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The Thermodynamic Properties of Some *Acacia* Gums

الخصائص الثيرموديناميكية لبعض أصماغ الأكشيا

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By

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GENERAL INTRODUCTION

Acacia gums are, polysaccharides, obtained from the stems and branches of various plant species from the genus *Acacia* as dried exudates (FAO, 1990).

Gums of commercial importance have a significant ecological and socioeconomic impact on inhabitants of the semi arid zones, especially, the African gum belt. These, natural, products enjoy remarkable diversity of applications which is, mainly, due to their ability to reduce surface tension, extremely high solubility in water and low viscosity (Osman ,1993). They find, wide, applications in the Food and Beverages Industries as a natural emulsifier, particularly, for citrus oils (Egadu *et al*, 2007) they are, also, used in the pharmaceutical industry as a suspending agent and stabilizer (Fennema, 1996). Ancient Egyptians used it, largely, in paintings as an adhesive for mineral pigments.(Caris, 1939).

They are high molecular weight polymeric compounds, composed mainly of carbohydrate moieties capable of possessing colloidal properties in appropriate solvents.

They are either hydrophobic or hydrophilic in nature. Hydrophobic gums are insoluble in water and include resins such as olibanum gum. Whereas hydrophilic gums are soluble in water and can be subdivided into natural, semi synthetic and synthetic gums (Glicksman, 1973).

Acacia nilotica var.nilotica produces a gum which is, highly, soluble in water. However, very few analytical data about the relevant structural features of the polysaccharide from *A.nilotica var.nilotica* gum have been reported (Anderson *etal,* 1996, 1977, Chal *etal,* 1998, karamalla, 1999, Al-Assaf *etal*, 2005, Satti, 2012).

The objectives of this work are:

- To collect and authenticate samples of *Acacia nilotica var. nilotica* and *Acacia seyal var.seyal* gums.
- To compare and contrast the physiochemical properties of *A.nilotica var.nilotica* gum and *A.seya var.seyal* gum with previous studies.
- To determine functions such as partial specific volume of solvent and solute, Osmotic pressure, number average molecular weight, second virial coefficient, chemical potential of solute and solvent and free energy of mixing.

- To investigate the thermodynamic properties of gum solutions of *Acacia seyal var.seyal* (control).
- To compare the thermodynamic properties of *A.nilotica* var. *nilotica* and other gums from the Gummefereae subgenous.

LITERATURE REVIEW

2.1 Definition of *Acacia* gums

Acacia gums can be defined as the dry exudates obtained from the stems and branches of botanically aspecific species of a subgenous from family leguminosae (JECFA 1998).

Gums are an important article of commerce since ancient times. It was used by the Egyptians for embalming mummies and also for paints for hieroglyphic inscriptions.

Hence to-day, the term "gum arabic" includes two different types of gum which are produced in Sudan and marketed in significant quantities: one, the hard gum, known as "hashab" and originates from *Acacia senegal*. The other, known as "talha" is a flaky or crumbly variety, which originates from another type of *Acacia* tree, *Acacia seyal* var.*seyal* Gum has made its impact recently on the world market whereas trade in the hard gum from *Acacia senegal* dates from far earlier times. The two types of trees are relatively easily distinguishable.When the gum dries out, the two types again become easily distinguishable, *Acacia seyal* gum becomes flaky and is reduced into a granulated form, whereas the hard gum of the *Acacia senegal* var.*senegal* retains its form as hardened lumps or nodules.

According to Bentham's taxonomic classification of the *Acacia* genus, *A. seyal* var.*seyal* belongs to series 4 (*Gummiferae*) and *A.senegal* var.*senegal* to series 5 (*Vulgares*) (Bentham, 1875), subsequently modified somewhat by Vassal (Ross, 1979):

Series 4 *Gummiferae* Benth.= Subgen. *Acacia* Vas. also called '*Acacia seyal* complex which comprises: - *A.abyssinica* subsp. *calophylla, A. nilotica* (*syn. A. adansonii and A. arabica), A. drepanolobium, A. farnesiana, A. gerrardii, A. giraffae, A. hebeclada, A. karroo, A. kirkii, A. leucophloea, A. nebrownii, A. nubica, A. reficiens, A. rigidula, A. seyal, A. sieberana (var. villosa, var. woodii), A. seyal (var. fistula, var. seyal), A. tortilis* (subsp. *heteracantha*).

Series 5 *Vulgares* Benth. = Subgen. *Aculeiferum* Vas. Also called '*Acacia senegal* complex that contains:- *A. berlandieri, A. polyacantha subsp. campylacantha, A. catechu, A. erubescens, A. fleckii, A. goetzii subsp. goetzii, A. laeta, A. mellifera, subsp detinens, A. senegal, A. sundra*.

Examples only are given here of *Acacia* species belonging to these two important categories from which commercial gum is derived. Many studies have investigated a selective range of gum arabic samples from both *Vulgares* and *Gummiferae* series in order to obtain more precise information about whether there is conformity in molecular properties within these two taxonomic series and any differences which may be evident between them. (Al-Assaf *et al*., 2005).

Acacia senegal var.*senegal* gum have an optical rotation of between –24° and –34°, a pH between 4.1 and 4.8, a viscosity less than 140 cps and an insoluble content of less than 3%. *Acacia seyal* var.*seyal* gum have an optical rotation of between +45° and +55°, a pH between 4.1 and 4.8, a viscosity below 70 cps.

2.2 Geographical location of the gum belt

Acacia senegal var. *senegal* trees, the main source of gum, are spread through the African gum belt (Glickman and Sand, 1973). This belt is located north of the Equator and south of the Sahara deserts, an arid zone between latitude 10°and 14°, and extends from east to west continuously from Somalia through Ethiopia, Sudan, Chad, Niger, Nigeria, Burkina Faso, Mali, Mauritania and Senegal. It is also found in some parts of Africa south the Equator e.g. Tanzania, Zimbabwe, Malawi and South Africa (Figure 2.1). In Asia, *Acacia senegal* was found in Arabia and India.

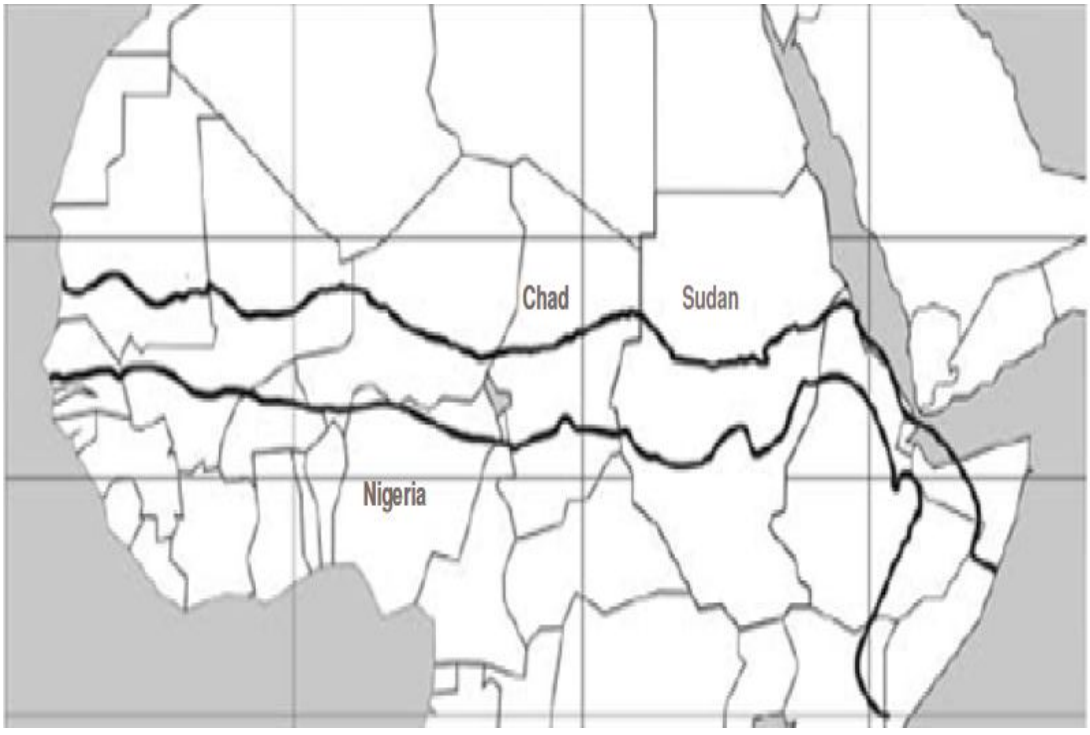

Figure 2.1: African gum belt

In the Sudan more than thirty distinct *Acacia* species found, most of them are produce gum, but *Acacia senegal var.senegal* is the more predominant, that made Sudan the world's largest producer of gum, followed by Chad and Nigeria (D.Verbeken *et al*., 2003). The gum belt in the Sudan covers an area of 520,000 km^2across central Sudan and accounts for one fifth of the country total area (IIED and IES, 1990). It covers two main regions namely western and eastern Sudan. The west comprises Kordofan (north, south, and west), Darfur (north, south, and west) and part of the White Nile region; while the east includes the Kassala, Gadaref and Sinnar regions. This area, however, exhibits diverse soil and climatic conditions. Nowadays gum production started shifting towards south and south east according to the rain fall belt, which resulted in the time of tapping also shifted from October to November. This means that some areas have become unproductive such as Kassala and White Nile and other regions entered the gum belt which was out of the boarder of the gum belt latitude such as Upper Nile and Blue Nile (Figure 2.2).

