Variation in Morphological, Physical and Chemical Constituents of *Balanites aegyptiaca* Fruit between Geographical Sites

By

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Dedication

To my devoted husband and dear kids

Yusra, Amro, Zeinab and Mustaffa

To my precious parents, beloved brother and sister

With great love

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Abstract

Variation in Morphological, Physical and Chemical Constituents of *Balanites aegyptiaca* Fruit between Geographical Sites

The objectives of this work were to study the variation in morphological characteristics, physical and chemical constituents of *Balanites aegyptiaca* fruit according to shape and geographical locations. *Balanites aegyptiaca* fruits were collected from Abu Jibeiha Province, Southern Kordofan State (three different sites) and Dindir Province, Sinnar State. The size and weight of the fruit samples were measured; percentages of the fruit different parts were determined and chemical and statistical analysis were carried out to obtain the percentages of sugar, saponin, protein, oil and moisture content in the *Balanites* fruit.

There were significant differences between the four fruit shapes (oblong, elongate, spherical and oval fruits) in all of the studied morphological characteristics across and within sites and between locations. Fruit weight had the greatest variation among all fruit characteristics and fruit diameter showed the least degree of variation. The majority of fruits (300 fruits from five trees from each of the three sites) were oblong in shape (61%) and they were the largest fruits and had the greatest variation in fruit characteristics. Spherical (shortest) fruits had the least variation and they were the fewer

(7%). Elongate fruits were the longest fruits. The values of fruit weight for the four shapes were significantly higher in Abu Jibeiha than in Dinder location. Hejlij seeds also showed significant variation in the morphological characteristics. Fruit shape and location had significant effects on fruit physical (fruit layers) and chemical constituents. The highest average percentages of fruit layers obtained by fruit shapes were as follows: highest *epicarp (۲۵,۲%) by* spherical fruit, highest *mesocarp* (37.4%) by elongate fruit, highest *endocarp* (35%) by oblong fruit, and highest *kernel* (9.9%) by oval fruits. Abu Jibeiha location obtained the highest kernel percentage. The highest saponin content (4%) was obtained by oblong fruits while the highest invert sugar (40.9%) and oil content (44.9%) were obtained by oval fruits. Saponin average percentage obtained in Dindir location was double that obtained in Abu Jibeiha; the higher sugar percentage was obtained in Abu Jibeiha location. Protein content was found to be of higher content than that reported in the literature; it ranged between 49.6 (oval fruit) and 53.8% (oblong fruit). Moisture content was not significantly different between shapes and locations of a mean 9.3%. The amounts of sugar, saponin, oil and protein, were found in considerable percentages to introduce *Balanites* different types to the food and medicinal industries.

بسم ا   الرحمن الرحيم

Arabic abstract

ملخص البحث

التباين فى الشكل والتركيب الفيزيائي والكيميائي لثمار شجرة الهجليج بين المواقع الجغرافية

الهدف العام لهذا البحث هو دراسة الاختلافات في الشكل الخارجى لثمار شجرة الهجليج وتركيب الثمرة الفيزيائي و الكيميائى بينما كانت الأهداف المحددة هى دراسـة الاختلافـات فـي أشـكال وأحجام ثمار شجرة الهجليج لمعرفة تأثير شكل الثمرة عموما ومصدرها (الموقع) على صـفاتها المورفولوجية وتركيبها الفيزيائي والكيميائى (الأجزاء المختلفة). اعتمدت طريقة البحـث علـى جمع ثمار أشجار الهجليج من منطقتين هما محافظة أبو جبيهة - ولاية جنوب كردفان ، ومحافظة الدندر ولاية سنار. ومن ثم قياس حجم ووزن الثمار وايجاد نسب الأجزاء المختلفة ثـم التحليـل الكيميائى لايجاد نسب السكريات، الصابونين، البروتين،الزيت و الرطوبة فى الثمرة الى جانـب التحليل الاحصائى .

أوضحت نتائج البحث ان هنالك تباين واضح في أشكال الثمار فهي إما مستطيلة ، اقل اسـتطالة بيضاوية او مستديرة .هنالك اختلاف جوهري واضح فى وزن الثمرة بـين الأشـكال المختلفـة للثمار و الموقع ، بينما الاختلاف في قطر الثمرة هو اختلاف غير جوهري.

معامل الشكل (Shape Index) ذو اختلاف جوهري فى أشكال الثمـار الأربعـة (المـستطيلة والأقل استطالة والبيضاوية و المستديرة). الأغلبية من (٣٠٠ ثمرة من ثلاثة مواقع بواقع خمس أشجار من كل موقع شكلها أقل أستطالة وهي الثمار التي تظهر فيها الاختلافات بصورة واضحة وتمثل ٦١% بينما تمثل الثمار المستديرة أقل نسبة (٧%) و اقل اختلافآ.

الثمار المستطيلة هي الأكثر طولاً بينما الثمار الأقل استطالة تمتاز بكبر قطرها ووزنها ولكن لا تختلف اختلافاً كبيراً عن المستطيلة في الطول و معامل الشكل. الثمار المستديرة هـي الأقـصر. وتمتاز منطقة أبو جبيهة بالثمار ذات الأطوال والأوزان الأكبر كما أن هنالك تباين واضـح فـي أشكال البذور .

أن شكل الثمرة ومصدرها (الموقع) له تأثير واضح على تركيب الثمرة الفيزيائي والكيميائي حيث حازت الثمار المستديرة على أعلى نسبة في القشرة الخارجية (الطبقة الأولى من مكونات الثمرة)

بينما حازت الثمار الأقل استطالة على أعلى نسبة من اللب (الطبقة الثانية). أعلى نسبة من الطبقة الخشبية(الطبقة الثالثة) تواجدت في الثمار المستطيلة بينما أعلى نسبة من نواة الثمرة وجدت في الثمار البيضاوية.

الثمار البيضاوية تحتوى على اكبر نسبة من السكريات المتحولة (٤٠,٩%) و الزيت (44.9%) وهى الأقل نسبة فى محتوى السكروز (٣,٢٥%).

الثمار الأقل استطالة يحتوى لبها على اكبر نسبة من الصابونين حوالي ٤%وهى تقريباً ضعف الكمية الموجودة في الثمار المتسديرة. متوسط نسبة الصابونين في ثمار محافظة الدندر هى ضعف نسبتها فى ثمار محافظة أبو جبيهة. بينما نسبة السكريات هي الأكبر في ثمار منطقة أبو جبيهة.

متوسط نسبة البروتين بالنواة يصل إلى ٥٢,٢٢% وهى نسبة عالية ويوجد اختلاف بسيط بين الأشكال المختلفة للثمار وليس هنالك اختلاف بين المواقع. نسبة الرطوبة حوالي ٩,٣%. نسبة وجود هذه المكونات الكيمائية فى ثمرة الهجليج يؤهلها للمنافسة فى مجالات الصناعات الكيمائية و الدوائية وصناعة الأطعمة.

Chapter One
Introduction

1.1. Back ground

Balanites aegyptiaca (Hejlij) of the Family *Balanitaceae* is a small to medium size tree (Figure 1.) that varies in height from 7m (El Ghazali *et al*. 1997) to 15 m and in diameter from 30 to 50 cm (Thirakul 1984). It is an ever green tree (Suliman and Jackson 1959). The leaves are bifoliate, alternate (Thirakul 1984) and they vary greatly in size (Al Amin 1990). Inflorescence is subaxillary clusters (El Ghazali *et al.* 1997). Flowering is in November and April (Von Maydell 1986 and Thirakul 1984). Fruiting is in December and January and from March to July.

The tree produces about 125 kg of ripe fruit, which resembles date fruit in size and appearance (Ecky 1954). The fruit is drupe, oblong, elliptic, olive or egg-shaped, about 2.5-4.0 cm long and 1.5-2.5 cm in diameter (Thirakul 1984, Von Madell 1986 and Sahni 1968). It is green and shortly velvety when young, turning yellow and glabrous when ripe and of stringent and bittersweet mesocarp.

Balanites aegyptiaca is widely spread throughout Sudan and Africa; absent only where rainfall is over about 1100 mm. It usually grows under rainfall varying from 200-800 mm per annum and in sand, clay, cracking clay and gravel soils. It occurs in pure stands or associated with *Acacia seyal.* (Suliman and Jackson 1959). The deep-rooted trees of this species live for 75 years in average and can live for more than 100 years (Ecky 1954).

Balanites aegyptiaca wood is used for furniture and firewood. Seeds are used for rosary beads, necklaces and in the game of '*seiga*' played in Sudan. Flowers and leaves are used as food in Africa. The fruit is edible and the maceration of the fruit is used against constipation and as anti-diabetic (El Ghazali *et al.* 1997). The sapogenin, yamogenin and diosogenin, which are extracted from all parts of the plant, are used in partial synthesis of steroidal drugs (Vogt 1995). A soap substitute is locally made of saponin extracted from the root, fruit and barks and it is used in washing clothes (Mbuya *et al.* 1994). The bark extract is used for toothaches and against stomachs; heartburn and malaria (Von Maydell 1986; BuySomali.com. 2003; AOAD 1988). The powdered leaves and bark are used to enhance wound healing and for wound cleaning (AOAD 1988; El Ghazali *et al.* 1994). The fruit is used in treatment of stomach complaint, epilepsy, sterility, and it is used for sex hormones production (Vogt 1995). The emulsion of the fruit is used for treatment of wells and water supplies and as a fish poison (Suliman and Jackson 1959). The boiled extraction of the bark is used for jaundice

Figure1. ***Balanites aegyptiaca*** **Tree**

treatment (Mohamed *et al.* 1997). The kernel cake and oil are edible. Oil is applied for rheumatism (Maydell 1986) and is also used to treat skin diseases and sores on camels (Suliman and Jackson 1959). The root, bark, and leaves are purgative and act as vermifuge (Broun and Massy 1929).

Balanites aegyptiaca fruit is composed of four layers. The outer shell layer is known as epicarp and forms about 19% of the fruit. It is followed by the fleshy soft wall mesocarp (30%) and then by the hard stone endocarp (50%) in which, the seed kernel (10%) is embedded (Von Maydell 1986).

Fruit constituents are protein, sugars, saponin, vitamins, mineral acid, and stable oil (Suliman and Jackson 1959; Elamin 1979). Oil and protein are the two major constituents of the kernel (Mohamed *et al*. 2002), while saponin and sugars are the major component of the fleshy pulp (mesocarp). All parts of the tree even the kernel yield saponins, which they are glycosides or steroidal alkaloids, found in plants and marine animals and referred to as natural detergent of foamy nature (Harpe 1980). Saponins of *Balanites aegyptiaca* are found to be diosgenin and yamogenin; both of which are used in the partial synthesis of steroidal drugs. The two compounds are considered to be important raw material for a wide range of industries. According to their diverse biological activities, they play important role in pharmaceutical properties, food and animal feed stuff and are also used in fermentation and soap making. (Eltohami 1999).

1.2. Justification

In the Sudan there had been previous studies on benefits and chemical constituents of *Balanites aegyptiaca*. Abu Al Futuh (1983) showed that about 400,000 tons of *Balanites* fruits could be obtained annually from Sudan. This would enable the production of large quantities of ethanol, carbonic acid, amylic acid, diosgenin, oil and fuel wood from residues. All these products may offer a net profit of about $ 25 million per annum and the natural resources of Sudan can cover about 50% of world demand of steroid materials Abu Al Futuh (1983). The main potential of *Balanites* industrial utilization lies in extraction of the group of chemicals known as saponins (www.aun.edu.eg/community). Saponin of *Balanites aegyptiaca* can be extracted by simple method. It can yield about 98.95of saponin content in mesocarp and this saponin is of high purity and suitable to be used in pharmaceutical industry e.g. as starting material for preparing cortisones (Abdel Hafeez 1999). The tree is described as an unutilized raw material potentially ready for agro-industrial exploitation (Abu Al Futuh 1983) and a useful tree, which deserves greater recognition (Vogt 1995). El feel (2004) reported that the evidence of current and future environmental and socio-economic potentials and values of *Balanites* was emphasized by its multiple uses, wide occurrence and drought tolerance. Therefore protection and conservation of this species are needed, to secure steady supply of fruits to *Balanities*-based industries (Elnour 1994). Taking in consideration that this valuable natural resource is threatened by the continuous felling for many purposes, especially as results of expansion in crop production and in Sudan *Balanites aegyptiaca* is considered as an endangered species (Warag *et al.* 2002; Elfeel 2004) so the preservation of the wild gene pools of this medicinal plant was highly recommended.

Balanites aegyptiaca, which was described as an all-purpose tree for Africa, it offers food and income (FAO 1985). It is a multipurpose tree, of wide range of uses and distribution, of great potential in the tropics, with considerable amounts of oil, sugars and protein. Rich with the most important saponin products which are subjected to continuous studies to expand the scientific understanding of the health benefits of saponins for both human and animal, and it was indicated that saponins are the plants active immune system (herbs 2000. com.). According to scientific evidence the steroidal and triterpenoid saponins have wide biological effects and considerable potentials in improving human health. Saponin material is found in all parts of *Balanites* with considerable amounts, and if the tree will find more attension and care, further researshes and studies, and cultivation on a large scale, it could represent an important source for many chemical and phamaceutical industries, which will contribute in the rural development. Especially that if the pharmaceutical industry is developed and all stages of production is undertaken within the country, this would open up opportunity for jobs and simultaneously lower the prices of drugs, satisfying the market need, beside creating hard currency and saving considerable hard currency which is presently paid for import of similar drugs (Eltohami 1999). This, in turn, should increase the living standards of the population and improve welfare.

However, if more attention drawn to this tree, there will be a scientific foundation to establish industrial sector especially in areas where there is an abundance of the raw material. E.g. Abu Jibeiha Province, which is rich of *Balanites* trees and there had been an experience of oil and soap production, in the form of the small old factory of the oil and soap production in Abu Jibeiha. This factory must be rehabilitated and should be improved to continue the work in this line.

1.3. Research problem

Balanites aegyptiaca showed a wide range of variation in tree shape and crown, leaf shape and size and fruit shape and size (Von Maydell 1986; Mahgoub 2002). El Amin (1990) mentioned that leaves of the same or different seedlings were found to be variable in shape and size and range from linear, lanceolate to oblong, obovate or ovate. Also, there are significant differences in seed length between trees, indicating that, there are trees with long seeds and others with short seeds, irrespective of their geographical environment (Mahgoub 2002). It was assumed that narrow leaves are associated with narrow fruits. Mahgoub (2002) found that seed shape (elongate, oval, oblong and spherical) had an effect on germination, which was best in oblong fruits. She recommended that further studies are needed. Elfeel (2004) noted that natives in Kordofan believe that Hejlij trees are largely variable between and within soil types.

This significant variation in the morphological features of *Balanites aegyptiaca* fruit (Figure 2) may be accompanied by variation in the chemical constituents of the fruit. The oil produced from *Balanites* kernel was found to be ranging from 19.8% (Elfeel 2004) to 58-60% (Suliman and Jackson 1959; NAS 1983; Buy Somali. Com. 2003). Protein content varies from 26% (Abu Al Futuh 1983) to 51% (Adam and Lescot 1972). Abdelmutti *et al*. (1954) reported that the *Balanites* fruit mesocarp contains about 36.5% sugars while Abu Al Futuh (1983) reported that sugar reaches up to72%. The fresh mesocarp was found to contain 2.5% saponin (Babiker 1983), which differed greatly from the value of 7.2% reported by Watt and

Brandwijk (1962). So it is assumed that, there may be some kind of effect of fruit morphology on the physical composition and chemical constituents of *Balanites aegyptiaca* fruit according to fruit shape and tree location.

1.3. Objectives of the study

The main objective of this research was to study the variation in morphological characteristics, physical and chemical constituents of *Balanites aegyptiaca* fruit. This is expected to help in identifying the potential of using the fruits of this species in the chemical and food industries. The specific objectives were

- To study the variation in fruit size and shape
- To investigate the effect of fruit shape and tree location on fruit, morphology, physical composition (parts/layers) and chemical constituents.

Figure 2. Varaition in *Balanites aegyptiaca*

Chapter Two
Literature Review

2.1. General description

Botanic name: *Balanites aegyptiaca*

Family: Balanitaceae (previovsly placed in Zygophyllaceae, Simaraoubaceae) (NAS 1983).

