuri, *et al.*, 2020), these are lower than (65.540 µmolTE/g obtained for sample 'SE' and 33.630 µmolTE/g for sample 'WE'. *M. arboreus* plant extract showed a lower reducing power of 115.31 mg/100g (Niyukuri, *et al.*, 2020) when compared to the oil samples in this study.

Vitamins Analysis

Vitamin A is an essential nutrient needed in little amount for proper functioning of the body, for growth and development such as embryonic development and immunity functions as reported by Aguebor-ogie, (2021). Deficiency of Vitamin A may lead to development of deficiency diseases such as night blindness, reduced immunity causing high susceptibility to infections, and increased mortality risk in severe cases. The retinol content determined in sample 'WE' were 613.350 µg/dl and sample 'SE' had 856.760 µg/dl. Significant difference were observed between the two samples and agreed with reported by Asouzu *et al.*, (2023). This showed that retinol was destroyed by thermal processing and the contents of retinol for fresh and reused oil were lower than retinol content obtained in samples 'WE' and 'SE' (Aguebor-ogie, 2021).

Table 5 carotenoid contents were determined to be 9693.1 µg/dl in sample 'WE' and 12188 µg/dl in sample 'SE'. The amount of carotenoid is higher in sample 'SE' than in sample 'WE' (Atta and

Mohamed, 2017). The values obtained were significantly lower than the carotenoid content of samples 'WE' and 'SE'. The stability of vitamin A in oil is greater than other currently used food fortification vehicles such as flour, sugar or corn soy blends.

Vitamin E is a fat-soluble antioxidant that is found in most vegetable oils. Vitamin E showed a strong antioxidant ability against lipid peroxidation and the scavenging of reactive oxygen species (Nivya *et al.*, 2022). Oil is a good source of vitamin E and this promotes its oxidative stability when compared to other vegetable oils (Norhayati *et al.*, 2015). Vitamin E is essentially required by the human body, it helps to prevent oxidative stress and tissue ageing (Gueye *et al.*, 2022). Vitamin E is adsorbed as fat component of food through the lymphatic system and released into the blood. Vitamin E deficiency occurs very rarely in humans, deficiency can result in the oxidation of polyunsaturated fatty acids which brings about damage, causing neurological problems (Admassu *et al.*, 2013). This value is very much lower than that obtained in this study. Asouzu *et al.*, (2023) and Nivya *et al.*, (2022) reveals that heating decreases the vitamin E content of vegetable oils.

CONCLUSION

In conclusion Aduwa (*Balanites aegyptiaca*) seed can be considered as a potential source of vegetable oil and also a good source for other important nutrients such as protein (18.760 %) and fibre (12.790 %). There were great variation in physicochemical properties of Aduwa seeds used compared with other studies due to differences in ecology as well as storage time and conditions etc. The oil samples extracted had similarities in physicochemical and vitamin contents and slight variations were observed between the samples mainly due to the difference in wet and soxhlet extraction methods employed. *Balanites aegyptiaca* seed oil are good source of fat soluble vitamins such as carotenoids and vitamin E. The quality characteristics of *Balanites aegyptiaca* seed oil in this study were comparable with other well known locally extracted and some branded vegetable oils from soybean, groundnut, sesame, sunflower, olive, and coconut. Utilization of *Balanites aegyptiaca* seeds for oil extraction would boost economy and uplift the living standards of Nigerians especially those living in the rural communities where this plant species is in abundance.

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