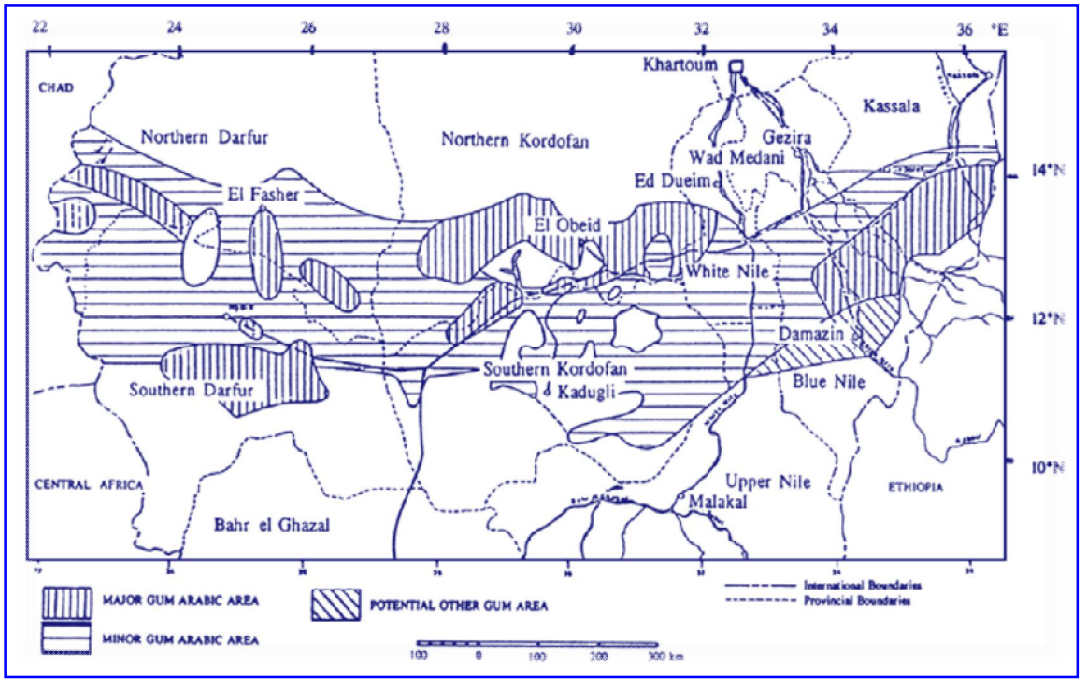

Figure 2.2: Sudan gum belt

2.3 *Acacia* distribution

There are many species (some 700) of which few can provide gum volume of industrial interest. A total of 17 *Acacia* species were identified in the twelve African

countries are producing gum collected by local communities either for export or for domestic use (Casadei, 1998). *A.senegal, A.seyal and A.polyacntha* have wide spread distribution within the gum belt. Even these species are found in more than one variety .*A.senegal* has three positively identified varieties and a fourth one not completely decided *var.senegal* (syn.A. verek Guill and pesry),*A.senegal* (L) willd *var.kerensis Schweinf,A.senegal* (L) willd *var.* rostate Brenon and *A.senegal (L)* willd *var.leiarhachis* Bernon, *seyal*occurs in two variations, *A.seyal* Del. *var. seyal A.seyal* Del. *var.fistula* (Hassan,2000).

Other gum yielding *Acacia* species have limited regional distribution. For instance *A. Karoo* is confined to southern Africa, while *A. dudgeoni* are confined to West Africa. *A. gourmeansis, A.macrothyrsa* has been more restricted distribution in West Africa. *A.senegal* and *A.seyal* were confirmed as the main sources of gum of commerce accounting for up to 95% of total gum produced. *A.senegal* contributes about 70% and *A. seyal* 15-25% the remaining comes from *A. polyacantha* and *A.laeta* that are often sold in admixture with *A.senegal* gums among West Africa producing countries (Casadei, 1998).

2.4 Gum sources

Gum exudates from certain *Acacia* (family leguminosae) trees which occur in semi arid land stretching across sub-saharan Africa .There are more than thousand species of *Acacia* that a summary of their botanical classification following Bentham (Bentham, 1875; Vassal, 1972 and Ross1979) has been presented by Philips and Williams (1993).Gum may be classified according to their sources (Table 2.1).

The gum belt occurs as abroad band from the horn of Africa, and from there it extends through east Africa to southern Africa covering southern Angola, Namibia, Zambia, Zimbabwe, Botswana, South Africa and part of Mozambique.

Sudan is the world largest producer of the gum, with production reaching sixty thousand tones. Chad is the second largest producer followed by Nigeria.

Table 2.1 Classification of Gums according to their sources

Sources	Gum
Tree exudates • *Acacia Senegal;Acacia seyal and other Acacia* of African origins • Astrgalus species (Iran /Turky) • Sterculia urens (India /African • Anogeiss latifolia	*Acacia senegal* Gum tragacanth Gum karaya, Gum ghatti
Seaweed extracts • Gelidicum and Gracilar species • Euchemacottonii;Euchema spinosum ;Choandus crispus and Gignrtina species • Laminaria hyperborean ;Macocystis purifera and Ascophyiius nodosum	Agar Carrageenan Aginate
plant extracts • peels of various citrus fruits and apples pommace	Pectins
Seed roots and gum • Cyamopsis tetragonolobba • Ceratonia • Cesalainia • Amorphophallus konjac	• Guar gum • Locust bean gum • Tera gum • Konjac mannan
Microbail gums • Xanthamonas Camestris • Auromonas **Cellulose gums** Cellulose pulps and cotton linters	• Xanthan gum • Gellan gum • Sodium carboxymethyl cellulose, Methylcellulose, Hydroxypropylmethylcellulose

2.5*Acacia Senegal* and *Acacia seyal*

The *Acacia Senegal* species has a wide distribution and remarkable adaptability. It is essentially a semi-arid zone species, but it is both drought and frost resistant and can grow with a rainfall of between 100 and 800 mm per year. To be able to get gum from this tree, it has to be tapped about 3-6 weeks in advance of collection. In the Sudan, particularly in the Kordofan and Darfour provinces, the species is uniform

and found in pure stands giving the Sudan an important advantage of being the most important producer of this type of gum Senega. In other producing countries, *Acacia Senegal* is often found mixed with other species. Another feature of the Sudan system of production is that this species occurs both as a wild and as a cultivated species – it is often replanted by man in village plantations, for example, in this country. The *Acacia seyal* on the other hand grows and regenerates naturally; it does not require tapping and exudes its gum naturally. It grows in the Sudano-Sahelian belt where the rainfall is slightly higher than in the regions populated with the *Acacia senegal*. It can grow on clay soils and resists well to climatic changes from temporary wet to prolonged dry periods with a consequent cracking of the soil surface. Whilst *Acacia senegal var.senegal* and the *Acacia seyal* var.*seyal* are grow together in the same geographical zone, they have their own biotope in rain fall region of southern part of kurdofan and blue nile state.

2.5.1 Botanical classification of *Acacia seyal*

Family: *Leguminoseae.*

Subfamily: *Mimosoideae.*

Genus: *Acacia.*

Species: *seyal*.

English name: *seyal*

Arabic name: Talha (EL Amin, 1977, Voget, 1995).

2.5.2 Description

Tree 3-17m high. Bark powdery, smooth or sparsely flaking, whitish to greenish yellow or orange-red. Stipules spinescent. Leaves 1-12 cm long, leaflets 7-20 paired 3-7 x 0.5-1.3mm, oblong to linear, flower bracts pubescent, medium line onspicuous, and 2.5mm long. Calyx pubescent, 4-6 lobed, white toyellow. Ovaries sessile brown 0.5mm long, style 3-4mm long.Pods falcate, dehiscent, constricted between seeds, venation longitudinal, 7-22cm long, 0.5-0.9cm wide. Seeds olive to olive-brown, glabrous, compressed, elliptic lying longitudinally in the bod, funicle very long and coiled, 1.5cm long. Flowering November–April, fruiting January–May (EL Amin, 1977, Voget, 1995).

Figure 2.3: *Acacia seyal* tree

2.6 Physicochemical properties of gum

The identification of a particular gum from a series of different gum exudates needs an extensive number of analytical tests to perform as shown in Tables (2.3 and 2.4). This approach enables "a chemical finger print" of each gum to be determined. The five most important parameters that can be used to identify raw gums are: (1) Specific optical rotation, (2) Nitrogen content, (3) Ash content, (4) Moisture content and (5) Absence of tannins. (Karamallah, 1999). The most fundamental properties of a gum which makes it unique amongst polysaccharide generally are its solubility and viscosity. The majority of gums dissolve in water at different concentration.

2.6.1 Moisture content

Moisture content of the gum determines the hardness of the gum and hence the variability of densities and the amount of air entrapped during nodule formation. It can be determined by measuring the weight loss after water evaporation. Reducing the moisture content of the natural gum can be readily used as a tenable method of reducing the microbial counts. (Karamallah, 1999).