Synonym: *Ximenia aegyptiaca L.*

Other names (Vernacular names):

Arabic names: Hejlij, fruit Lalob; in Egypt: known as shashut, in Somalia Called 'ghot', 'god', 'gut' and 'quud' (Buysomali.com. 2003); in Chad: Arabic leaves, *Hidjilit.* in Hausa: *Aduwa*. in Kanuri: *Bizo*, *Bito (*Abdelmuti *et al*. 1954).

English names: Desert date, soap berry tree, Jericho, balsam and thorn tree.

French name: Dattier du desert, Hague leg, Balanit d' Egypt.

Local names: Shashoba (Adendowa and Bisharin), Tau, Tu (Dinka, Shlluk, Jur and Nuer), Saronga (Golo), Q-og-g-ogat (Beni Amir), Loba, logba (Madi and Lugbari), Kurak (Nuba, J. Dair), Tira (Nuba, Dilling and Ghulfan), Kuri (Nuba j Elliri), Kha, go (Hamej), (Suliman and Jackson 1959).

2.2. Varieties

There are five varieties of *Balanites aegyptiaca* distributed throughout Africa (Sands 2001).

- Variety *aegyptiaca:* distributed throughout most of Africa. This is the only variety recorded to appear in Sudan (Elfeel 2004).
- Variety ferox: Occurs at the western extreme of the Sudano –Sahilian belt.
- Variety pallida: Found in Somalia and Ethiopia.
- Variety quarrei: Present in Zambesia and Zambia.
- Variety tomentosa: Occurs in Tanzania.

2.3. Habit

Balanites aegyptiaca is an evergreen species, which loses its leaves only during very dry period (Suliman and Jackson 1959). Sometimes it is semi deciduous. It is easily recognized, either by its drooping branch lets, or by its longitudinal-fissured bark, with a fluted bole and the simple straight prickles distinguish this species from *Balanites wilsoniana* (Thirakul 1984). It is small to medium size tree, varies from 7m (El Ghazali *et al*. 1997) to 15m high, 30-50cm in diameter (Thirakul, 1984). The crown is spreading usually with dense drooping vertical green branch let (Thirakul 1984). It is spherical or irregular (subject to the site condition, age and treatment) (Sahni 1968).

Branches are obtuse, spreading at the ends; very flexible, green with grey lenticels, very branched and mostly crooked. Bole straight, short, fluted, slightly enlarged and fluted at the base (Thirakul 1984).

2.3.1. Bark

It is grey to dark brown, yellowish gray in drier regions, with long deep vertical fissures, in which the yellow color of new bark can be seen (Thirakul 1984). Scales are long, thick, prominent and ragged; slash pale yellow. Thorns are stout, green, straight with a brown tip up to 5cm long, directed foreword alternative in the axis of the leave, are often of 8cm long (Sahni 1968, Mbuya *et al.* 1994 and Vogt 1995).

2.3.2. Leaves

They are bifoliate, alternative; consist of two leaflets on a short petiole 1-1.5cm long, slightly flattened, thin glabrescent or puberlous (Thirakul 1984). Leaflets subsessile, obovate to orbiculate-rhomboid, 0.7-5cm long and 0.4-4.5cm broad, pubescent beneath, then glabrescent (Sahni 1968). They are green with gray lenticels varies greatly in size, green in color, usually 2 -5cm long, by 1-2.5cm broad, ovate to rhomboid, entire, and nerve prominent (Von Maydell 1986). Leaves sometimes are considerably larger and evergreen and it sheds a lot of leaves in the dry season (Sahni 1968).

2.3.3. Flowers

Inflorescence supraxillary clusters up to 2cm long and pedicels up to 1cm long (El Ghazali *et al*. 1997). Flowers are yellow green, about 1.3 cm across, sepals 5, deciduous, petals 5, about 0.5cm long, disc is fleshy covered with white hairs (El Amin 1990). Flowering occurs in November and April (Von Maydell 1986 and Thirakul 1984). Flowers are of a good taste for honey production (Dafaalla 2001).

2.3.4. Fruit

It is drupe, oblong, elliptic (ellipsoid), about 2.5cm in diameter and 3-4 cm long. Fruiting is in December to January and March to July (Thirakul 1984). In the Red Sea Hills, fruiting is in August (Sahni 1968).

2.3.5. Wood

Wood is pale yellow or yellowish brown, fine- grained, hard, tough and heavy specific gravity about 0.65 (Von Maydell 1986). In transverse section the rings are distinct as wary light lines; the pores are small, open and in little groups in concentrated rings; the rays are clearly visible as light lines of various overlapping lengths and in radial section adding a figure to the wood (Suliman and Jackson 1959). The wood is termite resistant (Mbuya *et al*. 1994). The charcoal has high calorific value, about 4.600 kcal / kg (Vogt 1995).

2.3.6. Roots

This tree has deep tap root system. Roots are shallow, wide spreading and lateral with a narrowly branched taproot, which may penetrate several meters to the water table (NAS 1983).

2.4. Distribution and habitat

Balanites aegyptiaca occurs in a wide ecological range from the Saharan, through the Sahelian and Sudanian zones and Sudan is a major producer of ***balanites*** as is Nigeria (Buy-somali.com. 2003). *Balanites* trees are found in most arid to sub humid tropical savannas of Africa, all over the sahel and on coast line of Senegal to the Red Sea and Indian Ocean and the Arabian Peninsula (Von Maydell 1986). It is also found in the drier region of northern Africa, from Mauritania through Nigeria, and the French West Africa to Egypt; in the drier parts of Kenya, Uganda and Tanganyika and in Palestine and Arabia (Suliman and Jackson 1959). *Balanites aegyptiaca* is widely distributed in Sudan (Figure 3.); the main belt of hejlij in Sudan lies within the low rainfall savannah (Badi *et al.* 1989). It is found mostly in the dark cracking clay soil, on nun water receiving sites under rainfall of 500mm and upwards, commonly associated with *Acacia seyal* and usually occurs scattered sporadically among it, but also often forms pure stands, being absent only from the wettest parts, rainfall over about 1100mm; though in dry areas it is confined to water receiving sites, such as wades and riverbanks (Suliman and Jackson 1959, Von Maydell 1986). In fact there are few types of soils from which it is absent, it occurs on the Red Sea coast, up to the northern frontier of the Sudan, in the flood region of the upper Nile Province, it is more tolerant of flooding than *Acacia seyal*, in sandy soils it is more sporadic and tends to occur as scattered trees only, found on fringe of the ironstone in the so-called (gok) region; it also occurs on hard surfaced sandy clays and it is particularly common on the detritus slopes at the foot of rocky hills (Suliman and Jackson 1959).

2.5. Environmental requirements

2.5.1. Soil type

It grows on different kinds of soil; sands, clay, cracking clay, alluvial soils, gravel and skeletal soils (Von Maydell 1986). However on sandy soils it grows poorly, and only scattered trees occur; it is sensitive to salinity and does not tolerate prolonged water logging (NAS 1983).

2.5.2. Rain fall

Rain fall ranges between 200-800mm, in areas of lower rainfall; it requires a high water table and initial irrigation (Vogt 1995). It grows well in valleys with available ground water and on riverbank (Von Maydell 1986).

2.5.3. Altitude

The latitudinal range of the tree is from 380 m below sea level to 1500 m above sea level (Vogt 1995). It grows on depressions, on the foot and slope of rocky hills, up to 1.500m above sea level, in East Africa, usually it is found mixed with *Acacia seyal, Acacia tortilis* and other species, also it is found forming pure stands (Von Maydell 1986).

2.5.4. Temperature

The Tree is found in areas with mean temperature about 20-30 C (Buy.Somali.com. 2003). It tolerates high temperature up to 40.5 C (NAS 1983).

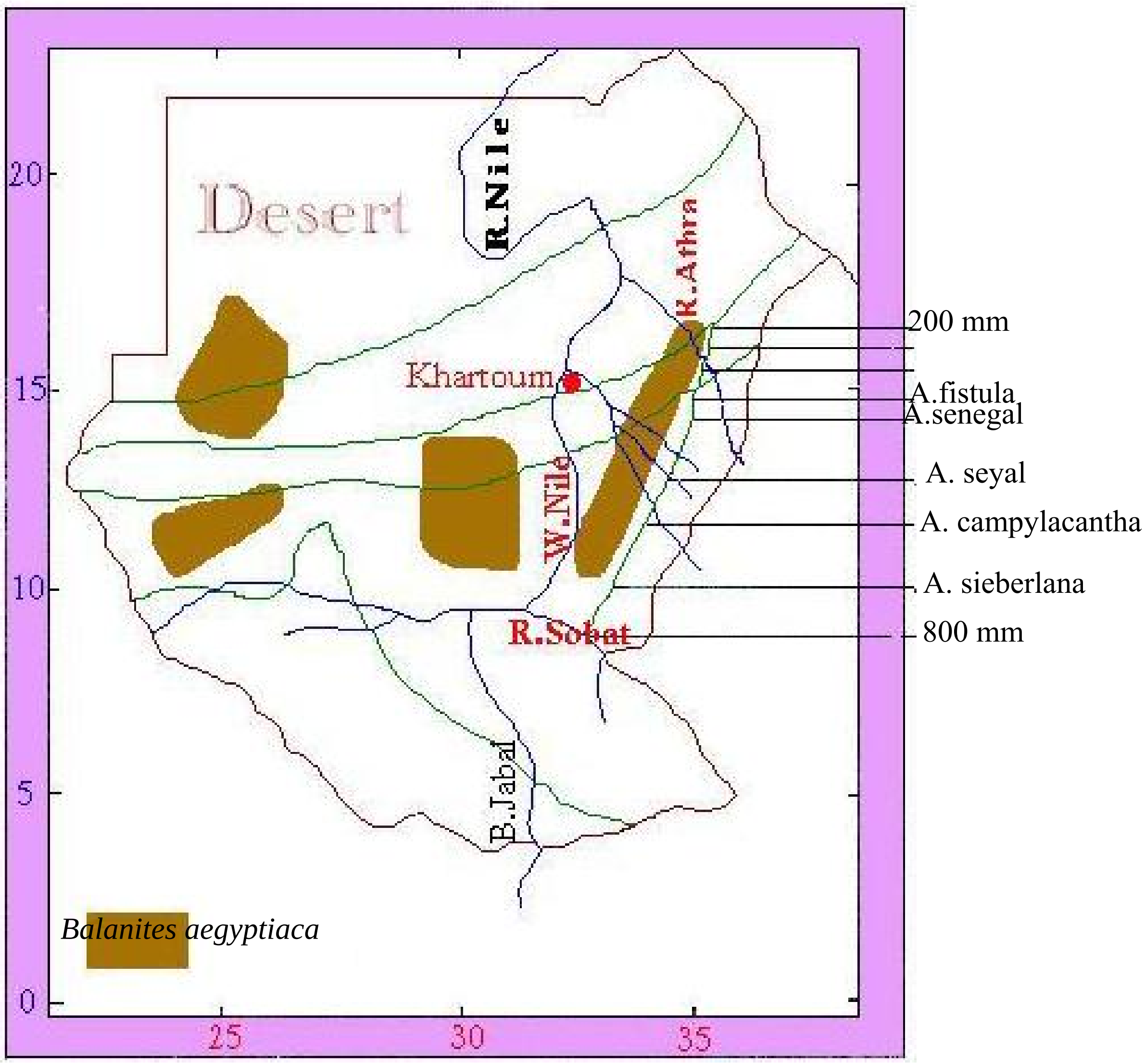

Figure 3 Distribution of *Balanites aegyptiaca* in Sudan

Adapted from Journal of agric. science Vol. 2 No.2. U of K 1994

2.6. Silvicultural characteristics

Hejlij is semi deciduous; it drops parts of its leaves during the dry season, but it always retains some leaves and ecologically it is a very flexible species (Suliman and Jackson 1959). It is one of the few species in the clay plain that sends its roots to depths of several meters. Due to its deep taproot, it is draught resistant, and it is grass fire resistant because of its thick bark (Von Maydell 1986).

2.6.1. Pollination

It is both self- and cross compatible. Cross-pollination is mainly by flies and bees (Mohamed *et al*.1997).

2.6.2. Fruits dispersal

The fruits, which are indehiscent and edible, specially the sticky mesocarp, are widely dispersed by animals, human being and birds. The endocarps are indigestible (Mohamed *et al*.1997).

2.6.3. Propagation and management

Regeneration is usually by seeds; also the tree coppices and pollard slightly (Suliman and Jackson 1959). Artificial regeneration is mainly by direct sowing of seeds at the end of the dry season (July), covered with soil, and a small microcatchment is suggested, for areas with high runoff; root suckers and cuttings may be used for propagation (Vogt 1995: Mahgoub and

Daffaalla 1996). El Nour (1994) reported that the natural regeneration of Hejlij on clay soil of central Sudan is possible, both by natural seedlings (53.3%) and by coppicing (46.7%).

2.6.3.1. Seed treatment

Seeds should be treated by washing of the fruit flesh or it can be eaten, none is needed when fruits and seeds are sown in summer or autumn, in winter seeds are soaked for 24 hours, at room temperature (NAS 1983). El Nour and Massimo (1995) reported that, the sugary mesocarp delays the germination and the epicarp inhibits it. To enhance germination seeds should be treated by, soaking in sulphuric acid for 1 hour or shallow nipping opposite the hilum side, at the narrow end (Mahgoub and Daffaalla 1996). Seeds should be sawn horizontally to avoid delay or suppression of germination, as the shoot height and number of leaves should be affected (El Nour and Massimo 1995). Seeds can be sown directly into polythene bags. Seed viability is high and usually germinates to a potential of 80-85% without treatment but it takes a long time to complete germination, about 6 weeks or more (Mahgoub and Daffaalla 1996).

2.6.3.2. Field operations

Initial protection is required (Vogt 1995). In the first three years it must be protected from fire and animals, so as to ensure the survival of the plantation, high grass and other shading materials impede regeneration and should be removed from the planting site, where direct seeding is undertaken. The spacing for planting depends on future use, less than 1 m for hedging and more than 10m in open grazing land (Vogt 1995). The tree grows slowly and according to some trials, coppice shoots have reached a range from 1 to 5 m in height at age range from 2-8 years (NAS 1983 and Von Maydell 1986). First fruit yield may be expected after 5-8 years of age, with yield increasing up to 25 years of the tree age (Mahgoub 2002). The tree can attain an age of more than 100 years (Von Maydell 1986, Mahgoub and Daffaalla 1996). *Balanities aegyptiaca* when established well, is very resistant to all damage and injuries, and has an excellent persistence (Von Maydell 1986).

2.6.3.4. Seed and fruit yield

The *Balanites* tree lives for more than 100 years, three quarters of which is productive with an annual ripe fruit yield of 125 kg (Buy Somali.com. 2003). A mature tree may produce 8000-10000 fruits a year (Mahgoub and Daffalla 1996 and Von Maydell 1986). Suliman and Jackson (1959) reported a little amount of fruits/kg, 70-100. Mahgoub and Daffaalla (1996) reported that there are about 280 seeds on average per kg which can produce 210 seedlings and seeds differ widely in size and weight. Mbuya *et al*. (1994) reported that seeds per kg are about 600-1000 and they are very susceptible to attack by insect borer. Seeds removed from fruit (stored dry and insect free) can be stored for up to a year (Mbuya *et al*. 1994).

2.7. Limitations

The desert date is thorny, very slow growing and it is usually browsed by animals when young (NAS 1983). In Sudan, the species has been subjected to severe felling, for different purposes (Mahgoub and Daffaala 1996). It is considered as endangered species (Warrag *et al*. 2002)

2.8. Fruit morphology

2.8.1. Description

The fruit is edible for both man and animal. It has a gummy bittersweet pulp, surround a hard pointed seed 4x2 cm (Mbuya *et al*. 1994).

2.8.1.1. Shape

Fruits are drupe, oblong, elliptic (ellipsoid) (Von Maydell 1986, and Sahni 1968). Fruits are date like, both ends rounded (Mbuya *et al*. 1994). It is Drupe, oval, pear- shaped (Mohamed *et al*. 1997); olive or egg shaped, resemble yellow dates when ripe (Vogt 1995; Von Maydell 1986 and Sahni 1968).

2.8.1.2. Size

The fruit is about 2.5cm in diameter and 3-4 cm long (Thirakul 1984), 3-4 cm long (Von Maydell 1986), 5cm long and 1.5-2.5 cm in diameter (Mbuya *et al*. 1994) and up to 5x2.5 cm (Mohamed *et al.* 1997).