Anderson *et al*., (1963) reported the moisture content of *A.seyal var.seyal* gum in the range from 11% to 16.1%. Randall *et al*., (1988) found that the moisture content of Kordofan *A.senegal var.senegal* 15.5%. Osman (1993) reported the moisture content of *A.senegal var.senegal* gum was range between12% to 15%.Osman (1993) reported the moisture content of *A.senegal var.senegal* in the average of 13.0%.

Karamallah *et al*., (1998) reported a mean value of moisture content for 803 *A.senegal var.senegal* gum samples collected in season 1994/1995 was 10.75% and the range was 8.1% –14.05%.Also they reported the moisture content for authenticated *A.senegal var.senegal* gum samples collected in season 1995/1996, the minimum value was 9.15% and the maximum value was 14.3%. Moisture content for 100 commercial samples of *A.senegal var.senegal* gum collected between 1992 and 1996 in the same study had a mean value of 14.16%. The moisture content of *A.senegal var.senegal* gum samples collected from trees of various ages and different locations by Idris *et al* (1998) was found to be in the range of12.5%-16%. Karamallah (1999) measured the moisture content in *A.senegal var.senegal* and *A.seyal var.seyal* gum collected between 1960 and 1999 in Sudan, it was found equal to 10.75% and 9.4% respectively. Hassan (2000) in the study of *A.seyal var.seyal* gum from different locations of Sudan reported an average of 8.5% moisture content. Hassan *et al*., (2005) reported the moisture content of *A.seyal var.seyal* gum in the range from 7.4% to 8.3%. Siddig *et al*., (2005) reported the value of 12.6% for the moisture content of *A.seyal var.seyal* gum. Omer (2006) found that the moisture content of *A.senegal var.senegal* and *A.seyal var.seyal* gum were in the range of 11.76% to 14.8% and 5.66% to 11.11% respectively. Moisture content in *A.senegal var.senegal* and *A.seyal var.seyal* gum was determined by Abdelrahman (2008) and it was found to be 11.01% and 11.07% respectively. Younes (2009) reported the mean value of moisture content for *A.senegal var.senegal* gum as 11.01% and the range was 9.91% – 14.72%, and the mean value of moisture content for *A.seyal var.seyal* gum was 10.10% and the range was 9.90% – 10.35%. Satti(2012) reported the mean value of moisture content for *A.nilotica var.nilotica* the range was 10.33% - 10.81%.

Table 2.2: Chemical analysis of some African *Acacia* species gums. (Younes, 2009)

Species	Ash%	N %	$(\alpha)_D^{25}$	(η)	Mw X 10^6	A.E.W	Uronic acid%	References
A. ehrenbergiana	3.10	0.09	-0.7	07.00	0.27	1060	17.00	Anderson *et al*., (1984)
A. hockii	1.30	0.23	+91	13.00	nd	521	34.00	Anderson *et al*., (1984)
A. karoo	0.56	0.13	+54	nd	1.46	Nd	12.00	Anderson *et al*., (1984)
A. kirbii	1.40	0.09	+54	08.00	0.21	1817	09.70	Anderson & Farquhan (1979)
A. nilotica	2.48	0.02	+108	09.50	2.20	1890	09.00	Anderson (1976)
A. nubica	1.54	0.20	+98	09.80	0.87	3030	07.00	Anderson (1976)
A. rubusta	Nd	2.80	+36	ns	0.72	1660	09.00	Chrmus & Stephen (1984)
A. sieberana	1.50	0.19	+103	12.00	0.14	1230	04.00	Anderson *et al*., (1973)
A. acatechii	0.28	Nill	-30	nd	0.40	Nd	03.30	Aganwwal & Soni (1988)
A. erubescens	3.90	1.08	-13	08.00	200	874	20.10	Anderson & Farquhan (1979)
A. fleckii	4.00	0.58	-32	13.00	415	918	19.20	Anderson & Farquhan (1979)
A.laeta	Nd	0.56	-42	20.70	725	1250	14.00	Anderson (1976, 1977)
A. mellifera	2.90	1.45	-56	23.50	410	843	20.90	Anderson & Farquhan (1979)
A. polyacantha	Nd	0.37	-12	15.80	nd	2020	09.00	Anderson (1986)

Table 2.3: Analytical data of the gum exudates from different *Acacia* species of the Sudan. (Karamalla, 1999).

Species	Moisture (%)	Ash (%)	Nitrogen (%)	protein (%)	pH	Titrable acidity	Relative Viscosity	Sp. Rot (degree)	Arabinose (%)	Rhamnose (%)	Methoxyl (%)
A. sieberana var. sieberana	5.30	1.90	0.35	02.19	3.95	5.82	1.36	+74.16	41	03.0	-
A. sieberana var .*vermesenii*	4.90	2.10	0.35	02.19	3.88	6.00	1.47	+77.16	48	05.0	-
A .nubica	4.60	0.03	0.35	02.19	3.50	10.20	0.50	+64.16	48	04.3	0.15
A. tortilis subsp. raddiana	4.40	1.80	1.84	11.50	3.60	8.50	0.77	+71.33	43	07.0	-
A. tortilis subsp. spirocarpa	6.40	2.03	1.40	07.50	3.85	6.50	0.76	+68.66	41	08.0	-
A. tortilis subsp. tortilis	6.10	1.90	1.20	08.75	4.15	4.80	0.80	+69.00	58	05.0	0.57
A. drepandolobium	6.10	0.01	0.87	05.44	4.05	5.10	1.01	+75.83	49	02.0	0.40
A. grrardii	5.90	3.10	2.31	14.44	4.40	3.80	2.75	+48.50	37	09.0	-
A. ehrenbergiana	7.90	2.60	0.22	01.37	3.45	11.0	0.37	+5.66	39	08.0	-
A. nilotica subsp. nilotica	6.10	0.03	0.06	00.37	4.10	5.00	0.69	+97.66	42	01.8	1.14
A. nilotica subsp .tomentosa	5.80	0.04	0.10	0.62	4.48	4.15	0.90	+80.16	4	01.9	0.88
A.nilotica subsp. astringen	5.60	0.06	0.06	00.37	3.75	7.00	0.68	+75.16	39	01.0	-
A. laeta	3.20	2.80	0.51	03.19	3.70	7.70	1.12	-37.50	23	12.0	0.33
A. polyacantha	6.50	2.70	0.34	02.12	4.25	4.50	0.66	-19.10	31	9.0	-
A. seyal var. *seyal*	7.20	2.30	0.10	00.63	4.35	4.18	1.28	+50.50	52	04.0	1.02
A. seyal var. *fistula*	8.00	1.60	0.14	00.87	3.80	6.90	1.77	+42.66	49	07.0	0.90
A. Senegal	7.40	3.70	0.33	01.87	4.66	3.60	1.40	-31.30	21	14.0	0.36

2.6.2 Ash content

The ash content indicates the presence of inorganic elements existing in salt form. Anderson *et al*., (1968) and Karamallah (1999) showed that the type of soil (clay or sand) affected the ash content significantly.

Anderson *et al*., (1963) reported the ash content of *A.seyal var.seyal* gum in the range from 1.94% to 3.55%.Anderson (1977) reported the ash content of *A.senegal var.senegal* and *A.seyal var.seyal* gum in the value of 2.87% and 3.93% respectively. The same author in (1991) in the final report of the safety assessment of acacia gums reported the mean value of ash content 3.61% on *A.senegal var.senegal* samples provided by importers in 1990/1991. Jurasek *et al* (1993) found that the ash content of *A.senegal var.senegal* 3.0%.

Osman (1993) reported an ash content of *A.senegal var.senegal* in the average of 3.6%. The mean value of ash content had been determined for 803 *A.senegal var.senegal* gum samples collected in season 1994/1995 by Karamallah *et al*., (1998) and was found 3.77%.The same author reported value of 3.7% ash content for authenticated sample and 3.62% for commercial sample of *A.senegal var.senegal* gum. Again Karamallah (1999) reported the value of 3.7 and 2.3ash content for *A.senegal var.senegal* and *A.seyal var.seyal* gum respectively collected between 1960 and 1999 in Sudan.

Hassan *et al*., (2005) in the study of *A.seyal var.seyal* gum from different locations of Sudan reported an average of 0.21% ash content.Omer (2006) reported the ash content of *A.senegal var.senegal* in the average of 3.27% and in the average of 2.61% for *A.seyal var.seyal* gum.The mean value of ash content reported by Abdelrahman (2008) in *A.senegal var.senegal* and *A.seyal var.seyal* gum in the average of 3.32% and 2.43% respectively. Younes (2009) reported the mean value of ash content for *A.senegal var.senegal* gum was 4.89% in the range of 4.0% – 5.23%, and the mean value of ash content for *A.seyal var.seyal* gum 4.47%. Satti(2012) reported the ash content in *A.nilotica var.nilotica* gum in mean value the range from 1.82% - 1.91%.

2.6.3 pH value

The hydrogen ion concentration plays great importance in the chemistry and industry of the gums. The change in the concentration of hydrogen ion may determine the solubility of gum and the precipitation of protein, therefore

functional properties of a gum may be affected by change in pH for example viscosity and emulsifying power. Crude gum is slightly acidic because of the presence of few free carboxyl groups of its constituent acidic residues, D-glucuronic acid and its 4-O-methy1 derivatives.

Karamallah *et al*., (1998) reported the pH mean value of 4.66 for the 755 authentic *A.senegal var.senegal* gum samples, collected in season 1994/1995. The same author in the same study reported the mean value of 4.54 for commercial samples collected between 1992 and1996, also they reported an average value of 4.4 for *A.senegal var.senegal* gum samples, collected between 1960 and 1995. Karamallah (1999) reported 4.66 pH values for *A.senegal var.senegal* and 4.2 for *A.seyal var.seyal* gum. The pH value had been determined by Younes (2009), he reported a value of 4.78 for *A.senegal var.senegal* and 5.16 for *A.seyal var.seyal* gum. Satti (2012) reported the mean value of pHvalue for *A.nilotica var.nilotica* the range was 5.15–5.24.

2.6.4 Specific optical rotation

The optical activity of organic molecules (saccharrides and carbohydrates) is related to their structure and is a characteristics property of the substance, and thus the specific rotation is considered as the most important criterion of purity and identity of any type of gum.

Anderson *et al*., (1963) reported the specific optical rotation of *A.seyal var.seyal* gum in the range from +44^{o} to +56^{o}.Anderson (1977) reported a value of -30^{o} specific optical rotation for *A.senegal var.senegal* and +51^{o} for *A.seyal var.seyal* gum.Vavdevelde and Fenyo (1985) reported specific optical rotation of *A.senegal var.senegal* to be ranging between -29^{o} to -34.4^{o}. Anderson (1991) reported the mean value of specific optical rotation -30.5^{o}on*A.senegal var.senegal* samples provided by importers in 1990/1991. Jurasek *et al*, (1993) reported a range of -20° to -32° for *A.senegal var.senegal*, and a value of +51^{o} for *A.seyal var.seyal* gum. Osman (1993) reported specific optical rotation of *A.senegal var.senegal* to be ranging between -29^{o} to -31^{o}. Karamallah *et al*., (1998) reported the specific optical rotation for the 789 authentic *A.senegal var.senegal* gum samples, between-26^{o}to-34^{o}.Specific optical rotation of *A.senegal var.senegal* gum samples collected from trees of various ages and different locations by Idris *et al*., (1998) was found to be in the range of -27^{o} to -

36^{o}.Karamallah (1999) reported -30.3^{o} specific rotation for *A.senegal var.senegal* and +50.6^{o} for *A.seyal var.seyal* gum. Hassan (2000) reported that *A.seyal var.seyal* gum exhibit dextrorotatory optical rotation ranging from +40^{o} to +62^{o}. Hassan (2005) reported +53^{o} mean value of specific optical rotation of *A.seyal var.seyal* gum. Optical rotation of *A.seyal var.seyal* gum had been determined by Siddig *et al*., (2005) and found to be+45^{o}. Omer (2006) reported that an average values of specific optical rotation equal to -32^{o}, and +49.4^{o} for *A.senegal var.senegal* and *A.seyalvar.seyal* respectively. Abdelrahman (2008) reported the average value of optical rotation of *A.senegal var.senegal* gum -31.5^{o} whereas equal to +61^{o} for *A.seyal var.seyal* gum. Younes (2009) reported a value of -30^{o} specific rotation for *A.senegal var.senegal* and +52^{o} for *A.seyal var.seyal* gum. Satti(2012) reported the mean value of specific optical rotation for *A.nilotica var. nilotica* the range was found +90.92 - +99.17.

2.6.5 Viscosity

The viscosity of a liquid is its resistance to shearing, to stirring or to flow through a capillary tube. Viscosity was considered as one of the most important analytical and commercial parameters, since it is a factor involving the size and the shape of the macro – molecule (Anderson *et al*., 1969). Viscosity can be presented in many terms such as relative viscosity, specific viscosity, reduced viscosity, inherent viscosity and intrinsic viscosity. It is also presented as kinematic or dynamic viscosity.

The intrinsic viscosity has great practical value in molecular weight determinations of high polymers. This concept is based on the Mark-Houwink relation suggesting that the intrinsic viscosity of a dilute polymer solution is proportional to the average molecular weight of the solute raised to a power in the range of 0.5 to 0.9. Values of the proportionality constant and the exponent are well known for many polymer-solvent combinations. Solutions viscosities are useful in understanding the some polymers.

The stiffness of the polymer can be known from the relationship between intrinsic viscosity and changing ionic strengths of gum solutions.

Anderson (1977) reported a value of 13.4 $cm^{3}g^{-1}$ intrinsic viscosity for *A.senegal var.senegal* and 12.4$cm^{3}g^{-1}$ for *A.seyal var.seyal* gum. Duvallet *et al*., (1989) reported that the intrinsic viscosity of *A.senegal var.senegal* had a value of

21.8cm^3g^{-1}. Jurasek *et al*., (1993) found that the intrinsic viscosity ranged between 13.4-23.1 cm^3g^{-1} for *A.sengal var.senegal* and equal to 12.4 cm^3g^{-1} for *A.seyal var.seyal*. Idris *et al*., (1998) studied the intrinsic viscosity of *A.senegal var.senegal* from trees of different ages and different locations and concluded that the intrinsic viscosity varies with age of the trees but no affect was seen from trees in different locations. They found that the intrinsic viscosity of *A.senegal var.senegal* was in the range from10.4 to19.8cm^3g^{-1}. Karamallh *et al*., (1998) reported that the mean value of intrinsic viscosity of 1500 samples of *A.senegal var.senegal* was 16.44cm^3g^{-1}. Also Karamallh, (1999) reported the intrinsic viscosity was equal to 16.6 cm^3g^{-1} for *A.senegal var.senegal* and 11.0 cm^3g^{-1} for *A.seyal var.seyal*. Hassan *et al*., (2005) reported that the intrinsic viscosity of *A.seyal var.seyal* in the ranges between 11.9–17.6cm^3g^{-1}. The intrinsic viscosity had been determined by Flindt *et al*., (2005), they reported that the intrinsic viscosity of *A.seyal var.seyal* fall in the range from 11.6 to 17.7cm^3g^{-1}. Al-Assaf *et al*., (2005) reported that the intrinsic viscosity of sixty seven samples of *A.senegal var.senegal* in the range 9.7-26.5cm^3g^{-1}. The intrinsic viscosity of *A.seyal var.seyal* gum had been determined by Siddig *et al*., (2005), it was found to be 14cm^3g^{-1}. Omer (2006) found that an average values of intrinsic viscosity equal to 14.6cm^3g^{-1}, and 11.4cm^3g^{-1} for *A.senegal var.senegal* and *A.seyal var.seyal* respectively.Abdelrahman (2008) reported the average value of intrinsic viscosity of *A.senegal var.senegal* gum 15.4cm^3g^{-1} whereas equal to 11.6cm^3g^{-1} for *A.seyal var.seyal* gum. The intrinsic viscosity had been determined by Elmanan *et al*., (2008), they reported that the intrinsic viscosity ranged between 14.7 to 17.3cm^3g^{-1} for *A.senegal var.senegal* and between 14.6 to 14.9cm^3g^{-1} for *A.seyal var.seyal*. Younes (2009) reported a value of 18.9cm^3g^{-1}intrinsic viscosity for *A.senegal var.senegal* and 15.5cm^3g^{-1} for *A.seyal var.seyal* gum.Satti(2012) reported the mean value of intrinsic viscosity for *A.nilotica var.nilotica* the range was found 10.19–10.56cm^3g^{-1}.

2.6.6 Nitrogen and protein content

The role of nitrogen and nitrogenous component in the structure, physicochemical properties and functionality of gum was recently subjected to intensive investigation (Dickinson *et al.,* 1988, Randall *et al.,* 1989). Dickinson (1991) studied the emulsifying behavior of gum and concluded that there was a

strong correlation between the proportion of protein in the gum and emulsifying stability.

Anderson *et al*., (1963) reported that nitrogen content of *A.seyal var.seyal* gum ranged from 0.09 – 0.19% w/w. Nitrogen content of *A.senegal var.senegal* gum had been determined by Anderson (1977) and was found to be 0.29% and for *A.seyal var.seyal* 0.14%. Jurasek *et al*., (1993) reported 0.28 to 0.35% nitrogen content for *A.senegal var.senegal* samples and 0.14% for *A. seyal.* Osman (1993) reported that nitrogen content for the *A.senegalvar.senegal* gum to be 0.31% and protein content 2.4%. Idris *et al*., (1998) studied the nitrogen content of *A.senegal var.senegal* from trees of different ages and different locations and they found the range between 0.22- 0.39%, hence protein content ranged between 1.5-2.6%. Karamallah *et al*., (1998) reported the mean value of nitrogen content for 642 *A.senegal var.senegal* gum samples collected in season 1994/1995 as 0.33% .Also they reported the mean value of nitrogen content for authentic *A.senegal var.senegal* gum samples collected in season 1995/1996 as 0.3%. Nitrogen content for 100 commercial samples of *A.senegal var.senegal* gum collected between 1992 and 1996 in the same study had a mean value of 0.32%. Karamallah (1999) reported nitrogen content in comparative analytical data for *A.senegal var.senegal* and *A.seyal var.seyal* gums collected between 1960–1999 in Sudan to be 0.33% for *A.senegal var.senegal* gum, and 0.11% for *A.seyal var.seyal* gum. Hassan *et al*., (2005) reported protein content of *A.seyal var.seyal* had a mean value of 0.96%. The nitrogen content of *A.seyal var.seyal* gum had been determined by Siddig *et al*., (2005), it was found to be 0.15% and hence protein content found to be 1.0%. Omer (2006) determined the nitrogen content for samples of *A.senegal var.senegal* and *A.seyal var.seyal* from different locations, the values were 0.35% and 0.14% for *A.senegal var.senegal* and *A.seyal var.seyal* respectively, whereas protein content had a value of 2.3% and 0.93 respectively. Abdelrahman (2008) reported the average value of nitrogen content of *A.senegal var.senegal* gum 0.37% whereas equal to 0.14% for *A.seyal var.seyal* gum, he found that protein content of *A.senegal var.senegal* gum 2.4% and equal to 0.95% for *A.seyal var.seyal* gum. Recent study by Younes (2009) determined nitrogen content for *A.senegal var.senegal* 0.35% and protein content

2.3%, for *A.seyal var.seyal* the author reported nitrogen content 0.22% and protein content 1.4% .