2.8.1.3. Weight

The single fruit has an average weight of 10-15g (Von Maydell 1986). Elfeel (2004) reported that fruit weight showed significant variation between provenances; it ranged from 452.3 g/50 fruits for Dindir (clay soil) to 227gm/50 for Id Elfrissan in Darfur (sandy clay loam soil), giving number of whole fruit /kg of 110.63 to 220.31 kg; the higher fruit weight was found in clay soil and relatively higher rainfall. He also mentioned that, the fleshy pulp mesocarp showed significant variation between provenances, giving a range of 290.06 to 106.8 g/ 50 seeds.

2.8.1.4. Color

It is green shortly velvety when young, turning yellow and glabrous when ripe, smooth or wrinkled (epicarp) with a yellow brown sticky edible flesh and a single hard stone (Thirakul 1984). A leathery wrinkled epicarp covers the yellow brown mesocarp, which is of a stringent and bitter sweet taste in which, is embedded a hard pointed woody endocarp surrounds the kernel (Von Maydell 1986).

2.8.2. Fruit composition

The fruit is composed of four layers (Figure 4.):

Epicarp: The outer layer, leathery, smooth or wrinkled (Appendix figure 1)

Mesocarp: Middle part, yellow brown, sticky flesh, oily, gummy with bitter sweet taste (Appendix Figure 2)

Endocarp: Inner part, hard pointed woody and surrounds the kernel (Appendix Figure 3)

Seed (kernel): Ovoid, testa sub-fibrous, non- endospermic (Mohamed *et al.* 1997) (Appendix Figure 4).

Abdel- Rahim *et al.* (1986) reported that, the brown outer skin consists of a sticky pulp within which lies the oil bearing seed or nut. The fruit typically consists of 21.8% outer skin, 30.7% pulp, 36.7% shell and 10.8% kernel on a dry basis. Von Maydell (1986) reported that the fruit composition is bout 50% hard woody shell (endocarp), 30% soft fruit flesh (mesocarp), 10% oil seed (kernel) and up to 10% the outer skin (epicarp) and other smaller parts. Elamin (1979) reported that, about 19% outer shell epicarp, 31% pulp wood flesh mesocarp, 40% nut hard woody shell endocarp and 10% kernel. Elfeel (2004) reported that, pulp and epicarp form about 53% of the total fruit weight and 35% and 15% represented by hard woody shell and kernel, respectively.

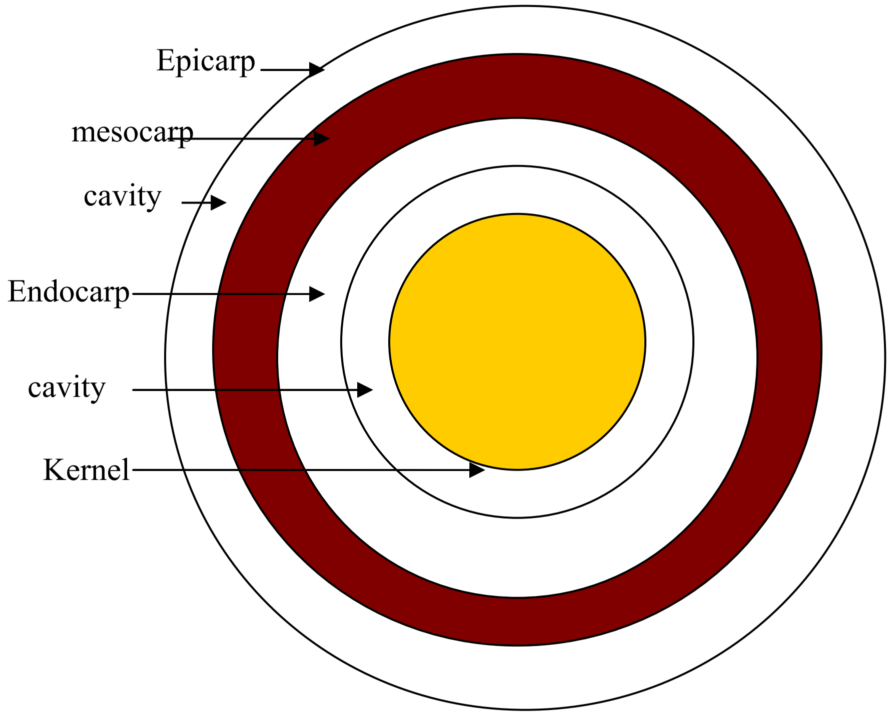

Figure 4. Cross section explains *Balanites* fruit layers

2.8. 3. Kernel hardness and processing

Mohamed *et al* (2002), found that the hardness of *Balanites aegyptiaca* kernels was high (10.4×10^5 N/m^2). The nuts are shelled to release the kernel. Every ton of whole fruit processed yields half a ton of hardy woody shell, which is highly combustible and produces a high quality charcoal (Buy-Somali. Com 2003). The pre-treatment of shelling has been noted as a problem, so it is efficient to saw the nuts in half to release the kernel (Hardman and Sofowora 1972).

2.9. Chemical constituents

2.9.1. Whole plant

All parts of the plant even the kernel yield sapogenins; diosogenin and yamogenin, both of which are used in the partial synthesis of steroid drugs (Vogt 1995).

2.9.2. Fruit

Oil and protein were the two major constituents of the kernel (Mohamed *et al.* 2002), while saponin and sugars are the major component of the fleshy pulp (mesocarp). The alcoholic extract of pulp and kernel showed that sterols, terpenes and saponins were the main natural compounds in the pulp and kernel and tannins, alkaloids and resins were slightly smaller amounts (Abdel Rahim *et al.* 1986). The pulp mesocarp contains 40% sugar and a saponin like substance, which forms a soapy lather with water (Suliman and

Jackson 1959). Phytic acid content was relatively high compared to other legumes; in contrast, antitryptic activities of the kernel flours were very low (Mohamed *et al*. 2002).

2.9.2.1. Protein

The kernel has a high oil and valuable protein content (Eltohami 1999). The kernel cake which was produced from *Balanites* fruit was characterized by high protein content (36.8%) and low crude fiber (5.9%) content (Elkhidir *et al.* 1983). The highest protein content was (27%) reported by Adam and Lescot (1972) and after oil extraction it reaches a range of 49 to 51%, which is not different from that (50%) reported by NAS (1983). Others reported different protein contents, 38.7- 41.2% Elfeel (2004), 32.4% (Mohamed *et al*. 2000 and 2002), 26-30% (Abu El Futuh 1983), 27.5% (Abdelmuti *et al.* 1954). In African regions *Balanites aegyptiaca* kernel proteins can play a considerable role in human and animal feeding and acts as alternative protein source where protein deficiency in nutrition is familiar. Mohamed *et al.* (2000) reported that, amino acid composition was high and the lysine content of the defatted kernel flour amounted to 74.2% of the recommended FAO, standard level in-vitro protein digestibility was found to be higher than of legume proteins; and in case of isoelectric precipitation followed by aqueous ethanol treatment both protein content (78.2%) and recovery (53.7%) were high.

2.9.2.2. Oil

Oil is obtained by simple cold press extraction. The kernel yields highly stable, edible, golden oil (Buy-Somali.com 2003). The oil extraction process produces oilcake, rich in protein and suitable for animal feed. The oil is yellowish in color (Appendix Figure 14). Kernel oil content showed wide range of variation. It varied from 19.8 -40% as was reported by Elfeel (2004) who justified this variation to the difference in ecological zones and locations. Oil content amounts to 46.5% (Abdelmuti *et al*. 1954), 46.8% (Sani 1968), 45% (Adum and Lescot 1972), 38 to 58% (NAS 1983 ;Suliman and Jackson 1959), 50% (Abu-Al-Futuh 1983), 49% (Mohamed and Spiess 2002), 44-51% (Mohamed *et al*.1997) and the higher oil percent (60%), was reported by Buy Somali. Com. (2003).

2.9.2.2.1. Oil characteristics

The characteristics of the oil are as follows:

(0.92) Specific gravity, (1.4) Acid value, (186.5) saponification value, (98.2) Iodine absorption, (98.6) Hehner value (Suliman and Jackson 1959).

2.9.2.2.2. Oil composition and recovery

The oil is composed mainly of triglycerides and with small quantities of diglycerides, phytosterols, sterolesters and tocopherols (Mohamed *et al.* 1997). The fatty acids were found to be palmitic acid about 14.5%, stearic 12.9%, oleic 34.7%, and linoleic 37.9%; other functional groups were found (Elamin 1979). Specific gravity of oil at 100 C 88919. Saponification value 186.5. Iodine absorption 99.2. Melting point about 8°C (Abdelmuti *et al*. 1954). Mohamed *et al.* (2002) reported that oil recovery obtained as a function of pressing time, pressure, temperature and particle size was 79.4% and the reduction of particle size had a negative effect on oil recovery under the same conditions.

2.9.2.3. Sugars

Balanites aegyptiaca fruits, from Sudan were reported to contain 38% sugars in the pulp, Nour *et al. (*1986).The pulp mesocarp contains mainly sugars (glucose, fructose, and sucrose) which make up a percentage of 68-72% (Abu Al Futuh1983). The percentage of sugar in the pulp amounts to 40% (NAS 1983). The sugar percentage is about 61.3% W/W as reported by Babiker (1983). The sugars of the mesocarp were found to be a mixture of Fructose and Glucose amounting to 56% of the weight of the mesocarp, plus a minor amount of sucrose (Elamin 1979). Abdelmuti *et al*. (1954), reported that, the fruit Sugars content were Sucrose (5.8%) dry, D-glucose (20.6%) dry and D-fructose (10.1%) dry.

2.9.2.4. Saponin

The chemical constituent of the whole fruit is the steroid yamogenin, diosogenin, in addition to the flavonoids isorhamnetin-3, rutinoside and 3-rhamnoglactoside (El Ghazali *et al.* 1997; Maksoud and El-Hadidi 1988). In the examination of alcoholic extracts of pulp and kernel reported by Abdel Rahim *et al.* (1986) the result showed that, sterols, terpenes and saponins were the main natural compounds in pulp and kernel, and tannins, alkaloids and resins were slightly smaller amounts. The same result had been reported by Elamin (1979) who found that, three mixtures A, B and C were obtained. He reported that they were proved to be mixtures of glycerides, sapogenins (mainly), fatty acids, sterols and unsaturated alcohol. The mother (fresh) mesocarp was found to contain 2.5%w/w saponin (Babiker 1983). As a result of the acid hydrolysis of the mesocarp and kernel; mixture A and C represent the acid insoluble mixtures respectively and mesocarp, showed a relatively high content of diosgenin (nearly 1.26% dry weight) in comparison with reports of 0.3% for an Egyptian source, it occurred as the sole sapogenin and was easy to isolate without the need for column chromatography (Dawidar *et al.*1985). Five saponins were isolated from the pulp and named as Balanitisnis A, B, C, D and E (Varshney and Janin 1979). Two other saponins named as Balanitisins F and G was isolated from the kernel (Varshney and Vyas 1982). Total saponin content was found to be 7.2% in the mesocarp and 6.7 in the kernel (Watt and Brandwijk 1962). On hydrolysis of the mesocarp and the defatted kernel with mineral acids, the saponins being glycosides, give sugar and aglycone the sugar of the saponins has been proved to be glucose (Dawidar and Fayez 1969) and aglycone a steriodal sapogenin (Marker *et al.* 1947). Later on, studies have shown that the steroidal sapogenin is a mixture of two epimers, diosogenin and yamogenin, which differ only in the conformation of the methyle group (Heftmann and Lloydia 1967). Infrared (IR) spectrophotometric analysis showed that 1% total steroidal sapogenin in the root, 0.7% in the stem bark and 1.2% in the soft fruit wall; also the elemental analysis of the sapogenin and its derivatives as well as mass, IR and Nuclear Magnetic Resonance (NMR) Spectroscopy data showed that the two epimers yamogenin and diosogenin occur in the stem bark and roots of *Balanites aegyptiaca* (from Tanzania) in the ratio of 2:1; which insure that, the major saponin in this plant parts is yamogenin (Brain *et al.* 1968, Hardman and Sofowora 1970). The physical and chemical analysis of characteristics and composition of *Balanites aegyptiaca* Kernels showed that, sapogenin contents of the full fat, defatted and testa flours were 1.5, 2.7 and 3.0%, respectively (Mohamed *et al.* 2000).

2.9.2.5. Percent of the fruit other chemical components:

Chemical composition of *Balanites aegyptiaca* fruit, as reported by Abdelmuti *et al.* (1954), was:

Amino acids (g [16g N]$^{-1}$): Aspartic acid = 5.1g. Threonine = 2.5g. Serine = 2.0g. Glutamic acid = 6.3g. Proline = 35.8g. Glycine = 3.3g. Alanine = 3.5g. Valine = 2.7g. Cysteine = 1.0g. Methionine = 1.0g. Isoleucine = 2.7g. Leucine = 4.1g. Tyrosine = 2.2g. Phenylalanine = 2.7g. Lysine = 1.6g. Histidine = 1.2g. Arginine = 2.4g. Sulphur = 0.10% (dry). Potassium = 0.04% (dry). Magnesium = 0.10% (dry). Calcium = 0.12% (dry). Na = 0.02% (dry). Zinc = 10mg/kg^{-1} (dry). Iron = 620mg/kg^{-1} (dry). Manganese = 3mg/kg^{-1} (dry). Copper = 2mg/kg^{-1} (dry).

Dry seed constituents:

Adam and Lescot (1972) reported that the dry seed constituents as a part from million as follows:

Dry seed constituents as a part from million (PPM):

CALCIUM	181PPM
PHOSPHOR	555 PPM
IRON	36.7 PPM
THIAMIN	68.1PPM
RIBOFLYEIN	73 PPM
NIASEIN	37.7 PPM

2.9.3. Leaves

The leaves and fruit contain disogenin (Eltohami 1999). Maksoud and El-Hadidi (1988) reported that, there were 6 diosgenin glycoside identified as quercetin 3-glucoside, quercetin 3-rutinoside, 3, 7, digluscoside and 3-rhamnogala-ctoside of isorhamnetin, were isolated from leaves and branches of the plant. According to the study that had been done in Nigeria, (leaves analysis) the data showed that, about 11.6% of the leave is crude protein, 4.2% ether extract, 13.6% fibers, 57.9% nitrogen, free extract, and 12.7 ashes (Suliman and Jackson 1959).

Leaves also contain 6 diosgenin glycosides as well as the fruit; and leaves and branches also contain 6 flavonoid glycosides (El Ghazali *et al.* 1994). The nutritive value of the leaves and twigs is as follows:

Crude protein 15%DM (6-24). Net energy 6.1 MJKg DM (5.5-6.2). Digestible protein 1 Fu 100(20-23b). P-0.11 (0.03-0.21) (Von Maydell 1986).

2.9.4. Stem bark

The overall chemical composition of *Balanites aegyptiaca* stem, as reported by Liu and Nakanishi (1982) showed that, three saponins (Yamogenin nucleus) known as Balanitisins 1, 2 and 3 were isolated from the East African specimen of *Balanites aegyptiaca*; also they reported that

Balanitisins 1and 3 are very similar and have only yamogenin as aglycone and that diosogenin is an artifact produced by the usual hydrolytic condition. El Ghazali *et al*. (1997) reported that the stem contains rotenone, coumarin and bergaptin and diosgenin ; in addition to the above saponins two other saponins were isolated and identified as the previously known saponin deltonin and protodeltonin. A furanocoumarin, bergapten and a dihydrofuranocoumarin, marmesin, were isolated from the chloroform extract of the bark (Ahmed *et al.* 1981). A new sesquiterpene named as balanitol was isolated from the bark of the Indian specimen (Cordano *et al*. 1978). A chloroform fraction of the stem *Balanites aegyptiaca* was chromatographed over a column of silica gel bark and yielded beta-sitosterol, bergapten, marmesin and beta-sitosterol glucoside. None of these compounds were active in either 9KB5 (in vitro) or PO388 (in vivo) systems (Seida 1979). The stem of the tree contains steroidal saponins made up of diosgenin, yamoenin and the other sugars glucose and rhamnose in ratio of 3:1, which have been shown to have an insect antifeedant and molluscicide properties (Jain 1987).

2.9.5. Stem wood:

Balantisin 1 was isolated from the stem wood of the Indian specimen (Varshney and Vyas 1982).