Satti (2012) reported the mean value of nitrogen content and protein content for *A.nilotica var.nilotica* were found 0.02% and 0.16% respectively.

2.6.7 Acid equivalent weight and uronic acid

Titrable acidity represented the acid equivalent weight of gum, from which the uronic acid content, could be determined (Anderson *et al.,* 1977, Vandevelde *et al*., 1985, Jurasek *et al.,* 1993). Gums were found to differ widely in their equivalent weight and uronic acid content (Anderson *et al.,* 1977).

Anderson *et al*., (1963) reported that the uronic anhydride of *A.seyal var.seyal* sample after electrodialysis was found to be in the range between 12.1 – 16.8%, while the crude gum in the range between 9.0–16.4%. Anderson (1977) reported a value of 16% uronic acid for *A.senegal var.senegal* and 12% for *A. seyal* gum. Jurasek *et al*., (1993) reported uronic acid for *A.senegal var.senegal* was found to be in the range between 12-28.3% and for *A.seyal var.seyal* 6.5%. Hence acid equivalent weight found to be in the range between 1430-1125 and for *A.seyal var.seyal* 1470.Osman *et al*., (1993) reported a value of 21% uronic acid for *A.senegal var.senegal*. Karamallah *et al*., (1998) reported the mean value of uronic acid for 115 *A.senegal var.senegal* gum samples collected in season 1994/1995 as 13.7% and a mean value of 1436 acid equivalent weight. Idris *et al*., (1998) found the uronic acid of *A.senegal var.senegal* from trees of different ages and different locations in the range of 15-16%, hence acid equivalent weight ranged between1118-1238. Karamalla(1999) calculated that the glucuronic acid percentage for *A.senegal var.senegal* gum in the range 16-17%. While for *A.seyal var.seyal* gum was in the range of 11-12%. Hassan *et al*., (2005) study seventy four authenticated different samples of *A.seyal var.seyal* from different location by using acid–base titrimetric method; he reported the mean value of equivalent weight 1489 and the uronic acid 11.9%. Siddig *et al*., (2005) reported uronic acid for *A.seyal var.seyal* 16%.Omer (2006) reported that the acid equivalent weight was to be 1161 in average, and glucouronic acid was to be 15.2% in average for *A.senegal var.senegal,* whereas acid equivalent weight was to be 1107.9 in average and glucouronic acid was to be 15.9% in average for

A.seyal var.seyal. Abdelrahman (2008) reported the value of 16.8% uronic acid of *A.senegal var.senegal* gum and 1153.8 acid equivalent weight value. The author found the value of uronic acid of *A.seyal var.seyal* 16.4% and 1185.8 acid equivalent weight value. Acid equivalent weight and uronic acid had been determined by Younes (2009), he reported the mean value of acid equivalent weight 1620 and uronic acid 11.89% for *A.senegal var.senegal* gum, and also he reported a value of 1180 acid equivalent weight and 16.34% uronic acid for *A.seyal var.seyal.* Satti(2012) reported the mean value of acid equivalent weight and uronic acid for *A.nilotica var. nilotica* the range were found 1904.48% - 1910.61% and 10.17% - 10.20% respectively.

2.6.8 Sugar composition

Monosaccharide composition of gum is determined by acid hydrolysis of the gum, complete hydrolysis yields four basic sugar constituents, D-galactose, L-arabinose, L-rhamnose and D-glucuronic acid.

Anderson (1977) reported that sugar content of *A.senegal var.senegal* was 41% galactose, 27% arabinose, 14% rhamnose and 14.5% glucuronic acid. Jurasek *et al*., (1993) reported sugar composition as 34-46% galactose, 23-35% arabinose and 9-16% rhamnose for *A.senega var.senegal*, and 38% galactose, 46% arabinose and 4% rhamnose for *A.seyal var.seyal*. The sugar content of *A.senegal var.senegal* studied by Osman *et al*., (1993), they reported the value of 35% galactose, 27% arabinose, 14% rhamnose and 21% glucuronic acid.

Idris *et al*., (1998) studied the sugar composition of *A.senegal var.senegal* samples collected from trees of various ages and different locations. They found that the average values were 39-42% galactose, 24-27% arabinose and 12-16% rhamnose. Karamallah (1999) reported comparative analytical data for *A.senegal var.senegal* and *A.seyal var.seyal* gums collected between 1960 and 1999 in Sudan, he reported sugar content had a value of 36-42% galactose, 24-29% arabinose,12-14%rhamnose and16-17%glucuronic acid for*A.senegal var.senegal*, whereas had a value of 37-38% galactose, 41-45% arabinose, 3-4% rhamnose and 11-12% glucuronic acid for *A. seya var.seyal*.

Islam *et al*., (1997) and Williams *et al*., (2000) reported the sugar content of *A.senegal var.senegal* 44% galactose, 27% arabinose, 12% rhamnose and 14.5% glucuronic acid. Also they reported the sugar content of *A.seyal var.seyal* as 38%

galactose, 46% arabinose, 4% rhamnose and 6.5% glucuronic acid. Flindt *et al*., (2005) reported the sugar content of *A.seyal var.seyal* 34.9% galactose, 26.5% arabinose,11.5%rhamnose and11.6%glucuronic acid. Siddig *et al*., (2005) reported the sugar content of *A.seyal var.seyal* 36% galactose, 44% arabinose, 3% rhamnose and 16% glucuronic acid. The average values of sugar content determined by Abdelrahman (2008) of*A.senegal var. senegal* 29.7% galactose, 21% arabinose and 10.1% rhamnose. He also found the sugar content of *A.seyal var.seyal* as 28.8% galactose, 34% arabinose and 1.6% rhamnose.

2.6.9 Cationic composition

The most four abundant cationic elements present in gum are calcium, potassium, magnesium, and sodium.

It had been cited in the final report of the safety assessment of different *Acacia* gum that Anderson *et al*., (1990) reported the cation composition of Sudanese *A.senegal var.senegal* samples between 1904 and 1989. In the same report United States Pharmacopoeia reported the specifications grade of *Acacia* as arsenic (3ppm), lead (0.001%) and heavy metals (0.004%). The specifications for food grade *Acacia* include arsenic (3mg/kg maximum), heavy metals (0.002% maximum) and lead (5mg/kg maximum) had been cited in the same report. Table (2.4) shows data of cationic composition of *A.senegal var.senegal* and *A.seyal var.seyal* gums.

2.6.10 Molecular weight of *A.senegal, A.seyal* and *A.nilotica*

The weight average molecular weights (M_w) had been determined for *A.senegal var.senegal* and *A.seyal var.seyal* in many publications, but there are a few literatures about *A.nilotica var.nilotica*.

Molecular weights of *A.senegal var.senegal* show wide variations which can be mainly attributed to the method used for the determinations and the heterogeneity of samples (Duvallet *et al*., 1989).

Valuable examination of the literature can be carried out only by taking into account the specificity and the limits of the experimental method.

Saverborn (1944) using ultra centrifugation method reported values of molecular weight in the range of 2.56×10^5 3.26×10^5 g/mol for *A.senegal var.senegal*.

Mukherjee *et al*., (1962) obtained molecular weight values of 2×10^5 to 11.6×10^5 for *A.senegal var.senegal* gum. Anderson *et al*., (1966) obtained a value of

5 x 10^5 and 8.5 x 10^5 for the number average molecular weight (Mn) using molecular sieve chromatography and for weight average molecular weight (M_w) using light scattering technique for *A.senegal var.senegal* gum.

Using the same method Anderson *et al*., (1969) reported the value of 5.8 x 10^5 for *A.senegal var.senegal* and this value were very close to the value reported by Churms *et al.*, (1983). They cited a value of 5.6 x 10^5 using Steering Exclusion Chromatography. Anderson *et al*., (1969) estimated the weight average molecular weight for *A.seyal var.seyal* and the value was 8.5 x 10^5. Vandevelde and Fenyo (1985) reported that *A.senegal var.senegal* has weight average molecular weight in the range 2.5 x 10^5 to 1 x 10^6 g/mol. Connolly *et al*., (1988) calculated the molecular mass of the blocks of *A.senegal var.senegal* gum and found it to be of the order 2x10^5.