2.9.6. Root

The roots of *Balanites aegyptiaca* contain steroidal sapogenins, they contain rotenone and yamogenin (El Ghazali *et al*. 1997). Balanitisins 1, 2, and 3 are isolated also from the roots of the East African specimen (Liu and Nakanishi 1982).

2.9.7. Root wood

Balanitisin H was isolated from the root wood of *Balanites* (Varshney and Vyas 1982). Some studies of *Balanites aegyptiaca*, led to the isolation of five new steroidal saponins from the roots (http://www.ibismedical.com/ibis.html)

2.10. Uses

Hejlij is a very useful tree. It has a wide range of uses:

2.10.1. In food

2.10.1.1. Fruit

The fruit is eaten fresh or dried as desert date, unripe as Egyptian myrobalan, when ripe it has a bitter sweet pulp, it can be processed to produce multipurpose intermediate products, sometimes fermented to make an alcoholic drink. So it is a source of fermentation products e.g. ethanol (Von Maydell 1986). This fermentation usually increases the steroidal material in the fruit (AOAD 1988). *Balanites* fruit makes a refreshing beverage when macerated in water. According to local people in Kordofan, they extract the fleshy mesocarp, mix it with gum Arabic and make some sort of sweet called serney. Also they boil the kernel in continuous changes of water to di-bitter it and then should be eaten (kornaka). According to Abdelmuti *et al*. (1954), the de-bitter kernel should be eaten with sorghum. It is considered as a supplement to food products, like edible nuts, peanutbutter-like products (Von Maydell 1986). The kernel cake, after the extraction of oil, is a source of protein and carbohydrates for livestock (Abu Al Futuh 1983). In addition, it has been made into bread and soup. The yellowish oil, which is released by extending boiling of the kernel, is edible. In Sudan, it is highly prized by the natives, and would be extracted in much larger scale (Elamin 1979).

2.10.1.2. Leaves

Young leaves sprouts and green thorns are occasionally eaten as vegetables (Von Maydell 1986). Abdelmuti *et al*. (1954) reported that, in Kordofan and Darfor, green leaves are eaten in salads or cooked and leaves and fruits are eaten in Chad central, in Nigeria, fruit, seeds, oil, flower and resin are also eaten.

2.10.2. Traditional medicine and ethnomedical uses

2.10.2.1. Whole plant

Babiker (1983) described *Balanites aegyptiaca* as a tree containing diosgenin that affect different aspects of the activity of the female reproductive tract and used for gynecological purposes (interact with steroid sex hormone metabolism). He reported that *Balanites* fruits when compared with palm dates for ability to induce salivation were by far the more powerful siole. He also reported that *Balanites* crude saponin given to pregnant rats produced post-coital antifertility, in addition produced regression effect on the size of the implants. El-Sheikh (1994), reported that aqueous extracts from *Balanites* saponin were tested for toxicity to Schistosoma mansoni miracidia, cercariae and worms; most of these extracts/chemicals exhibited some miracidicidal and cercariacidal effects; this saponin mixture suitable for further testing as a plant molluscicide in field studies. He also reported that supplementary studies showed no synergistic molluscicidal effects occur between three already known molluscicides (niclosamide, tomatine and bergapten, furanocumarin).

The maceration of the fruit, leaves and seeds is used as a laxative and anthelemintic materials; it is used in the food, animal feed and pharmaceutical industry as a precursor (Eltohami 1999). All plant parts yield diosgenin that is an important source of steroidal drugs, like corticosteriods, contraceptives and sex hormones (Farid *et al*. 2002; FAO 1985). Currently science has begun to understand certain health benefits for the human body from the saponins. These health benefits include prevention of growth and viability of cancer cells, immunologicial support, effective cholesterol reduction, and anti-oxidant properties besides, heart strengthening (Malinow 1997). Also it is found that saponin is used in development of experimental vaccines against HIV which is responsible for AIDS (Cheeke 1997). The common use of saponins today is mainly as a cough remedy and for diuretics, in toothpaste as well as in gurgles, shampoo to fight dandruff and hair loss (herbs 2000. Com.); or as foaming agents in drinks; they are also used in fire extinguishers as a foam producer and in photographic emulsions and cosmetic preparations. Unlike the cardiac glucosides, saponins do not affect the heart. Saponins also result in the break down (hemolysis) of red blood cells (erythrocytes) and may be fatal when solutions are injected into the bloodstream of animals (Miller 1957).

2.10.2.2. Fruit

Hejlij fruit steroidal sapogenins are of interest and can be used as a starting material (precursor) for the synthesis of certain steroidal hormones (Miller 1957). It is used in traditional medicine, for treatment of stomach complaint, epilepsy, sterility, sex hormones and mental diseases (Vogt 1995; Farid *et al*. 2002; FAO 1985). In India, it is also used in curing some skin diseases, like leucodermia and it is used for syphilis, yellow fever and remifuge (Eldahawee 1996). Fruits and seeds are used as laxative and against bilharzia (El Ghazali *et al.* 1994). In north Kordofan, the maceration of the fruit is used against constipation and as anti-diabetic (El Ghazali *et al*. 1997). The macerated fruit had been mixed with millet to make porridge given to women, after childbirth and during lactation, to give them energy, strength and to increase milk production (Abdelmuti *et al*; 1954). In treatment of liver and spleen diseases (www.fao.org) and it has antheliminitic activity (Ibrahim 1992). The aqueous extract of mesocarp exhibit a prominent antidiabetic activity (Elshanawany *et al*. 1991).

2.10.2.3. Kernel

The kernel oil is released from the seeds by boiling and has many uses; it is used in the treatment of headache and influenza. The kernel is also used after childbirth and during lactation to release stomach colic and facilitate milk production (Abdelmuti *et al*. 1954). It is also applied for rheumatism (Von Maydell 1986). Oil also is used to treat skin diseases and sores on camels (Suliman and Jackson 1959). In Sudan, the kernel is de-bittered by boiling and change of water for many times, then it is used as snacks or mixed with honey and used to increase the male sexual drive and it is called kornaka (Elfeel 2004). Also local people used the kernel after some processing to cure hemorrhoids and Asthma and it was found very effective in curing fire wounds.

2.10.2.4. Leaves

Leaves clean malignant wounds (Mohamed *et al*.1997) and powdered leaves are used to enhance wound healing (El Ghazali *et al.* 1994).

2.10.2.5. Branches

They are used as fumigant for rheumatism (El Ghazali 1986) while shoots are chewed into a paste for dressing wounds (Mohamed *et al*.1997).

2.10.2.6. Bark

The bark is used for malaria and it is found that, the boiled extract of the bark is used to treat jaundice (Mohamed *et al*.1997). The bark extract is also used for toothaches and against stomachs (Von Maydell 1986; BuySomali.com. 2003). The powdered leaves and bark are used to enhance wound healing and for wound cleaning (AOAD 1988). The bark infusion is used to treat heartburn soar throats and as a remedy, for sterility, mental diseases, epilepsy, yellow fever and syphilis (Von Maydell 1986; BuySomali.com. 2003). Gum from the wood is mixed with maize meal porridge to treat chest complaints (www.fao.org).

2.10.2.7. Root

The roots boiled in soup are used to act against many diseases. The bark and roots are used as laxatives, and for colic, malaria, oedema, abdominal and stomach pains, and as a purgative (Buy-Somali.com. 2003; AOAD 1988; Eldahawee 1996).

2.10.3. Folkloric uses

A soap substitute is locally made of saponins extracted from the root, bark and fruit of Hejlij (Maydell 1986), which is used in washing clothes There is an emulsion made from the fruit, when add to the fresh water snails that transmit the debilitating and fatal disease like bilharzias Schistosmiasis (acting as intermediate host) is toxic and should kill it, also it is toxic to water flea Cyclops, which harbors guinea-warm and it is used for treating wells and water supplies (Suliman and Jackson 1959). This steroid material is very poisonous and can be used as fish poison (Von Maydell 1986). The toxin acts on the respiratory organs of the fish without affecting their edibility (Kirk 1954). This poisonous material was proved effective in killing Zebra mussels, which disrupt water flows by attaching themselves to pipes and other hard surfaces forming a major problem in North America (www.oregonstate.edu.). In India the nuts are made into crackers by drilling small holes, removing the kernel and filling them with gum powder (Wealth of India 1948). In Sudan Seeds are used as rosary beads, sibha and in siga playing. The unripe fruit, the root, bark, and leaves are used as a purgative and vermifuge and remedy for chills (Abdelmuti *et al*. 1954; Broun and

Massy 1929). Fat was used in perfumery in ancient times (Buy Somali.com.2003).

2.10.4. Industrial uses:

The kernel oil is used in various industries e. g. soap making (Von Maydell 1986). The sapogenin yamogenin and diosogenin which were extracted from all parts of the plant are used in partial synthesis of steriodal drugs. Diosogenin is an important source of steroidal drugs such as corticosteroids, contraceptives and those steriodal saponins of *Balanites* are used as a basic or intermediate raw material for synthesis of very important sex hormones, like progestrone, pregnenolone, cortisone and others which are cheaper than that extracted from animal origin (Vogt 1995; Farid *et al.* 2002). Elamin (1979) reported that, the amount of the two epimers (yamogenin and diosogenin) in the fruit is considered to be of commercial importance and can be used in many industries.

2.10.5. Other uses

2.10.5.1. Firewood

The wood makes excellent firewood and good quality charcoal (NAS 1983). The calorific value is 4.600 kcal/kg (Vogt 1995). The cellulosic shell of the products (after extracting the mesocarp), is a source of fuel (Von Maydell 1986).

2.10.5.2. Hedges and afforestation

The thorny branches are massed together to form lives hedging. The Hejlij tree, as it is a drought resistant, has been used effectively to stabilize sand dunes in India (Sharma and Gupta 1990). In Sudan it is used for afforestation, especially for rural people to provide shade and amenity (Mahgoub and Daffaalla 1996).

2.10.5.4. Wood

It is attractive and easily worked, fine grained, hard, compact, durable and resistant to insects (Vogt 1995; Broun and Massey 1929). It saws and planes well and is used for bowls, mortars and pestles, used for tool handles, gunstocks, cabin work and furniture (Von Maydell 1986; NAS 1983).

2.10.5.5. Forage

The young leaves, fruits and even the thorns are eaten by goats, camels and wild life. The branches with long spines and small leaves are much favored by giraffes (www.travelafricamag.com). It is considered as a browse of high protein (Billore 1990) and Dafaalla (2001) reported that the kernel contains protein of high amount of lysine, which is an important amino acid for man and animal nutrition.

2.11. *Balanites aegyptiaca* as a medicinal plant

Medicinal plants contain active chemical ingredients (phytochemicals) which are volatile oils, saponin, tannins, carbohydrates, lipids, resin and resin combination, sterols, alkaloids and glycosides (AOAD 1988; www.oregonstate.edu.) and these active ingredients have the physiological or medicinal effect. *Balanites* was recognized as a medicinal plant, containing these chemical ingredients. The most important materials are saponins, oil, carbohydrates and protein which are found in considerable amounts in *Balanites aegyptiaca*. Saponins, which are defined as natural detergent compounds found in certain plants, yellow to yellow-tan crystalline powder in appearance, are a steroid, or triterpene compounds of creamy, even foamy texture used for cleansing purposes (Miller 1957).

Balanites aegyptiaca is recognized as an important source for steroidal and triterpenoid saponins which have wide biological effects and considerable potentials in improving human health. Recent studies, which focus on the active chemical constituents of medicinal plants, indicate that saponins act as natural antibiotic (active immune system of the plants) (herbs 2000. Com). Saponin is an important compound which, had been subjected to a series of studies and its health benefits include prevention of cancer, immunologicial support and anti-oxidant properties (Cheeke 1997) and for the purpose of cholesterol control. Malinow (1997) reported that Saponin causes a depletion of body cholesterol by preventing its reabsorbing, thus increasing its excretion, as the other cholesterol-lowering drugs (cholestyramine). He also reported that, the blood cholesterol-lowering properties of dietary saponins are of particular interest in human nutrition; saponins act by binding with bile acids and cholesterol, so it is thought that these chemicals clean or purge these fatty compounds from the body and hence lowering the blood cholesterol levels and recent studies suggested that the low serum cholesterol levels of Masai tribes in East Africa who consume a diet that very high in animal products, cholesterol, and saturated fat are probably due to the consumption of saponin-rich herbs (http://www.ntsearch.com.). This is a great advantage of all parts of Hejlij tree (fruits, seeds, leaves and branches), which were considered as supplementary food in Africa.

2.12. Socio-economic aspects

Many people used traditional medicine and herbs as remedies. Nowadays medicinal plants are considered as primary health source for the pharmaceutical industry. Large quantities are used for the preparation of infusions and decoctions both in the countries where traditional medicine is still of great therapeutic, social and economic importance and in the production of important pharmaceutical products abroad (Eltohami 1999).

Ancient use of herbal extracts for medicinal purposes is developed and the current commercial value of drugs and pharmaceuticals derived from botanical sources is projected at twenty billion dollars a year on a global basis (www.oregonstate.edu.). There are many plants that are saponaceous, but only a few are known to contain appreciable amounts of saponin or have commercial importance. *Balanites aegyptiaca*, which lies under the category of wild medicinal plants in Sudan, can play a considerable role in food and income opportunities. Saponin material is found in all parts of *Balanites* and the amount of the yamogenin and diosogenin the most important compounds, found in the fruit is considered to be of commertial importance (Elamin 1979). In the Sudan there had been previous studies on benefits and chemical constituents of Hejlij, as a medicinal and promising tree. Dawidar *et al*. (1985) reported that *Balanites* tree grown in Sudan is an important source of diosgenin which is of higher percent compared with the percent reported from the Egyptian source. Abdel Hafeez (1999) reported that about 98.95% of high purity saponin content in mesocarp of *Balanites* fruit, can be extracted by foam method(not expensive), which is suitable to be used as starting material for preparing cortisones and other hormons. Abu Al Futuh (1983) reported that, about 400,000 tons of Balanites fruits can be obtained annually from the natural Hejlij forests of the former Kordofan, Darfor, Blue

Nile and Kassalla Provinces (Figure 4). This quantity enables the production of large quantities of ethanol (5 million gallons), carbonic acid (1500 tons), amylic acid (120 tons), diosgenin (1200 tons), oil (13,600 tons), Balanites cake (2,400 tons) fuel wood (200,000 tons) and residues (2,500 tons). These entire products offer 80 million dollars annually with a net profit of about 25 million dollars per annum and the natural resources of Sudan can cover about 50% of world demand of steroid materials . Blue Nile area alone could produce up to 100 000 tones of fruit annually from the million Balanites trees growing there to contribute in production of 14000 tones of oil annually (Abu Al Futuh 1983). The oil and seeds are being traded in small quantities in the international markets. According to (Buy Somali.com.2003) in early 2002, 100 ml of the oil was retailing at $ 20 in the USA. In Sudan, the de-bittered kernel one sack contains 22 malwa kernels and one malwa of de-bittered kernel earn about $ 16 in Saudi Arabia (Elfeel 2004), the kernel is exported to Saudi Arabia and Yemen, or sold locally by malimo tribes in Umdurman (Elfeel 2004). In Sudan, entrepreneurs could start businesses to process the oil and kernel for local and/or international markets. Community and nomadic groups could benefit from the business of extracting oil, fruit collection and kernel processing. *Balanites aegyptiaca* is one of those trees of great need to be cultivated as a commercial product. It is described as an unutilized raw material potentially ready for agro-industrial exploitation, valuable and highly recommended tree (Abu Al Futuh 1983; Vogt 1995).

Chapter Three
Materials and Methods

3.1. Materials

The material used in this study were *Balanites aegyptiaca* ripe fruits (about 7.5 kg) collected from two locations, namely, Abu Jibeiha and Dinder Provinces.

3.1.2. Instruments

- Vernier scale (digital)
- Metler P1200 balance
- House field Tensometer machine, type W 2 tons capacity. Maximum rate of loading 500 kgm
- Spectrometer model 6405 uv1vis (JENWAY) nm (544) (wave length)

3.1.3. Chemicals

Fehling solution (A) consists of hydrous cupper sulphate (blue color).

Fehling solution (B) consists of sodium-potassium tartrate, 346 gm in 100 gm of caustic soda, in one liter of distilled water (white color).

Saturated sodium hydroxide for neutralization; two indicators methyl blue as redox indicator, for assessing the end point; phenolphthalein white and concentrated hydrochloric acid.