Duvallet *et al*., (1989) reported value of 7.2x10^5 for molecular weight of *A. senegal* gum using low angle laser light scattering technique in IM NaCl at 25.0^{0}C, they also obtained the value of 1.9 x 10^5 for the number average molecular weight (Mn) using osmometry determination in 0.01M NaCl at 37.0^{0}C. Randall *et al*., (1989) reported the value of 9.0 x 10^5 for *A.senegal var.senegal* gum using hydrophobic affinity chromatography (HAC). Using GPC-MALLS, Idris *et al*., (1998) obtained values between 2 x 10^5 and 7.9 x 10^5 of the weight average molecular weight and values between 1.6 x10^5 and 4.5 x 10^5 of the number average molecular weight (Mn) for *A.senegal var.senegal* gum.

Hassan *et al*., (2005) obtained the molecular weight of *A. seyal var.seyal* from the light scattering measurement using multi angle laser light scattering system. The value of Mw, Mn and Mz were found to be 1.94 x10^6, 1.08x10^5 and 1.11 x10^6 respectively.

Al-Assaf *et al*., (2005) reported a value of 5.99 x 10^5 for the weight average molecular weight using GPC-MALLS of *A.senegal var.senegal* and a value of 10.4 x 10^5 for *A.seyal var.seyal* (Abdelrahman 2008) estimated the molecular weight using GPC-MALLS technique. The values of Mw and Mn of *A.seyal var.seyal* were found to be 15.5 x 10^5 and 5.16 x 10^5. For *A.senegal var.senegal* were found to be 8.64 x 10^5 and 2.86 x 10^5. He also determined the Mn using osmotic pressure technique and it was found to be 4.7x10^5 and 2.4x10^5 for

A.seyal var.seyal, *A.senegal var.senegal* respectively. Younes (2009) obtained the weight average molecular weights of *A.senegal var.senegal* and *A.seyal var.seyal* samples; it was ranged from 8.08 x 10^5 to 1.34 x 10^6 for *A.senegal var.senegal* and ranged from 6.40 x 10^5 to 1.90 x 10^6 for *A.seyal var.seyal*.

For *A .nilotica var.nilotica* gum Anderson *et al*., (1969) reported a value of 2.27 x 10^6 g/mol, and a value of 6.74 x 10^5 was reported by Al-Assaf *et al*., (2005). He also reported a value of 1.17 x 10^6 g/mol, 3.86 x 10^5 g/mol, 26 nm and 1.84 for arabinoglactan protein (AGP), arabinoglactan (AG), radius of gyration and polydispersity respectively.

Table 2.4: Cationic composition of some gum samples (ppm).

Species	Mg	Ca	K	Na	Zn	Cu	Fe	Mn	Pb	references
senegal	24000	206000	1600	8400	9.0	32	54	3	0	Anderson *et al.*,1984[a]
senegal	39000	316000	221000	10200	40	66	110	57	11	Anderson *et al.*, 1989[b]
senegal	38000	256000	237000	940	24	52	128	106	6.0	Anderson *et al.*, 1990
senegal	1345–1987	5387- 6314	6664- 7735	3.9- 12	0.2- 0.4	1.1 – 1.5	2.5 -6.9	2.4- 8.8	< 0.84	Buffo *et al.*, 2001[c]
senegal	1009	6797	8057.9	792.4	-	23.96	4353	-	-	Omer (2006)
senegal	2159.704	7092.2	9459.459	67.1296	20.513	-	37.037	-	7.5757	Abdelrahman (2008)
senegal	267	6490	261	266	-	-	-	-	-	Younes (2009)
seyal	11.7	11200	7900	5.49	620	130	-	750	-	Siddig (2003)[d]
seyal	27	7000	101100	9.67	13	51	190	200	-	Siddig (2003)[e]
seyal	761	9824	2683	505.5	-	18.82	4339	-	-	Omer (2006)
seyal	1229.0424	9417.20	2802.803	111.054	7.8632	-	43.982	-	7.5757	Abdelrahman (2008)
seyal	419	7370	380	195	-	-	-	-	-	Younes (2009)
nilotica	16.2	118	626	18.3	2.03	6.35	1.5	-	4.8	Satti (2012)

a,b,d,e cited in Younes (2009), **c** cited in Abdelrahman (2008).

2.7 *Acacia nilotica var.nilotica* Tree (Sunt)

Sunt has been found the most valuable timber producing species. An ability to regenerate successfully on flooded sites along the Nile and its tributaries, coupled with timber properties that satisfy most of the utilization standards make the species the most important in the economy of the Sudan. Exploitation of the natural sunt forests started at the beginning of last century when the first sawmill was installed in 1901 for trials of railway sleeper production .However the industry of sleeper production progressed very slowly.

Acacia nilotica var. nilotica plantations of the Blue Nile flood basins form significant resource with an area exceeding 13,190,069 feddan (5.7 million hectares). The contribution of *Acacia nilotica var. nilotica* species to the total sawn timber production in northern Sudan is estimated at 40%-50%. Its contribution to the production of round timber may be considered as second to the Eucalyptus. The latter continues to be the major source of round timber in the Sudan. Sunt also adds substantial volume to the production of fuel wood estimated at 10%-15% of the country's total production.

Figure 2.4:*Acacia nilotica* var. *nilotica*

2.7.1 Botanical classification of *Acacia nilotica* tree

Kingdom: *Plantae*
Class: *Magnoliopsida*
Order: *Fabales*
Family: *Leguminosae*
Subfamily: *Mimosoideae*

Tribe: *Acacieae*
Genus: *Acacia*

Species: *Acacia nilotica* (L.) Willd. ex Delile.

Subspecies:*A.nilotica*.subsp.*nilotiaA.nilotica* subsp.*Tomentos*

*A.nilotica*subsp.*Subalata*,*A.nilotica* subsp. *Adstringens*

Synonymes: *Acacia nilotica* (L.) Willd. ex Delile, *Acacia arabica* (Lam.) Willd. *Acacia scorpioides* W.Wight, *Mimosa arabica* Lam., *Mimosa nilotica* (L)., *Mimosa scorpioides* (L).

Latin name: *Acacia nilotica*

English name: Egyptian thorn, red thorn

Indian name: Babul

Arabic name: Sunt (tree), Garad (fruit). (EL Amin, 1977, Voget, 1995).

2.7.2 Description of *Acacia nilotica var.nilotica* tree

Small tree, 2.5–14 m tall, quite variable in many aspects, bark of twigs not flaking off, gray to brown, branches spreading, with flat or rounded crown, bark thin, rough, fissured, deep red-brown, branchlets purple-brown, shortly or densely gray-pubescent, with lenticels, spines gray-pubescent,slightly recurved, up to 3 cm long, leaves often with 1–2 petiolar glands and other glands between all or only the uppermost pinnae, plnnae 2–11 (~17) pairs, leaflets7–25 (~30) pairs,1.5–7mm long, 0.5–1.5mm wide, glabrous or pubescent, apex obtuse, peduncles clustered at nodes of leafy and leafless branchlets, flowers bright yellow, in axillary heads 6–15mm in diam., involucel from near the base to about half-way up the peduncle, rarely somewhat higher, calyx 1–2mm long, subglabrous to pubescent. Corolla 2.5–3.5mm long, glabrous or pubescent outside, pods especially variable, linear, indehiscent, 8–17 (~24) cm long, 1.3–2.2cm broad, straight or curved, glabrous or gray-velvety, turgid, blackish, about 12-seeded, seeds deep blackish-brown, smooth, subcircular, compressed, areole 6–7mm long, 4.5–5mm wide. Flowering July – September, fruiting March – May. (EL Amin, 1973, 1990).

Rainfall 100-1000mm, soil type tolerates a variety of soils from sand to heavy clay. (Voget, 1995).

2.7.3 Distribution of *Acacia nilotica var.nilotica* tree

Extensive in tropical Africa and Asia from South Africa north to Egypt and from Arabia to Pakistan and India. Altitude from near sea level to 500 m. Introduced widely throughout the tropics and becoming neutralized, such as in

the West Indies. Large areas of forests established in India and Pakistan. Planted in Africa along the Blue Nile in the Sudan, in the bushveld of Natal and Transvaal, in Zambia and Botswana. (Elbert). In Sudan the species is widely distributed along banks of Nile and its tributaries on light silty soils, or along the banks of seasonal rivers and valleys on light soils. It is distributed In White Nile from Jebelein northwards and Western Sudan in Kordofan, Darfur and Northern Bahar El Ghazal, Blue Nile, Central and Southern Sudan. (EL Amin, 1973).

2.7.4 Phytochemical constituents of *Acacia nilotica* tree

Phytochemical analysis of the aerial parts of the plant demonstrated the presence of flavonoids and polyphenolic compounds in the flowers, tannins, glycosides, volatile oils, organic acids, coumarins, rutin (quercetin 3-O-rutinoside) and carbohydrates in the fruits (El-Shanawany, 1996). *A.nilotica var.nilotica* leaf is very digestible and has high levels of protein, the fruit is has high glutamic and aspartic acid and low content in most other amino acids (Spies *et al*., 2004). The seeds of *A.nilotica var.nilotica* contained coronaric acid (cis-9,10-epoxyoctadec-cis-12-enoic). Many flavonol and flavone glycosides, aglycones, flavan-3-ols, and flavan-3, 4- diols, apigenin-6, 8-bis-C-ß-D- glucopyranoside (vicenin) are found in the leaves, bark, and heartwood. In general, barks contain much more complex flavonoid mixtures than heartwoods. The flavonoids present in the bark are (+)-Catechin-5, 7-digallate, (+)-Catechin-3, 5-digallate, (+)-Catechin-4, 5-digallate, (+)-Catechin-5-gallate, melacacidin (heartwood). Phytochemical analysis has shown the presence of two types of tannin (gallotannins and catechins) which explain its therapeutic action as well as its use in tanning hides. The bark of Kenyan *Acacia* species has relatively high tannin content: *A.hockii* 24.1%, *A.kirkii* 16.1%, *A.nilotica* ssp. *indica* 11.6%, *A.nilotica* ssp. *Subulata* 13.1%, *A.seyal* var. *fistula* 13.3%, *A. sieberiana* 4.7%, and *A.xanthophloea* 17.0% (subgenus *Acacia*), *A. mellifera* 19.3%, *A.polyacantha* ssp. *campylacantha* 9.3%, *A.senegal* 25.1% (subgenus *Aculeiferum*), and *A.mearnsii* 28.8% (subgenus *Phyllodineae*). Seed oil fatty acids from species of *A.nilotica* (29% oleic, 44.5% linoleic acid). (Seigler, 2003).

2.7.5 Chemical properties of *Acacia nilotica* gum

In a preliminary study of the gum exudates from several *Acacia* species, *Acacia nilotica* (L.)Willd.ex Del. was found to differ in a number of interesting respects from those species studied prior to 1963 (Anderson *et al*., 1963). Thus, *A.nilotica var.nilotica* gum gave a high, positive specific rotation ($+106^0$),a high methoxyl content (1.05%), and contained only traces of rhamnose (Anderson *et al*., 1966).*A.nilotica var.nilotica* gum gave solutions of low viscosity, and its unusually low nitrogen content (0.08 %). (Anderson *et al*., 1963, 1966).

Later Anderson *et al*., (1966) studied the inter-nodule variation in the composition and properties of *A.nilotica var.nilotica* gum and noted that the variation may occur even between two different nodules picked from the same tree. It was observed that the results for nodule (5) differed significantly from the others, however, no evidence that specimen (5) did not originate from *A.nilotica var.nilotica*. The specimen studied was collected by an accepted authority on the Sudanese *Acacias,* whose undertaking was, in the research coliaboration between the Sudanese Department of Forests and this laboratory, to collect, personally, only specimens which could be authenticated beyond doubt. These results indicate the variation between *A.nilotica var.nilotica* nodules in the composition and properties.

Anderson *et al*., (1966) investigations on the structural features of *A.nilotica var.nilotica* gum have shown it to contain galactose, arabinose, rhamnose, and four aldobiouronic acids, 6-O-(ß-D-glucopyranosyluronic acid)-D-galactose, 6-O-(4-O-methyl-ß-D-glucopyranosyluronicacid)-D-galactose,4-O-(α-D-gluco pyranosyluronicacid)-D-galactose,and4-O-(4-O-methyl-a-D-glucopyranosyl uroicacid)-D-galactose.

The high optical rotation data presented for 4-O-(α-D-glucopyranosyluronic acid)-D-galactose,gave an indication of the extent to which heteropolymolecularity was displayed by *A.nilotica var.nilotica* gum.

Later Chalk *et al*., (1968) isolated two crystalline arabinobioses, 2-O-ß-L-arabinofuranosyl-L-arabinose,and3-O-ß-L-arabinopyranosyl-L-arabinose. They report that specific optical rotation of *A.nilotica var.nilotica* gum is positive rotation ($+ 98^0$), and nitrogen content equal to 0.69%.

A chemotaxonomic aspect was applied by Anderson (1977) to distinguish between various species of arabinogalactan protein gums Table 2.5.

All results corrected to a dry weight basis. [a] Exeprssed as apparent% of free pentose. [b] In 4% saline at 25^{O}C, water.

According to Bentham's classification,*A.nilotica var.nilotica* belongs to series 4 (*Gammiferae*), Anderson found that the gums of this series was characterized mainly by the high positive optical rotation and high molecular weight, with a tendency towards intermediate values of acidity and viscosity, and low proportions of rhamnose. Wide variations in nitrogen and methoxyl values occur. Data obtained by Anderson for *A.nilotica var.nilotica* and some *Gammiferae* species are shown in Table (2.5).

Kapoor, *et al*., (1991) studied six samples (1-6) of Indian gum (*A.nilotica*) obtained from different locations, in addition to one sample of *A. senegal* from Sudan and one sample of *A. seyal* from Nigeria. The investigation showed that all the gums studied had typical differences. As suggested by the various optical rotations (+73 to +81), some particular physicochemical characteristics differentiate the Indian gums from the African gums. The observed variations in optical rotation values must be indicative of differences in interglycosidic linkage configurations. The authors confirmed this assumption by the patterns of the anomeric signals in the ^{13}C-NMR spectra.

Indian gums showed negligible amount of rhamnose, lower amount of uronic acid, and higher amount of arabinose than *A.senegal* gum, as shown in Table (2.٦).

Analytical parameters of the authenticated *A.nilotica var.nilotica* gum collected from Nigeria by an FAO Mission and other acacia gums were reported by Al-Assaf *et al*., (2005) (Table 2.٧), in comparison of *Vulgares* and *Gummiferae* series of *Acacia* gums.

Table 2.5: Data for *A.nilotica* and some *Gammiferae* species. (Anderson, 1977)

	Acacia *Derpanolobium*	***Acacia*** *nilotica*	***Acacia*** *nubica*	***Acacia*** *Seyal*
Ash%	2.52	2.48	1.94	2.87
Nitrogen%	1.11	0.02	0.20	0.44
Methoxyl%	0.43	0.96	0.05	0.94
Specifi rotation, degrees	$+178^0$	$+108^0$	$+98^0$	$+51^0$
Intrinsic viscosity, ml/g	17.8	9.5	9.8	12.4
Molecular weight, $M_w x\ 10^6$	0.95	2.2	0.87	0.89
Equivalent weight	1980	1890	3030	1470
Hence, uronic acid, %	9	9	7	12
Sugar composition after hydrolysis				
4-O-Methylglucuronic acid	2.5	6.0	0.5	5.5
Glucuronic acid	6.5	3.0	6.5	6.5
Galactose	38	44	33	38
Arabinose	52	46	59	46
Rhamnose	1	0.4	1	1

Table 2.6: Constiuent sugar analysis of *Acacia nilotica* gum exudates Compared with *Acacia senegal* and *Acacia seyal.* (Kapoor, et al 1991) (Satti 2012)

	Protein%	**Rhamnose%**	**Arabinose%**	**Galactose%**	**Uronic acid%**
1	1.8	2.0	53.5	36.6	7.9
2	2.1	2.4	54.9	30.6	14.1
3	2.5	3.4	49.4	33.7	12.4
4	2.2	Trace	65.7	24.2	8.2
5	1.6	Trace	62.6	23.1	13.2
6	1.3	Trace	53.6	32.7	11.9
Satti 2012	0.156	7.23	49.99	19.02	10.35
Acacia Senegal	2.0	13.5	33.0	37.0	16.0
Acacia seyal	1.9	2.7	44.5	34.1	14.3

Table 2.7: Analytical parameters of the authentic *Acacia* gum samples from the FAO study. (Al-Assaf et al, 2005)

Species	rotation	(n) (ml/g)	Series	Ara(%)	Rha(%)	Gal (%)	Uronic acid	Protein (%)
Karoo	+45	12	*Gammiferae*	51	1	47	15	0.9
Seyal var fistula	+52	10	*Gammiferae*	57	0.5	37	14	1.1
Seyal var seyal	+37	9	*Gammiferae*	51	2	39	-	0.7
Seyal	+41	12	*Gammiferae*	44	1	40	12	0.9
Seyal	+42	13	*Gammiferae*	17	3	38	16	1.0
Laeta	-23	17	*Vulgares*	35	9	49	18	2.5
Polycantha	+8	10	*Vulgares*	49	7	35	14	1.5
Senegal x laet	-25	16	*Vulgares*	34	8	47	35	2.5
A.paoli	+91	15	*Gammiferae*	50	3	20	7	0.8
A.nilotica	+21	35	*Gammiferae*	25	6	18	21	4.7

Table 2.8: Analytical data for *A.nilotica var.nilotica* gum.