Catalyst mixture 8 g as a tablet (96% anhydrous sodium sulfate, 3.5% copper sulfate and 0.5% selenium dioxide), concentrated sulfuric acid, boric acid, hydrochloric acid, sodium hydroxide and methyl red indicator.

Petroleum ether 40-60 °C boiling point as a solvent.

N-butanol, methanol, diethyl ether, anhydrous sodium sulfate, 8% (w/v) vanillin solution: 800gm of vanillin (reagent grade) dissolved in 10ml of ethanol (99.5% v/v, reagent grade), prepared freshly, 72 % (v/v) sulfuric acid: to 28 ml of deionized water, 72 ml of concentrated sulfuric acid (reagent grade, 95% w/w).

3.2. Methods

3.2.1. Sample Collection

Materials used *(Balanites aegyptiaca* fruits) were collected from two different locations, namely, Abu Jibeiha and Dinder. Abu Jibeiha Province is in Southern Kordofan State and it is located between latitudes 11° 45' and longitudes 31°.233' and its elevation is 543 m above sea level. The soil is silt clay and rainfall is 700 mm/annum.

Dinder Province (Sinnar State) lies between latitudes 12.600 and longitudes 35.033. Its elevation is 479 m above sea level and it is part of the low rainfall savanna zone. The soil is dark cracking clay. The rain fall is between 400-700 mm per annum.

Location (1): Abu Jibeiha Province samples:

Three sites were selected:

Site (1): Wad Abid village, about 25Km eastern Abu Jibeiha.

Site (2): Om Sagaa village about 35km southern Abu Jibeiha.

Site (3): Mujeigha village about 25km western Abu Jibeiha, Five trees were selected from each site, about 100 m or more apart. A fruit sample of about 1kg per tree was collected.

Location (2): Dinder Province samples:

Algulla village, Northern Dinder Province.

Draba village, Southern Dinder Province.

Elazaza village, Eastern Dinder Province.

Samples were collected from those three villages (about one kg of fruit sample per village) and bulked together unlike Abu Jibeiha samples, which were collected from each site separately. Then four fruit shapes (oblong. Elongate, oval and spherical shapes) were drawn from the whole group to be subjected to the morphological and chemical analysis to study the variation between the two locations.

3.2.2. Study of fruit morphological features

The variation in fruit morphological characteristics was studied

- across the three sites of Abu Jibeiha area (Wad Abid, Mujeigha and Om Saga villages)
- within each of the three sites in Abu Jibeiha area
- between locations (Dindir and Abu Jibeiha).

3.2.2.1. Variation of fruit morphology across sites and within sites in Abu Jibeiha

Description of the morphological features of *Balanites aegyptiaca* fruit included: Size and weight determination of each fruit for each shape, carried out as follows:

From Abu Jibeiha samples, twenty fruits from each of the five trees from each site (three sites) were selected to represent the four fruit shapes (oblong, spherical, elongate and oval shape) giving a total of 300 fruits. A digital vernier scale was used to measure fruit diameter and length and a three-decimal Metler P1200 balance was used to measure fruit weight.

3.2.2.2 Variation of fruit morphology between locations

Fifteen fruits were randomly selected for each fruit shape per location and were used to determine fruit size (length and diameter) and weight using the instruments mentioned above.

3.2.3. Determination of fruit composition

The fruit consists of four main parts: The outer shell (epicarp), the fleshy pulp (mesocarp), the endocarp (the hard stone) and the kernel embedded in the hard stone.

Ten fruits were taken from each fruit shape (oblong, spherical, elongate and oval shape) per location and the weight, diameter, and length of the fruit with epicarp (whole fruit) were found, then the epicarp was removed manually to find out diameter and weight of the mesocarp (fruit without epicarp), then the mesocarp was removed by dissolving in water, air dried for two days to find out diameter, length and weight for endocarp (fruit without epicarp and mesocarp) which had been broken by machine, to release the kernel, and to determine the breaking force. Lastly kernel was weighed out, and the following percentages were determined:

1-Percent of epicarp = (TW - MW) x 100 / TW

2-Percent of mesocarp = (MW – EW) x100 / TW

3-Percent of endocarp = (EW - Kernel weight) x 100 / TW

4-Percent of kernel = (Kernel weight / TW) x100

Where

TW: Total weight of the fruit.

MW: weight of fruit without epicarp.

EW: Weight of fruit without epicarp and mesocarp.

3.2.4. Seed characteristics

Seed length and diameter were measured using the instruments mentioned above. Shape index was calculated as the ratio of seed length/diameter. Breaking force of seed was determined using House field Tensometer machine. Diameter and length per ten fruits per four shapes were taken, and then each fruit was placed in the machine and had been broken widthwise, to find out the breaking force of seed per each seed shape.

3.2.5. Chemical ana1ysis

The objective was to identify the percentage of the major chemical constituents (sugars, saponin, oil, protein and moisture content) of *B. aegyptiaca* fruit of the different shapes in Abu Jibeiha and Dindir Provinces and to study the variation between them. Sugars and saponins are found in the mesocarp, while oil, moisture content and protein were determined in the kernel. Two components, namely, oil and standard purified saponin, were extracted firstly from the kernel and mesocarp respectively, and then their percentage was determined.

3.2.5.1. Sugars determination

Sugars were determined according to the volumetric method of Lane and Eynon (Pearson 1970). Three types of sugar were determined:

- Invert sugars fructose and glucose namely reducing sugars.
- Total sugars (invert sugars plus sucrose).
- Sucrose

3.2.5.1.1. Invert sugars detection

Dissolving

Three fruits per each sample (fruit shape) were weighed, the epicarp was manually removed, and then the mesocarp dissolved in 300 ml tap water in 500 ml beaker. The shelled fruits were soaked in water at temperature 65^0c for about 40-55 minutes. The mixture was agitated with a glass rod till the mesocarp was completely removed from endocarp to avoid sugar loss. Then it was transferred to 500 ml volumetric flask to complete the volume to 500 ml with distilled water. A small amount of lead acetate and potassium oxalate was added to clarify the solution. The solution was then filtered under vacuum using a Buckner funnel.

Titration

The sugar solution was placed in 50 ml burette, fitted with a pinch cask instead of a tap and a glass jet bent twice, so that the graduations are not directly over the flask. Ten ml of fehling solution (five ml fehling A and five ml fehling B) were pipetted into 250 ml conical flask and mixed with 15 ml of the sugar solution. The liquid was boiled on flame (asbestos-covered gauze). Further quantities of solution were added (1 ml at a time) at 10-15 seconds intervals, to the boiling liquid, until the blue color was nearly discharged. In some samples the liquid color changed to red immediately so it was diluted, otherwise, three to five drops of aqueous methyl blue were added (1%). Titration continued till the indicator was completely decolorized.

Titration was repeated, adding before heating almost all of the sugar solution required to effect reduction of the copper (25 ml of the solution). Then it was boiled gently for about two minutes, three to five drops of the indicator were added. The titration was completed within a total boiling time of three minutes, at the end point all the blue color had been discharged and the liquid had turned to orange red color (brick). Then the volume was noted. Referring to fehling table, the proportion of the various sugars equivalent to ten or 25 ml of fehling solution were given in tables.

Calculations

Invert sugar percentage = (sugar x100x500 ml) /sample weight.

3.2.5.1.2. Total sugars detection

To 50ml of the solution in 100 ml volumetric flask, 6.5ml concentrated hydrochloric acid were added and left in the water bath. When the temperature of the solution reached 70^0c it was left in the water bath for five minutes. Then it was removed and left to cool. A sufficient amount of saturated sodium hydroxide was added for neutralization, plus three to five drops of phenolphthalein white, as indicator to determine the color (pink color). The volume was completed to100 ml then 50ml burette was filled with the sugar solution. Ten ml of Fehling A and Fehling B were pipetted in 250 ml conical flask and mixed with 15 ml of the sugar solution. Titration was carried out as was mentioned above (the invert sugars). Referring to Fehling table, the calculations were:

Total sugars percentage = (sugar x 500 ml x (100/2) /sample weight

3.2.5.1.3. Sucrose percentage

Sucrose percentage was determined as the difference between total sugars and invert sugars.

3.2.5.2. Protein determination

Semi-micro Kjeldal method (Pearson 1970) was used for protein determination. It included two steps; firstly, digestion of the powdered matter then distillation.

Digestion

An amount of 0.2 g of the defatted powdered kernel for each sample was weighed out, using a three decimal 1200 meter balance. Transferred to Kjeldal flask, using 0.8 g of catalyst mixture (as a tablet) to accelerate the reaction. Two to three ml of concentrated sulfuric acid, were added. Then it was placed on the heater, in an inclined position, gently. The flask was shacked from time to time. Heating continued for two to three hours till the black color turned to pale blue and the fumes disappeared, which indicated that digestion was completed.

Distillation

The digest was cooled and transferred to the distillation apparatus using the minimum volume of water, made alkaline with concentrated aqueous alkali (Fifteen ml of sodium hydroxide, 40 percent concentration), to release the ammonia. Then the released ammonia was steam distilled into ten ml of boric acid (2%), in a conical flask, adding to it, two to three drops of methyl red indicator; for five to ten minutes. Ammonium sulfate, which was converted to ammonia, was received by the boric acid.

Titration

Fifty-ml burette was filled with 0.1 normality hydrochloric acid. Titration continued till the color of the solution turned to red (pink), the end point.

Calculations

Protein% = (TV x N x 0.014 x 6.25) x 100/0.2 g

Where:

TV= Total volume

N= HCL titration normality

0.014= normality ml equivalent to nitrogen

6.25= NCF

0.2 g= Sample weight

3.2.5.3. Oil extraction and determination

Oil extraction

Oil was conveniently determined in the sample by extraction of the dried material using petroleum spirit in a continuous extraction apparatus soxhlet type. In order to insure that all the oil was obtained, the material was removed from the apparatus, and returned to the extractor (Pearson 1970).

The powdered kernel, of about 20 fruits of each sample (fruit shape) was transferred to a Petri dish of a known weight (W1). Using a three decimal 1200 Metler balance, the weight of the dish with the sample was found out (W2) (for moisture content determination).Then it was oven dried and re-weighed to consistent weight (M3). The dried sample was transferred to an extraction thimble, covered with a piece of cotton, and was placed in the soxhlet apparatus, connected to it a round bottom flask of a known weight (W4) to receive the oil and the solvent. After the solvent was added to the sample, it was placed on water bath, for about four hours. When it was sure that all the amount of oil was extracted the sample was removed from the soxhlet apparatus.

Distillation

The solvent was extracted in the soxhlet to separate it from the oil, which was placed on the oven for few minutes to release any remaining amount of the solvent. Then the weight of the flask with oil was found out (W5)

Calculations

Oil percentage = (W5-W4) x 100/ (W3-W1)

Where:

W1= weight of the empty dish.

W2= weight of the dish with sample (wet).

W3=weight of the dish with sample (dry).

W4= weight of the empty flask.

W5= weight of the flask with the oil sample.

3.2.5.4. Moisture content determination

The moisture content (MC) was calculated as the loss in weight after drying.

Calculations:

MC percentage= (M2-M3) x 100/(M2-M1)

Where:

W1= weight of the empty dish.

M2= weight of the dish with wet sample.

M3= weight of the dish with dry sample.

3.2.5.5. Saponin extraction and determination

Saponins have long been known to have strong biological activity, they lower the surface tension of aqueous solutions and form colloidal dispersions in water, which when shaken produce a nonalkaline soap-like froth. The amount of foam produced is a rough indication of the amount of saponins present in the solution. Some methods used foam amount in determination of saponin content in the solution. In this study saponin was extracted and purified according to the adapted method reported by Abdel Hafeez (1999). Saponin (diosogenin) was extracted from the mesocarp and purified to plot a calibration curve (Appendix figure 15). Then a regression line was prepared after preparation of different concentrations, and from which the diosogenin content in the mesocarp in different fruit shapes was determined.

3.2.5.5.1. Preparation and purification of standard saponin (diosogenin)

The mesocrp of twenty shelled fruits of *B. aegyptiaca* was dissolved in 500 ml distilled water in a beaker, overnight. The volume was completed to 500 ml, and then filtered through cotton and filtered again using a Whatmann filter paper no.41 under vacuum. Fifty ml of n-butanol were added to the solution, and transferred to a separating funnel. Butanol extracted saponin from the solution, forming a separate layer over the solution, which was transferred to a beaker. Addition of 50 ml butanol, and separation was repeated four times, till there was no more saponin is isolated. A sufficient amount of anhydrous sodium sulphate was added to dry the saponin extract. Then it was filtered using a Whatmann filter paper no. 41 under vacuum. Butanol was removed on a rotary evaporator, under reduced pressure. The residue (diosogenin) was dissolved in 40ml methanol, and precipitated by addition of 60 ml diethyl ether. The precipitate was redissolved in methanol and precipitated by diethyl ether about four times, till saponin was completely purified. The purified saponin (diosogenin) was dried at low temperature and it was collected and kept in a tightly closed sample bottle to protect it from moisture.

3.2.5.5.2. Preparation of standard curve (calibration curve)

Of the prepared purified diosogenin, 0.1 g was weighed out, dissolved in 100 ml distilled water (1mg/ml) and the solution was adjusted to different concentrations (seven solutions) by the addition to 10 ml of distilled water to each solution taken from the original one of different volume, forming the following concentrations in mg/ ml:

Solution 1 (10 ml) = 0.1 mg/ml

Solution 2 (8 ml) = 0.08 mg/ml

Solution 3 (6 ml) = 0.06 mg/ml

Solution 4 (4 ml) = 0.04 mg/ml

Solution 5 (2 ml) = 0.02 mg/ml

Solution 6 (1 ml) = 0.01 mg/ml

Solution 7 (04 ml) = 0.004 mg/ml

Absorbance of these solutions was determined by a colorimetric method (Haita *el al.* 1975). Each prepared volume of the seven solutions was kept in a labeled beaker. Seven test tubes were labeled according to concentration. To 0.5 ml of solution of each sample, 0.5ml of 8% vanillin solution in ethanol, then 5 ml of 72% of sulfuric acid, were added, and mixed well in test tubes in an ice- cold-water bath. Then the test tubes were warmed in a water bath at 60^0c for 10 minutes, and then cooled in an ice cold water bath. Absorbance of the reaction mixture was recorded against the blank solution with Spectrometer at a wave length of 544 nm (Appendix Table 34). The data on Appendix Table 34 was entered through excel to obtain the linear regression equation (calibration curve) from which the concentration for each fruit sample was calculated (Appendix Table 35).

3.2.5.5.3. Determination of diosogenin content in the mesocarp of different fruit shapes

Three fruits per each sample were weighed out; the epicarp was removed, and then dissolved in distilled water till the mesocarp completely dissolved. The volume was completed to 500 ml. Then it was filtered using a

Whatmann filter paper no. 41. Two ml of each sample were diluted with two ml distilled water. Then to 0.5 ml of each sample 0.5 ml of vanillin 8% solution in ethanol, then 5ml of 72% sulfuric acid were added, and the method continued as described previously. After recording the samples' absorbance from the spectrometer at (544) nm (wave length), the concentration for each sample was calculated from the standard curve, according to the equation: Y= 0.0295X-0.0094, where Y is the concentration and X is the absorbance of the fruit samples (Appendix Table 35). Then saponin (diosogenin) content in *Balanites* different fruit shapes was determined as follows:

Saponin (diosogenin) % = Concentration x (500 x 2) x 100 /sample weight

Where:

(500 x 2) = sample volume x dilution factor.

Then the percentages of invert and total sugar, sucrose and saponin were calculated as percent of the mesocarp weight.

3.2.6. Statistical analysis

The data of the samples (weight, length and diameter) of fruit samples was entered in excel for further calculation of study variables (application of equations) and preparation of figures. Statistical analyses were carried out using SAS Statistical package (SAS Inc 1990). Analysis of variance and

Duncan's Multiple Range Test were carried out to study the variation in morphological features and chemical components.

Chapter Four
Results and Discussions

Means of fruit statistics between and within sites (Wad Abid, Mujeigha and Om Sagaa villages, in Abu Jibeiha area) were given in Tables 1-5 for Duncan's Multiple Range Test, while ANOVA test results were given in Appendix Tables 1-16.

4.1. Fruit description

E**longate** fruits are long with length almost twice the diameter, one end is pointed (Appendix Figures 6 and 12). Oblong fruits may be similar to elongate ones in length, but both ends are rounded and they had the biggest weight and diameter (Appendix Figures 7 and 9). Oval fruit has one pointed end and egg like shape (Appendix Figures 5 and 10). Both ends are rounded in **spherical** fruits, and there is no great difference between length and diameter (Appendix Figures 8 and 11). These descriptions formed the criteria used for segregation of the fruits to different shapes**.** The four-shape groups (Figure 5) were in agreement with the fruit description reported by (Von Maydell 1986, Mohamed *et al*. 1997, Sahni 1968, Mbuya *et al.* 1994, Vogt 1995 and Mahgoub 2002).

Some observations

In this study, it is observed that the fruit epicarp color is mostly yellow to dark yellow (Figure 5). Mesocarp color was observed to vary from a yellowish color for oval and elongate fruits to yellow brownish one for oblong fruits and more brownish for spherical fruits (Appendix Figure 13). This observation is in agreement with what was reported by Thirakul (1984) and Von Maydell (1986). They reported that *Balanites aegyptiaca* fruit epicarp color is green, shortly velvety when young, turning yellow and glabrous when ripe, while the mesocarp is yellow- brown. There were two types of spherical fruits in Abu Jibeiha location; one with smooth epicarp and the other with wrinkled brownish epicarp (Appendix Figure 8) and mostly resemble date in shape, while fruit epicarp is smooth in oval, elongate and oblong shapes and some spherical fruits (Appendix Figures 5,6,7 and 11). This observation is similar to that, reported by Thirakul (1984) and Von Maydell (1986), the epicarp is smooth or wrinkled when ripe. Also it was observed that the brownish color of the mesocarp should turn to dark brown if it was left for long period. The dissolved mesocarp color for saponin test, ranges from pale yellow in oval fruit to medium yellow in elongate and dark brownish in both oblong, which had the highest value of saponin and spherical fruits.

Figure 5. Spherical, oval, elongate &oblong shapes of *Balanites aegyptiaca* fruit

4.2. Variation in fruit morphology

4.2.1. Simple statistics of *Balanites aegyptiaca* fruit morphology

Simple statistics of fruit morphology results (regardless of shape or site for the 300 fruits randomly taken) are given in Table 1. The mean weight value of fruit was 6.64 g with a minimum of 2.43 g and maximum of 10.91 g. These results are in line with the findings of Elfeel (2004), who stated that fruit average weight approximately ranges between 5.5 and 9 g. However, Von Maydell (1986) reported that single fruit weight ranges between 10 and 15 g. The fruit length values ranges between 1.82 cm and 5.79 cm around a mean of 3.36 cm. These values were almost the same as those reported by Von Maydell (1986) and Thirakul (1984). Mohamed *et al*. (1997) and Mbuya *et al*. (1994) reported that the *Balanites* fruit can reach up to 5 cm in length.

The average fruit diameter was found to be 2.08 cm and it ranged from 1.35 cm to 3.88 cm. These fruit diameter values are slightly higher than the values reported by Mohamed *et al*. (1997), Thirakul (1984) and Mbuya *et al.* (1994), who reported that fruit diameter ranges between 1.5 and 2.5 cm.

Fruit shape index (ratio of the fruit length to its diameter) varied from 0.86 to 2.50 and averaged 1.63, indicating that the length of hejlij fruit can vary from measuring less than its diameter (shape index < 1) to more than two and a half times its diameter. Judging by the values of coefficient of variation, fruit weight had the greatest variation among all fruit characteristics, followed by fruit shape index, length and then by fruit diameter. This variation could be due to actual differences between the sites in fruit characteristics and/or to the fact that the four fruit shapes were not represented in all sites.

Table 1. Simple statistics of *Balanites aegyptiaca* fruit morphology

Fruit Characteristics	Minimum	Mean	Maximum	Coefficient of variation
Weight (g)	2.43	6.64	10.9	25.09
Length (cm)	1.82	3.36	5.79	15.02
Diameter (cm)	1.35.	2.07	3.88	11.32
Shape index	0.86	1.63	2.5	15.94

4.2.2. Simple statistics of fruit morphology by fruit shape

Statistics of fruit morphology according to shapes showed that the fruit average weight for oblong fruits ranges between 3.47 g and 10.9 g with a mean of 7.22 g (Table 2). The average weight for elongate fruits ranges between 4 g and 7.8 g with a mean of 6.08 g. The average weight for spherical fruits ranges between 5.8 g and 8.36 g, with a mean of 6.95 g. The average weight for oval fruits ranges between 2.43 and 6.8 g of a mean of 4.83 g.

Table 2. Simple statistics of *Balanites aegyptiaca* fruit weight (g)

Shape	Number of fruits	Minimum	Mean	Maximum	Standard deviations	Coefficient of variations
Oblong	182	3.47	7.22	10.9	1.63	22.52
Elongate	20	4	6.08	7.8	1.04	17.04
Spherical	40	5.8	6.95	8.36	0.69	9.85
Oval	58	2.43	4.83	6.80	0.96	19.92

The mean value of length in oblong fruits was about 3.594 cm, the minimum value 1.82 cm and maximum 5.8 cm. The mean value of length in elongate fruits was about 3.66 cm the minimum value 2.62 cm and maximum 3.95 cm. The mean value of length in spherical fruits was about 2.71 cm the minimum value 2.49 cm and maximum 3.9 cm. The mean length value for oval fruits varied from 2.48 cm to 3.9 cm of a mean of 2.98 cm (Table 3).

Table 3. Statistics of *Balanites aegyptiaca* fruit length across sites

Shape	Number of fruits	Minimum	Mean	Maximum	Standard deviations	Coefficient of variations
Oblong	182	1.82	3.59	5.79	4.32	12.02
Elongate	20	2.62	3.66	3.95	2.82	7.7
Spherical	40	2.50	2.72	2.91	0.98	3.62
Oval	58	2.48	2.99	3.90	2.68	8.97

The diameter value for oblong fruits varied from 1.56 cm to 3.88 cm of a mean of 2.11 cm. The diameter value for elongate fruits ranges from 1.57 cm to 2.21 cm of a mean of 1.92 cm. The diameter value for spherical fruits varied from 2.05 cm to 2.57 cm of a mean of 2.26 cm. The diameter value for oval fruits varied from 1.35 cm to 2.18 cm of a mean of 1.90 cm.

Table 4. Statistics of *Balanites aegyptiaca* fruit diameter across sites

Shape	Number of fruits	Minimum	Mean	Maximum	Standard deviations	Coefficient of variations
Oblong	182	1.56	2.11	3.88	2.38	11.28
Elongate	20	1.57	1.92	2.21	1.6	8.36
Spherical	40	2.05	2.27	2.57	1.15	5.09
Oval	58	1.35	1.90	2.18	1.57	8.23

The mean value for shape index for oblong fruits was 1.7 with minimum value of 0.86 and maximum of 2.5. The mean value of shape index for elongate fruits was 1.2 with a minimum of 1.43 and a maximum of 2.27. The mean value of shape index for spherical fruits was 1.2, a minimum of 1.01 and a maximum of 1.35. The mean value of shape index for oval fruits was 1.58, with a minimum of 1.256 and a maximum of 2.11.

Table 5. Statistics of *Balanites aegyptiaca* fruit shape index across sites

Shape	Number of fruits	Minimum	Mean	Maximum	Standard deviations	Coefficient of variations
Oblong	182	0.86	1.7	2.5	0.2	11.7
Elongate	20	1.43	1.92	2.27	0.20	10.20
Spherical	40	1.01	1.2	1.35	0.07	5.87
Oval	58	1.26	1.58	2.11	0.17	10.47

Values of the coefficient of variation in the fruit characteristics of the four shapes indicate that, oblong fruits have the greatest variation, followed by oval and elongate ones, while spherical fruits have the least variation in fruit characteristics.

4.2.3. Variation in fruit morphology between sites and shapes

Results of the analysis of variance for the effect of site and shape on *Balanites aegyptiaca* fruit morphological characteristics are given in Appendix Tables 1-16. Mean values and results of Duncan's Multiple Range Test are given in Tables 6-9. There were significant differences between sites in Abu Jibeiha area in fruit weight, diameter, length and shape index ($p=0.0001$). This indicates that the fruit characteristics can vary within the same location.

Significant differences were found (p=0.0001) between shapes for hejlij fruit weight. The highest average weight values were obtained by oblong and spherical fruits and there were no significance differences between them. They were followed by elongate fruits, which were significantly different from the oval fruits (Table 6). The higher value for fruit length was obtained by elongate and oblong fruit and there was no difference between them. Spherical fruits were significantly the shortest among the four fruit types (Table 6). The largest diameter was found in spherical fruits followed by oblong ones and they were considerably different from each other. The lowest values were obtained by oval and elongate fruits, which had almost the same value and were significantly different from other two shapes (Table 6). The four fruit shapes were significantly different from each other in shape index. The highest value was found in elongate fruits and they were followed by oblong, oval and spherical ones (Table 6).

Table 6. Variation between fruit shapes in *Balanites aegyptiaca* fruit morphology (across sites) in Abu Jibeiha area

Shape	Weight (g)	Length (cm)	Diameter (cm)	Shape Index
Oblong	7.23 A	3.59 A	2.11 B	1.71 B
Elongate	6.08 B	3.66 A	1.91 C	1.92 A
Spherical	6.95 A	2.72 C	2.27 A	1.20 D
Oval	4.83 C	2.99 B	1.90 C	1.58 C

In the same column means with similar letters, are not significantly different (P =0.05)

4.2. 4.Variation in fruit morphology between fruit shapes within sites

4.2. 4. 1. Site Wad Abid

Out of the four identified fruit shapes only three fruit shapes were found in this site, oblong, elongate and oval shapes (Table 7). The highest values of weight, length and diameter were obtained by oblong fruits followed by elongate ones and they were significantly different from each other. Oval fruits, which obtained the lowest values in weight, length and shape index, were not significantly different from elongate ones in diameter value.

Shape index was significantly different among the three fruit shapes. The higher value was found in elongate fruits while the lower value was found in oval ones.

Table 7. Variation in fruit morphology between *Balanites aegyptiaca* fruit shapes in site Wad Abid

Shape	Weight (g)	Length (cm)	Diameter (cm)	Shape Index
Oblong	8.35 A	3.87 A	2.22 A	1.77 B
Elongate	6.08 B	3.66 B	1.91 B	1.92 A
Oval	5.08 C	3.11 C	1.91 B	1.64 C

In the same column means with similar letters, are not significantly different (P =0.05)

4.2. 4. 2. Site Mujeigha

In this site only two fruit shapes were identified (oblong and spherical shapes, Table 8). The higher weight value was obtained by spherical fruits and they were considerably different from oblong ones. Oblong fruits obtained the higher length value, the lower diameter value and higher shape index, which were considerably different from spherical ones that had the higher diameter, lower length and lower shape index values.

Significant differences were found between the two fruit shapes for the four studied fruit characteristics. The higher weight value was obtained by spherical fruits, which were associated with the larger diameters and the smaller length. Because they were longer and thinner, oblong fruits have significantly the higher shape index.

Table 8. Variation in *Balanites aegyptiaca* fruit morphology between fruit shapes in site Mujeigha

Shape	Weight (g)	Length (cm)	Diameter (cm)	Shape index
Oblong	6.21 B	3.30 A	2.03 B	1.63A
Spherical	6.95 A	2.72 B	2.27 A	1.20 B

In the same column means with similar letters, are not significantly different (P =0.05)

4.2. 4. 3. Site Om Sagaa

Oblong and oval shapes were only fruit shapes detected in site Om Sagaa. Oblong fruits had significantly the higher values of weight, length, and diameter and shape index (Table 9).

Table 9. Variation in *Balanites aegyptiaca* fruit morphology between fruit shapes in site Om Sagaa

Shape	Weight (g)	Length (cm)	Diameter (cm)	Shape Index
Oblong	7.38 A	3.67 A	2.11 A	1.75 A
Oval	4.36 B	2.74 B	1.88 B	1.46 B

In the same column means with similar letters, are not significantly different (P =0.05)

The study of variation in fruit morphology in Abu Jibeiha location within the three sites showed that, the four fruit shapes are not represented in each of the three sites. The spherical fruits were found in only one site as well as the elongate fruits (Tables 7 and 8). Two of the fruit shapes, which were oblong and oval, can attain different sizes.

Results of the variation among fruit shapes between sites in Abu Jibeiha area indicate that the ranking of fruit shapes according to fruit characteristics was consistent. In all comparisons, the highest values of length and weight were associated with elongate and spherical fruits respectively. The larger diameters are associated with spherical fruits followed by oblong fruits. Oval fruits have the smallest value of weight and diameter. Spherical fruits are the shortest and hence have the smallest shape index. The largest shape index is always associated with elongate fruits, which had a length almost twice the diameter (Table 7). The number of fruits (300 fruits from five trees per three sites) identified in the randomly selected samples from Abu Jibeiha area were 182, 20, 40, and 58 for oblong, elongate spherical and oval fruits, respectively. Although one might argue that more extensive sampling is needed, these results indicate that the majority of fruits (61%) at least in the study area, are oblong in shape. The proportion of elongate, spherical and oval fruits is in the order of 7, 14 and 18. Judging by values of coefficient of variation fruit weight has the greatest variation among all fruit characteristics, followed by fruit shape index, length and then by fruit diameter.

4.2.5. Morphological variation in *Balanites aegyptiaca* fruit between locations (Abu Jibeiha and Dindir)

Results of analysis of variance for the effect of location (regardless of fruit shape) and effect of location by fruit shape are given in Appendix Tables 17-20, and the means of Duncan's Multiple Range Test, are given in Tables 10-14. Fruit weight and length values were higher in Abu Jibeiha location and significantly different from Dindir location. There were no significant differences in fruit diameter and shape index between locations.

Table 10. Variation in *Balanites aegyptiaca* fruit morphology between locations

Location	Weight (g)	Length (cm)	Diameter (cm)	Shape index
Abu Jibeiha	6.90 A	3.31 A	2.13 A	1.58 A
Dindir	5.52 B	2.96 B	2.21 A	1.47 A

In the same column means with similar letters, are not significantly different (P =0.05)

4.2.6. Variation in *Balanites aegyptiaca* fruit morphology by fruit shape between locations

4.2.6.1. Variation in *Balanites aegyptiaca* fruit weight by shape between locations

The higher values of fruit weight for the four shapes were found in Abu Jibeiha location and they were significantly different from Dindir location, the respective values in Table 11.

Table 11. Variation in *Balanites aegyptiaca* fruit weight between locations for each fruit shape

Location	Fruit shape			
	Oblong	Elongate	Spherical	Oval
Abu Jibeiha	8.45A	6.32 A	7.11 A	5.81 A
Dindir	6.7 B	4.45 B	6.49 B	4.43 B

In the same column means with similar letters, are not significantly different (P =0.05)

4.2.6.2. Variation in *Balanites aegyptiaca* fruit length by fruit shape between locations

The fruit length showed a significant variation between locations; while it was higher in Abu Jibeiha than in Dindir for oblong and oval fruits, it was lower in spherical ones. There was no significant variation between locations in the average length for elongate fruits (Table 12).

Table 12. Variation in *Balanites aegyptiaca* **fruit length by fruit shape between locations**

Location	Fruit shape			
	Oblong	Elongate	Spherical	Oval
Abu Jibeiha	3.66 A	3.68 A	1.73 B	3.18 A
Dindir	3.46 B	3.67 A	2.84 A	1.87 B

In the same column means with similar letters, are not significantly different (P =0.05)

4.2. 6.3. Variation in *Balanites aegyptiaca* fruit diameter by fruit shape between locations

The effect of location on fruit diameter was not significant for oblong and spherical fruits. However it was significantly higher in Abu Jibeiha for elongate fruits and lower for oval ones than in Dindir (Table 13).

Table 13. Variation in *Balanites aegyptiaca* **fruit diameter by fruit shape between locations**

Location	Fruit shape			
	Oblong	Elongate	Spherical	Oval
Abu Jibeiha	2.26 A	1.93 A	2.29 A	2.02 B
Dindir	2.10 A	1.59 B	2.24 A	2.89 A

In the same column means with similar letters, are not significantly different (P =0.05)

4.2. 6.4. Variation in *Balanites aegyptiaca* fruit shape index by fruit shape between locations

Shape index was not significantly different between locations for oblong fruits. Shape index was higher for spherical and oval fruit in Abu Jibeiha and significantly different while it was lower in the elongate ones and significantly different between locations.

Table 14. Variation in *Balanites aegyptiaca* **fruit shape index by fruit shape between locations**

Location	Fruit shape			
	Oblong	Elongate	Spherical	Oval
Abu Jibeiha	1.62 A	1.92 B	1.95 A	1.58 A
Dindir	1.66 A	2.31 A	1.27 B	0.65 B

In the same column means with similar letters, are not significantly different (P =0.05)

Fruit weight and length values were higher in Abu Jibeiha location and significantly different from Dindir location. This variation could be caused by genetics effect or environment factors. Elfeel (2004) reported that fruit weight was greatly affected by soil and rain fall, where higher weight was obtained from clay soil sources and relatively higher rain fall; the fruit weight ranged from 227 g/50 fruits to 452.3 g/50 fruits. He also showed that the weight of fleshy pulp mesocarp showed significant variation between provenance, giving a range of 290.06 to 106.8 g.

4.2.7. Variation between *Balanites aegyptiaca* fruit shapes in seed morphology

Results of analysis of variance for the relationship between fruit shape and seed morphology are given in Appendix Tables 20-23, and the means of Duncan's Multiple Range Test, are given in Table 15. The seeds of elongate fruits had the highest values of length, followed by oblong ones and they were significantly different from each other (Table 15). The lowest length values were detected in the seeds of oval fruits and they were significantly different from all other fruit shapes. Oval fruits had the highest average seed diameter and it was not significantly different from spherical seed, which in turn was not significantly different from oblong fruit diameter. The lower seed diameter was obtained by elongate fruits. Seed shape index as well as fruit shape index was significantly different between the four shapes. So, Hejlij seed also showed significant variation in morphology. Seed size was reported to be of 2 cm in diameter and 4 cm in length (Mbuya *et al.* 1994). These values are higher than the average values, obtained in the current study. Oval fruits had the highest seed breaking force and at the time were not different from spherical and oblong seeds. There was no significant variation between oblong and elongate seeds that had the lower value.

Table 15. Effect of *Balanites aegyptiaca* fruit shape on seed morphology

Shape	Length (cm)	Diameter (cm)	Shape Index	Breaking Force
Oblong	3.28 B	1.42 B	2.3 B	181A B
Elongate	3.57 A	1.16 C	3.1 A	165.5 B
Spherical	2.52 D	1.47 AB	1.7 D	194.5 A
Oval	3.03 C	1.53 A	2.0 C	200.5 A

In the same column means with similar letters, are not significantly different (P =0.05)

4.3. Variation in *Balanites aegyptiaca* fruit composition and fruit chemical constituents

Results of the analysis of variance for the relationship between shape; location and fruit physical and chemical constituents for *Balanites aegyptiaca* (Hejlij) in the two locations are given in Appendix Tables 21-41, while means of Duncan's Multiple Range Test are given in Tables 16 -22.

4.3.1. Fruit composition

4.3. 1. 1. Effect of shape on fruit composition

Balanites aegyptiaca fruit is composed of four layers, the outer layer is known as epicarp (Appendix Figure 6), followed by the mesocarp (Appendix Figure 7), which is the middle part, sticky, flesh, oily, gummy and with bitter sweet taste. The endocarp is the inner part, which is hard, pointed, and woody and it surrounds the kernel (Appendix Figure 8). Seed (kernel) is ovoid, testa sub-fibrous, non- endospermic (Appendix Figure 9) (Mohamed *et al*. 1997).

There was significant difference (P=0.0001) in Hejlij fruit physical composition between shape and location (Appendix Tables 25-29). The average percentage of epicarp varied from 18.7 for elongate fruits to 25.2 for spherical fruits (Table 16). Spherical fruits had the highest epicarp percentage and it was significantly different from the other three fruit shapes. There was a significant variation between oblong and spherical fruits in epicarp average percentage at the same time there was no variation between the oblong and the other two fruit shapes (oval and elongate fruits). However, there was a significant variation between elongate and oval fruits in epicarp percentage. The average percentage of epicarp was 20.69%, showing significant variation between shapes and locations. These values are in agreement with the value of 19% reported by Elamin (1979), but considerably higher than the value of 10% reported by Mohamed *et al*. (1997).

The mesocarp average percentage varied from 30.3 for oval fruits to 37.4 for oblong ones. The highest proportion of mesocarp was detected in oblong fruit, followed by elongate and spherical fruits, which were in turn were not significantly different from oval ones (Table 16). A high percentage of the fleshy pulp mesocarp is a great advantage as this part of the fruit contains the most important compounds, saponin and sugars. The lowest mesocarp percentage was obtained by oval fruits (30.3%), which were not significantly different from spherical and elongate fruits (Table 16).

Mesocarp average percentage (34.11) is in agreement with the percentage of 30% and 31% recorded by both Von Maydell (1986) and Elamin (1979), respectively.

Endocarp average percentage was highest for elongate fruits followed by oval ones and they were not significantly different from each other (Table 16). Spherical fruits had the lowest value followed by oblong fruits and they were not significantly different from each other. Endocarp average percentage was 35% and it is much lowest than those values, reported by Von Maydell (1986) and Elamin (1979), which ranged between 40-50%, but it is in agreement with endocarp percentage of 35% given by Elfeel (2004). Although this part of *Balanites aegyptiaca* fruit can be used as fuel, but the pulp is the most important layer.

Spherical fruits obtained the lowest value of kernel average percentage, and they were significantly different from the other three fruit shapes (Table 16). The oval and elongate fruits had the highest values respectively, and were significantly different from spherical and oblong fruits (Table 16). Kernel average percentage was 9.9, where there was significant variation between fruit shapes and Location at $p=0.0001$ and it is in the range with the value of

10% reported by both Von Maydell (1986) and Elamin (1979) and it was significantly different from that value of 15% reported by Elfeel (2004). The highest proportion of kernel is demanded, to increase oil and protein content.

Table 16. Effect of *Balanites aegyptiaca* fruit shape on fruit composition

Shape	Epicarp%	Mesocarp%	Endocarp%	Kernel%
Oblong	19.7 BC	37.4 A	33.9 B	9.1 B
Elongate	18.7 C	34.6 AB	38.9 A	11.4 A
Spherical	25.2 A	34.4 AB	33.4 B	7.1 C
Oval	20.7 B	30.3 B	37.3 A	11.6 A

In the same column means with similar letters, are not significantly different (P =0.05)

There was no significant variation between the four fruit shapes in the percentage of epicarp, mesocarp and endocarp fruit layers between locations while there was significant variation between the four fruit shapes in the kernel percentages (Table 17).

Table 17. Effect of location on *Balanites aegyptiaca* fruit physical composition

Location	Epicarp %	Mesocarp %	Endocarp%	Kernel%
Abu-Jibeha	20.7 A	34.7 A	35.4 A	10.3 A
Dindir	21.1 A	33.2 A	36.5 A	9.2 B

In the same column, Means with similar letters are not significantly different (P =0.05)

4.3. 2. Fruit chemical constituent

Chemical constituents determined in this study are found in mesocarp and kernel parts of *Balanites aegyptiaca* fruit.

4.3. 2. 1. Mesocarp chemical constituent

4.3. 2. 1. 1. Sugars and saponin of the whole fruit

Sugars and saponin results were calculated firstly as percentages of the whole fruit and because they are found in the fruit fleshy pulp mesocarp as mentioned in chapter three; then their percentage in the mesocarp was determined for comparisons and discussion.

Sugars

Oblong fruit had the highest value in invert sugars per fruit and it was not significantly different from spherical and oval fruits; which were at the same time not significantly different from elongate fruit (Table 18). There was no significant difference between the four fruit shapes in total sugar values. Elongate fruits were significantly different and had the highest value of sucrose while there was no significant variation between the three fruit shapes, spherical, oblong and oval fruits and they had the lowest values of sucrose respectively.

saponin

Oblong fruit had the highest value of saponin per fruit and it was significantly different from elongate, spherical and oval fruits, which had the lowest saponin values respectively.

Table 18. Effect of *Balanites aegyptiaca* fruit shape on fruit chemical constituents:

Shape	Invert sugar/fruit	Total sugar/fruit	Sucrose/fruit	Saponin/fruit
Oblong	13.3 A	15 A	1.6 B	1.5 A
Elongate	10.9 B	15.4 A	4.5 A	0.81 B
Spherical	12.7 AB	14.9 A	2.2 B	0.78 B
Oval	12.3 AB	13.4 A	1.1 B	0.76 B

In the same column means with similar letters, are not significantly different at p =0.05

4.3. 2. 1. 2. Effect of fruit shape on fruit mesocarp chemical constituents

The pulp mesocarp contains mainly invert sugars (glucose and fructose), that are known also as reducing sugars, plus a minor amount of sucrose (Elamin 1979). Oval fruits had significantly the highest value in mesocarp invert sugars (Table 19); followed by spherical and oblong fruits, which were not significantly different from each other. A significantly lowest average percentage of invert sugars were obtained, by elongate fruit (32.5%). Mesocarp invert sugar was significantly different (P=0.0001) between shapes and location (Appendix Table 39). The overall mean was 38.88 % and it is in the range of the values given by Nour *et al*. (1986) and NAS

(1983), but it is lowest in comparison with the value of 56% given by Elamin (1979), and it is relatively higher than the value reported by Abdelmuti *et al.* (1954), who found that the total value for invert sugars was about 30.7% (20.6% D- glucose and 10.1% D-fructose on dry-base).

The higher average percentage of total sugar in mesocarp was obtained by elongate fruit (44.6) followed by oval and spherical ones (Table 1٩) and there was no significant variation between them. The lowest average percentage was obtained by oblong fruit (39.7). Total sugar of the mesocarp was significantly different between shapes and locations (Appendix Table 40) with a mean of 42.83% and it was greater than the value of 36.5% reported by Abdelmuti *et al.*(1954) and at the same time it was considerably lower than the value of 61% given by Babiker (1983). However, the above results indicate that *Balanites aegyptiaca* fruits can reasonably be introduced to the beverage and other sugar syrup using industries. Besides, they can be used for sweet and jam making, especially that the pulp mesocarp has a gummy bittersweet taste, similar to what is found in apricot jam.

The highest value of mesocarp sucrose was obtained from elongate fruit (Table 19) and it was significantly different from the other fruit shapes. There was no significant variation between spherical and oblong fruit, while they were significantly different from oval fruits, which obtained the least amount of sucrose (3.25%). However the low sucrose content in any sugar syrups is demanded for diet. Mesocarp sucrose percentage was significantly different between shapes and locations averaged about 5.83% (Appendix Table 41) and it is quite agreeable with the percentage of 5.8% that had been reported by Abdelmuti *et al.* (1954).

Saponin (diosogenin) average percentage represented considerable variation among fruit shapes and locations at p =0.0001 (Appendix Table 38).

Oblong fruit had the highest average percentage in mesocarp saponin and it was significantly greater than in the other three shapes, almost double the percentage of spherical ones. There were no significant differences between spherical, elongate and oval fruits in saponin average percentage (Table 1٩). Mesocarp saponin was significantly different between shapes and location with a mean of 2.95 %, which agreed with that (2.5%w/w) reported by Babiker (1983). Others reported that total saponin content was found to be 7.2% in the mesocarp and 6.7 in the kernel (Watt and Brandwijk 1962). This result and the obtained results may be regarded as considerable percentages for such valuable compound to contribute in the steroidal industries as intermediate products in sex hormones synthesis, curing cancer, cholesterols and other pharmaceutical industries. Dawidar *et al*. (1985) reported that the steroidal diosogenin from Sudanese Hejlij, showed a relatively high value of nearly 1.26% dry weight in comparison with reports of 0.3% for an Egyptian source. This higher content of *Balanites aegyptiaca* diosogenin grown in Sudan should contribute to Sudan national income; as Elfeel (2004) reported that Sudan can supply half of the world consumption of diosgenin and selling this product at 33% of the prevailing world price, it can generate about 36 million US Dollars per year. These results may emphasize the importance of the introduction of *Balanites aegyptiaca* fruits to the advanced saponin based industries. Abdel Hafeez (1999) stated that about 98.95 of high purity saponin content in mesocarp of *Balanites aegyptiaca* can be extracted by foam method, which is suitable to be used in pharmaceutical industry e.g. as starting material for preparing cortisones. So that great attention must be given to the conservation and sustainable management of this valuable species. However the overall earning from the chemical products (saponin, protein, sugars and oil) makes a total of 80 million US $ per year as was estimated by Abu-Al-Futuh (1983), which is a considerable amount to enhance the contribution of *Balanites aegyptiaca* different types to the national income through establishment of multipurpose factories concerning with *Balanites aegyptiaca* based industries.

Table 19. Effect of *Balanites aegyptiaca* fruit shape on fruit mesocarp chemical constituents

Shape	Invert sugar/ mesocarp	Total sugar/ mesocarp	Sucrose/ mesocarp	Saponin/ mesocarp
Oblong	35.5 AB	39.7 A	4.2 B	4.1 A
Elongate	32.5 B	44.6 A	12.08 A	2.5 B
Spherical	37.2 AB	43.7 A	5.9 B	2.2 B
Oval	40.9 A	44.2 A	3.25 B	2.6 B

In the same column means with similar letters, are not significantly different (P =0.05)

4.3. 2. 1. 3. Effect of location on fruit mesocarp chemical constituents

Significant differences between locations were found in invert and total sugar, sucrose and saponin content of fruit mesocarp. Abu Jibeiha had the highest sugar content while Dindir had the highest saponin content. Saponin average percentage obtained in Dindir location represents double the percentage that obtained in Abu Jibeiha location (Table 20).

Table 20. Effect of location on *Balanites aegyptiaca* fruit mesocarp chemical constituents

Location	Invert sugar	Total sugar	Sucrose	Saponin
Abu Jibeiha	38.4 A	45.3 A	6.7 A	2.1 B
Dindir	34.5 B	39.1 B	4.5 B	4.2 A

In the same column means with similar letters, are not significantly different (P =0.05)

4.3. 2. 2. Fruit kernel chemical constituents

4.3. 2. 2. 1. Effect of shape on fruit kernel chemical constituents

Moisture content was not significantly different between shapes with a mean of 9.3% and it is in agreement with 10.5% reported by Abdelmuti *et al*. (1954).

Oil is usually obtained by simple cold press extraction and in this study soxlet extraction was used. It is golden yellow in color (Appendix figure 19). It is fixed and similar to groundnut oil. The highest oil average percentage was obtained by spherical fruits followed by oval, elongate ones and there was no significant difference between them. On the other hand the elongate fruits were not significantly different from oblong fruits, which had the lowest oil content value (38.5%). However, kernel oil was not significantly different between locations with a mean of 41.7% and varied from 38.5 to 45.3%, which is in the range of the values of 46.8% reported by Sani (1968), 45% (Adam and Lescot1972) and 44-51% reported by Mohamed *et al*. (1997). The obtained value is relatively highest comparing with that percentage of 30% reported by NAS (1983). Other studies showed a relatively less /or highest amount of oil content ranging from 19.8 to 60% (Suliman and Jackson 1959, Abu-Al-Futuh 1983, Mohamed and Speiss 2002, Abdelmuti *et al*. 1954, Buy Somali 2003 and Elfeel 2004). As *balanites* oil is edible, highly prized by local (Elamin 1979), it can be used in food and medicine industries, at larger scales.

Protein was determined in the defatted kernel after oil extraction and it was not significantly different between locations at P=0.0001(Appendix Table 35) ranges between 49.6 and 53.8%, with a mean of 52.11% and was significantly different between shapes, where the oval fruit obtained the lowest value and it was not significantly different from spherical and elongate ones; on the other hand the highest protein percentage was obtained by oblong fruit and it was not significantly different from spherical and elongate ones. These obtained protein percentages from the defatted kernel, for the four fruit shapes and the two locations (Tables 20 and 21) were higher in comparison with 27.5%, 26 to 30%, 32.4% and 38.7 to 41.2% values given by Abdelmuti *et al*. (1954), Abu AL Futuh (1983), Mohamed and Spiess (2000 and 2002) and Elfeel (2004) respectively. But still, these protein values obtained in the current study were not considerably different from that range of 49-51% (after oil extraction, before extraction was 27%) given by Adam and Lescot (1972) and 50% reported by NAS (1983). The high protein percentage is an advantage of *Balanites* kernel cake, which is used for human and animal nutrition.

Table 21. Effect of *Balanites aegyptiaca* fruit shape on its kernel chemical constituents:

Shape	MC	oil	Protein
Oblong	8.9 A	38.5 B	53.8 A
Elongate	9.8 A	43 AB	52.97 AB
Spherical	9.4 A	45.3 A	52.5 AB
Oval	9.3 A	44.9 A	49.6 B

In the same column means with similar letters, are not significantly different (P =0.05)

4.3.2.2.2. Effect of location on *Balanites aegyptiaca* fruit kernel chemical constituents:

There were no significant differences between locations in moisture, oil and protein content of fruit kernel (Table 21).

Table 22. Effect of location on *Balanites aegyptiaca* fruit kernel chemical constituents:

Location	MC	Protein	Oil
Abu-Jibeiha	9.6 A	52.5 A	40.4 A
Dindir	8.8 A	51.4 A	43.7 A

In the same column means with similar letters, are not significantly different (P =0.05)

Chapter Five
Conclusions

5.1. Conclusions

The following conclusions are drawn from the study:

Four fruit shapes were identified for *Balanites aegyptiaca* namely, oblong, elongate, spherical and oval shape. The majority of fruits (300 fruits from five trees from each of three sites in Abu Jibeiha area) are oblong in shape (61%) and the proportion of elongate, spherical and oval fruits is in the order of 7, 14 and 18%, respectively.

Fruit weight has the greatest variation among all fruit characteristics, followed by fruit shape index, length and then by fruit diameter. Oblong fruits have the greatest variation while spherical fruits have the least variation in fruit morphological characteristics.

Significant differences are found between fruit shapes in fruit morphological characteristics irrespective to *site* or *location.* Elongate fruits are the longest fruits; its shape index shows that its length is almost twice its diameter. Oblong fruits are the largest fruits; they are not significantly different from elongate in length or shape index but larger in weight and diameter values. Spherical fruits are the shortest and its shape index indicates that the length of the fruit is not much different from its diameter. Oval and spherical fruits have the lower values in length and shape index. However, shape index is the only fruit characteristic which is significantly different between the four fruit shapes.

There is significant variation in fruit morphology between sites. Fruit shapes are not represented in all sites. Significant differences are also found between locations, where fruit weight and length values were higher in Abu Jibeiha location and significantly different from Dindir location and there were no significant differences in fruit diameter and shape index. The higher values of fruit weight for the four shapes were found in Abu Jibeiha location. Hijleij *seed* also showed significant differences in morphological characteristics.

There were significant differences in the fruit physical composition between the fruit different shapes. The highest percentage of epicarp (25.2%) was obtained by spherical fruits and the lowest was found in elongate ones (18.7%). Oblong fruits had the largest mesocarp average percentage (37.4) and the lowest was found in oval ones (30.3). Endocarp average percentage was 35% and it was highest in elongate fruits and lowest in spherical fruits. Spherical fruits obtained the lowest value of kernel average percentage while the oval ones obtained the highest percentage and kernel averaged 9.9

percentage. Out of the five variables only kernel showed significant variation between locations, where Abu Jibeiha location obtained the highest kernel percentage.

There was significant difference in fruit mesocarp and kernel chemical constituents between shapes and locations. The highest saponin (4%) was obtained by oblong fruits while the highest invert sugar (40.9%) and oil (44.9%) were obtained by oval fruits. Saponin average percentage obtained in Dindir location represents double that percentage obtained in Abu Jibeiha, while the higher sugar percent is obtained in Abu Jibeiha. Protein is found to be of higher content than that reported in the literature where it ranged between 49.6(oval fruit) and 53.8% (oblong fruit), with a mean of 52.11%. MC was not significantly different between shapes and locations averaged a mean of 9.3%.

The above results of (sugar, saponin, oil and protein), are considerable amounts to introduce our *Balanites* different types to the food and medicinal industries.

5.2. Recommendations

- Further botanical investigations are needed, taking into consideration variations in fruit characteristics according to the fruit shape and tree location and the effect of environmental and genetically conditions and different types or varieties of this species may be identified.

- Hejlij based industries can be established with regard to oval fruits in food processing (*Balanites* sugar syrups; jam) and oblong ones in saponin extraction for export, as raw material or to be used as intermediate product in sex hormones synthesis and other pharmaceutical industries.
- Due to the high protein content (52.11%) Hejlij kernel cake can have potential use for human and animal feed.
- More studies on the relationship between fruit shape, tree location and Hejlij fruits chemical constituents are needed.
- This multipurpose tree *Balanites aegyptiaca* is very precious, must be given great attention and care. It deserves intensive protection as natural stand and new more plantations, on purpose of fruit chemical content utilization, to enhance their contribution in the national income.

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1.Figures:-

Figure 1..Mixed epicarp of *Balanites aegyptiaca*

Figure 2.Mixed mesocarp of *Balanites aegyptiaca*

Figure 3. Mixed seeds of *Balanites aegyptiaca*

Figure 4.Mixed kernel of *Balanites aegyptiaca*

Figure 5. Oval fruits of *Balanites aegyptiaca*
(Om sagaa Village –Abu Jibeiha

Figure 6. Elongate fruits of *Balanites aegyptiaca*
(Wad- Abid Village –Abu Jibeiha)

Figure 7. Oblong fruits of *Balanites aegyptiaca*
(Mujeigha Village –Abu Jibeiha)

Figure 8. Spherical fruits (wrinkled, brown epicarp) of Balanites aegyptiaca
(Mujeigha Village –Abu Jibeiha)

Figure 9. Oblong fruits of *Balanites aegyptiaca*
(Elgulla Village –Dindir)

Figure 10. Oval fruits of *Balanites aegyptiaca*
(Draba Village –Dindir)

Figure 11. Spherical fruits of *Balanites aegyptiaca*
(ELazaza Village –Dindir)

Figure 12. Elongate fruits of Balanites aegyptiaca
(Draba Village –Dindir)

Figure 13.Yellow to dark brown mesocarp

Figure 14. Oil of *Balanites aegyptiaca* Kernel

Figure ١٥. Saponin of *Balanites aegyptiaca*

2. Variance Tables

Table 1. Variation in *Balanites aegyptiaca* fruit weight between sites in Abu Jibeiha area

Source	Df	Mean Square	F Value	Pr > F
Site	2	61.49	40.42	0.0001
Shape	3	126.93	83.44	0.0001
Error	294	1.52		

R Square= 0.46

Table 2. Variation in *Balanites aegyptiaca* fruit length between sites in Abu Jibeiha area

Source	Df	Mean Square	F Value	Pr > F
Site	2	522.5	52.38	0.0001
Shape	3	1114.05	111.68	0.0001
Error	294	9.98		

R Square= 0.615

Table 3. Variation in *Balanites aegyptiaca* fruit diameter between sites in Abu Jibeiha area

Source	Df	Mean Square	F Value	Pr > F
Site	2	43.77	10.94	0.0001
Shape	3	147.86	37	0.0001
Error	294	4		

R Square= 0.29

Table 4. Variation in *Balanites aegyptiaca* fruit shape index between sites in Abu Jibeiha area

Source	Df	Mean Square	F Value	Pr > F
Site	2	0.44	14.62	0.0001
Shape	3	2.18	72.31	0.0001
Error	294	0.03		

R Square= 0.56

Table 5. Variation in *Balanites aegyptiaca* fruit weight within site Wad Abid

: Source	Df	Mean Square	F Value	Pr > F
Shape	2	111.212	71.78	0.0001
Error	97	1.55		

R Square= 0.60

Table 6. Variation in *Balanites aegyptiaca* fruit length within site Wad Abid

Source	Df	Mean Square	F Value	Pr > F
Shape	2	584.28	52.79	0.0001
Error	97	11.07		

R Square= 0.52

Table 7. Variation in *Balanites aegyptiaca* fruit diameter within site Wad Abid

Source	Df	Mean Square	F Value	Pr > F
Shape	2	111.48	17.07	0.0001
Error	97	6.53		

R Square= 0.26

Table 8. Variation in *Balanites aegyptiaca* fruit shape index within site Wad Abid

Source	Df	Mean Square	F Value	Pr > F
Shape	2	0.550	12.28	0.0001
Error	97	0.05		

R Square= 0.20

Table 9. Variation in *Balanites aegyptiaca* fruit weight within site Mujeigha

Source	Df	Mean Square	F Value	Pr > F
Shape	1	13.219	11.17	0.0012
Error	98	1.18		

R Square= 0.102

Table10. Variation in *Balanites aegyptiaca* fruit length within site Mujeigha

Source	Df	Mean Square	F Value	Pr > F
Shape	1	814.98	63.35	0.0001
Error	98	12.9		

R Square= 0.39

Table11. Variation in *Balanites aegyptiaca* fruit diameter within site Mujeigha

Source	1	137.37	57.28	0.0001
Shape	98	2.4		
Error				

R Square= 0.369

Table 12. Variation in *Balanites aegyptiaca* fruit shape index within site Mujeigha

Source	Df	Mean Square	F Value	Pr > F
Shape	1	4.34	274.33	0.0001
Error	98	0.16		

R. Square= 0.736

Table 13. Variation in *Balanites aegyptiaca* fruit weight within site Om sagaa

Source	Df	Mean Square	F Value	Pr > F
Shape	1	145.74	79.19	0.0001
Error	98	1.84		

R. Square= 0.45

Table 14. Variation in *Balanites aegyptiaca* fruit length within site Om sagaa:

Source	Df	Mean Square	F Value	Pr > F
Shape	1	1386.74	238.34	0.0001
Error	98	5.82		

R. Square= 0.70

Table 15. Variation in *Balanites aegyptiaca* fruit diameter within site Site Om sagaa:

Source	Df	Mean Square	F Value	Pr > F
Shape	1	987.455	28.28	0.0001
Error	98	3.09		

R. Square= 0.22

Table 16. Variation in *Balanites aegyptiaca* fruit shape index within site Om sagaa:

Source	Df	Mean Square	F Value	Pr > F
Shape	1	1.30	46	0.0001
Error	98	0.02		

R. Square= 0.32

Table 17. Variation in *Balanites aegyptiaca* fruit weight between locations

Source	Df	Mean Square	F Value	Pr > F
Location	1	57.13	32.94	0.0001
Error	118	1.73		

R. Square =0.22

Table 18. Variation in *Balanites aegyptiaca* fruit length between locations

Source	Df	Mean Square	F Value	Pr > F
Location	1	360	9.93	0.0021
Error	118	36.25		

R. Square =0.07

Table 19. Variation in *Balanites aegyptiaca* fruit diameter between locations:

Source	Df	Mean Square	F Value	Pr > F
Location	1	16.65	1.06	0.305
Error	118	15.7		

R. Square =.0.009

Table 20. Variation in *Balanites aegyptiaca* fruit shape index between locations:

Source	Df	Mean Square	F Value	Pr > F
Location	1	0.32	1.32	0.25
Error	118	0.24		

R. Square =0.011

Table 21. *Balanites aegyptiaca* Seed length

Source	Df	Mean Square	F Value	Pr > F
Shape	3	197.4	106.7	0.0001
Error	36	1.85		

R Square=0.90

Table 22. *Balanites aegyptiaca* Seed diameter

Source	Df	Mean Square	F Value	Pr > F
Shape	3	197.4	25.6	0.0001
Error	36	1.04		

R Square=0.68

Table 23. ***Balanites aegyptiaca*** **Seed shape index**

Source	Df	Mean Square	F Value	Pr > F
Shape	3	3.6	99	0.0001
Error	36	0.04		

R Square=0.89

Table 24. ***Balanites aegyptiaca*** **Seed breaking force:**

Source	Df	Mean Square	F Value	Pr > F
Shape	3	2420.6	3.7	0.0195
Error	36	647.4		

R Square=0.24

Table 26. ***Balanites aegyptiaca*** **fruit epicarp layer%**

Source	Df	Mean Square	F Value	Pr > F
location	1	0.049	0.02	0.9
Shape	3	51.37	23.87	0.0001
Error	25	2.15		

R Square=0.74

Table 27. ***Balanites aegyptiaca*** **fruit mesocarp layer %**

Source	Df	Mean Square	F Value	Pr > F
location	1	18.3	1.32	0.26
Shape	3	76	5.47	0.005
Error	25	13.9		

R Square=0.41

Table 28. ***Balanites aegyptiaca*** **fruit endocarp layer %**

Source	Df	Mean Square	F Value	Pr > F
location	1	7.8	1.49	0.23
Shape	3	48.3	9.24	0.0003
Error	25	6.23		

R Square=0.54

Table 29. ***Balanites aegyptiaca*** **fruit kernel%**

Source	Df	Mean Square	F Value	Pr > F
location	1	6.9	8.6	0.007
Shape	3	30.2	31.14	0.0001
Error	25	0.80		

R Square=0.83

Table 30. ***Balanites aegyptiaca*** **invert sugar/fruit**

Source	Df	Mean Square	F Value	Pr > F
location	1	17.29	4.52	0.04
Shape	3	9.657	1.55	0.23
Error	25	3.828		

R Square=0.29

Table 32. ***Balanites aegyptiaca*** **total sugar/fruit**

Source	Df	Mean Square	F Value	Pr > F
location	1	63.68	11.4	0.002
Shape	3	9.16	1.64	0.21
Error	25	5.59		

R Square=0.37

Table 33. ***Balanites aegyptiaca*** **sucrose/fruit**

Source	Df	Mean Square	F Value	Pr > F
location	1	14.61	5.98	0.02
Shape	3	17.19	7.046.12	0.0014
Error	25	2.44		

R Square= 0.49

Table 34. Calibration curve

Concentration g/ml	Average Absorbance
0.01	0.83
0.008	0.57
0.006	0.51
0.004	0.482
0.002	0.39
0.001	0.319
0.0004	0.304

Average Absorbance at 544nm for pure saponin solutions in water

Table 35. Samples concentration of *Balanites aegyptiaca* fruit according to its average absorbance

Sample	Average Absorbance	Concentration g/ml
١	0.658	0.010011
٢	0.541	0.0065595
٣	0.563	0.0072085
٤	0.45	0.003875
٥	1.79	0.043405
٦	0.683	0.0107485
٧	1.79	0.043405
٨	0.824	0.014908
٩	1.04	0.02128
١٠	0.855	0.0158225

Average Absorbance at 544nm for saponin content in different fruit shapes

Table 36. *Balanites aegyptiaca* saponin/fruit

Source	Df	Mean Square	F Value	Pr > F
location	1	4.03	21.9	0.0001
Shape	3	1.79	6.9	0.002
Error	25	0.18		

R Square=0.61

Table 35. ***Balanites aegyptiaca*** **protein**

Source	Df	Mean Square	F Value	Pr > F
Location	1	11.7	0.98	0.33
Shape	3	30.03	2.52	0.08
Error	25	11.92		

R Square=0.25

Table 36. ***Balanites aegyptiaca*** **kernel oil**

Source	Df	Mean Square	F Value	Pr > F
location	1	79.6	2.9	0.099
Shape	3	68.1	2.6	0.08
Error	25	27.12		

R Square=0.29

Table37. ***Balanites aegyptiaca*** **moisture content**

Source	Df	Mean Square	F Value	Pr > F
location	1	0.065	10.95	0.003
Shape	3	0.014	2.33	0.099
Error	25	0.0059		

R Square=0.39

Table 38. ***Balanites aegyptiaca*** **saponin/mesocarp**

Source	Df	Mean Square	F Value	Pr > F
location	1	38.9	24.2	0.0001
Shape	3	7.2	4.8	0.009
Error	25	1.6		

R Square=0.58

Table 39. ***Balanites aegyptiaca*** **invert sugar/mesocarp**

Source	Df	Mean Square	F Value	Pr > F
location	1	81.4	1.9	0.18
Shape	3	83.2	1.7	0.15
Error	25	42.4		

R Square=0.2

Table 40. ***Balanites aegyptiaca*** **total sugar/mesocarp**

Source	Df	Mean Square	F Value	Pr > F
location	1	323	8.7	0.007
Shape	3	57	3.05	0.23
Error	25	36.97		

R Square=0.33

Table 41. ***Balanites aegyptiaca*** **sucrose/mesocarp**

Source	Df	Mean Square	F Value	Pr > F
Location	1	68.2	4.2	0.05
Shape	3	117.8	7.3	0.001
Error	25	16.17		

R Square=0.49