	Anderson (1966)	Anderson (1977)	Kapoor (1991) Indian gum	Karamalla (1999)	AlAssaf (2005) Nigerian gum	Satti (2012)
Moisture%	-	-	-	6.1	-	10.61
Ash%	-	2.48	-	0.03	-	1.91
pH	-	-	-	4.1	-	5.22
Nitrogen%	0.02	0.02	-	0.06	-	0.025
Protein	-	-	1.92	0.37	4.7	0.163
Specific rotation	+107	+108	-	+97.66	+21	+89.6
Intrin. viscosity, ml/g	-	9.5	-	-	35	10.23
Equivalent weight	1890	1890	-	-	-	1877.7
uronic acid, %	9.3	9.0	11.3	-	21	-
Glucuronic acid%	-	3.0	-	-	-	10.35
Galactose%	42	44	30.2	-	18	19.02
Arabinose%	46	46	55.1	42	25	49.99
Rhamnose%	-	0.4	2.6	1.8	6	7.23

2.7.6 Uses of *Acacia nilotica* tree

The powder of the leaves and bark is used externally to treat eye diseases. The powder of the gum is taken to treat diarrhea. A decoction prepared from the bark is used as a stimulant, to treat fever and indigestion. (El-Kamali *et al*., 1999). *Acacia nilotica* bark is used to treat haemorrhage, diarrhea, dysentery and leprosy. The root is used for the treatment of tuberculosis and impotence. The bruised leaves are used as poultices onto ulcers. The gum is edible and used to relieve throat and chest complaints. (El-Hadiyah *et al*., 2011). Inner bark contains 18–23% tannin, used for tanning and dyeing leather black. Young pods produce a very pale tint in leather, notably goat hides (Kano leather). Pods were used by the ancient Egyptians. Young bark used as fiber, twigs esteemed for tooth brushes (chewsticks). Trees tapped for gum. The gum is used in making candles, inks, matches, and paints (N.A.S., 1980).

Tender pods and shoots used as vegetable, and used as forage for camels, sheep and goats, especially in Sudan, where it is said to improve milk from these animals. Seeds are a valuable cattle food. Roasted seed kernels, sometimes used for flavoring and when crushed provide the dye for black strings worn by Nankani women.

Trees used in Sudan for a forestation of inundated areas. Sapwood is yellowish-white, heartwood reddish-brown, hard, heavy, durable, difficult to work, though taking a high polish. Because of its resins, it resists insects and water, and trees are harvested for the timber for boat-making, posts, buildings, water-pipes, well-planking, plows, cabinet-work, wheels, mallets and other implements. Extensively used, in India, for firewood and charcoal, this species has been used in locomotives and steamships as well as industry balers.

It is cultivated for industrial fuel in the Sudan. The calorific value of the sapwood is 4,800 kcal/kg of the heartwood 4,950. The species does nodulate and fix nitrogen. (Duke,1983). Bark decoctions of the tree are used in African traditional medicine for the treatment of diarrhea, dysentery, respiratory ailments, sore throats, dry coughs, children's fevers and toothache, eye complaints and as a nerve stimulant and as an aid to digestion. Ethanolic extract reduces tumors. (Duke,1983). The aqueous extract of the fruit, rich in tannin (18–23%) has shown algicidal activity against Chroccoccus, Closteruim,

Coelastrum,Cosmarium,Cyclotella,Euglena,Microcystis,Oscillatoria,Pediastrm, Rivularia, Spirogyra, and Spirulina (Ayoub, 1983).

Ivory coastal mix *Acacia nilotica* gum with *Acacia sieberana* gum for intestinal ailment, Masai consider the bark as stimulant, giving bark infusion to feverish children, Nigerians use the wood smoke against insects, lice, etc. North Africans use wood smoke as a fumigant for rheumatic pain, and to protect mothers against cold and fever 2 weeks after parturition. Also North Africans use the edible gum for respiratory inflammations and rheumatism, the bark and leaves for gastric ulcers. Senegalese mix powdered root with hedgehogs' ventral parts as an aphrodisiac. South Africans mention the gum's use as an emollient and astringent for colds, diarrhea, hemorrhage and ophthalmia. Sudanese use the direct smoke from the heartwood toward rheumatic pain, the women appreciating the aroma and reddish colour it imparts to their skin. Also Sudanese mix concentrated bark decoction with butter conjunctivitis and headache. Tanganyikans use the bark as stimulant, taking the root for gonorrhea.

Zulu use the bark for cough treatment,Chipi use root for tuberculosis. *A.nilotica var.nilotica* bark used for diarrhea, dysentery, and leprosy. The gum and bark is used for cancers and tumors (of ear, eye, or testicles) and indurations of liver and spleen, condylomas, and excess flesh. Also used for cancer, congestion, coughs, dysentery, gallbladder, leucorrhea, sclerosis, smallpox, and tuberculosis (Haj Ali *et al*., 2007). In Tonga, the root is used to treat tuberculosis. In Lebanon, the gum is mixed with orange-flower infusion for typhoid convalescence.

Egyptian Nubians believe that diabetics may eat unlimited carbohydrates as long as they also consume powdered pods. (Duke,1983). Extracts are inhibitory to at least four species of pathogenic fungi. (Umalkar *et al*.,1976). The studies showed that *A. nilotica* fruit extracts were effective inhibitors of bacterial growth in wounds. The presence of tannins may have accelerated wound healing probably due to their astringent effect. (Haj Ali *et al*.,2007).

In Sudan and the Upper Nile region it has been planted as part of the reforestation of the areas alongside river banks, which are subject to flooding. Sunt timber is preferably used in various utilization practices in Sudan

including railway sleepers, heavy construction, turnery, boat building and fuel. Its properties are very attractive to such uses that require hard and strong mechanical properties. *Acacia nilotica* trees make an ideal windbreak to surround fields as its narrow crown shades less than other windbreak species.

2.8 Gum *Acacia* processing

Raw gum in the form of tears from *Acacia* trees contains a significant amount of materials (tree bark, bug parts, sand, dirt, e t c.) which must be removed prior to use. The gum is processed to remove the foreign matter and to reduce the variability in quality.

There are three types of gum processing:

2.8.1 Kibbled or granulated gum

Kibbling is a mechanical size reduction technique which breaks up gum nodules into smaller fractions of various specific sizes. The advantages of this process no heat treatment and, therefore, the highest possible functionally; gum cannot be adulterated with starch, sugar, e t c. The disadvantages, are gum can be adulterated with other gums, highly variability in quality across lot, contains high foreign matter, high microbiological content high variable moisture, slow in process dissolution.

2.8.2 Mechanical gum powder

This is the same as kibbled gum but is milled to fine powder. The advantages, gum quality can be more uniform than kibbled, rapid dissolution, no functionality loss from heat treatment ,the disadvantages, can be adulterated with other gum , high microbiological content, still contain foreign matter, high variable moisture, gum can be adulterated with starch, sugar, e t c. in this powder form.

2.8.3 Spray dried gum powder

In spray drying, gum is kibbled (Williams, 1990) and dissolved in hot water, clarified by centrifugation and filtration, pasteurized to reduce microbiological content and enzymatic activity and subsequently spry dried. The advantages, gum quality can be extremely uniform across lot with good process control, low microbiological, low moisture content, rabiddissolution.The disadvantages, as with any heat treatment, the drying process affects the functionality of the gum.

2.8.4 Specifications for gum

Previously the regulatory specifications for *A.senegal var.senegal* are superficial and inadequate to ensure that is not adulterated with non permitted gums from other botanical sources (Anderson et al., 1989). Specifications for identity and purity of gum based on the American Food Chemical Codex were published in 1969 (FAO, 1969; WHO, 1969). The joint Export Committee on Food additives (JECFA) of the FAO/WHO monograph on gum specifications was first published in 1978 (JECFA, 1978), and has been reviewed every 4years (1982, 1986, 1990, 1995). In 1990 (JECFA, 1990), significant changes e.g. ranges for specific rotation (-26 to -34) and nitrogen content (0.27 to 0.39%) were introduced. However, in 1995 JECFA further recommended that specific rotation and nitrogen content be deleted.

Previously, Philips and Williams (1993) suggested that characterization of gum is possible using four parameters, e.g. specific rotation, viscosity, lysine and hydroxyproline composition. In 1996(European Union, 1996) introduced the molecular weight limits.

In 1997 *A.seyal var.seyal* was accepted as closely related species (FAO, 1997). In 1998 Codex Alimentarius Meeting, the JECFA proposed specification for gum, prepared at the JECFA meeting (1997), was due to objections from Sudan, send back to JECFA for further consideration. Sudan has strong objections against include *A.seyal var.seyal* gum in the specification of gum this lead to another recommendation for the specification of gum, where *A.seyal var.seyal* was accepted as gum, but gum from other *Acacia* species are not included in these specification.

In March 1999 the Codex Committee for Food Additives and Contaminants gave acceptance to the specification in category 11 (recommended for adoption after editorial changes, including technical revisions) those editorial changes included:

a. The deletion of the synonyms gum hashab, kordofan and talha.
b. The deletion of the sentence (gum from other *Acacia* species are not included).
c. The deletion of the sentences referring to immunological differentiation and technological interchange ability.

d. This proposal was accepted and sent to Codex Almintraius Commission at its 23 session in Rome in July 1999. The approved specification for gum establishes the definition as: Gum is dried exudation obtained from the stems and branches of *A. Senegal* (L) or *A.seyal var.seyal(* Family *leguminosae)*.

2.9 Properties and application of gums

Exudate gums are used in many applications, mainly situated in the food area. However, there are also considerable non-food applications.

Gum readily dissolves in cold and hot water in concentrations up to 50%. Because of the compact, branched structure and small hydrodynamic volume of its molecule, gum solutions are characterized by a low viscosity, allowing the use of high gum concentrations in various applications. Solutions exhibit Newtonian behavior at concentrations up to 40% and become pseudoplastic at higher concentrations. The pH of the solutions is normally around 4.5–5.5, but maximal viscosity is found at pH 6.0 (Verbeken *et al*., 2003). Gum arabic has excellent emulsifying properties, particularly the AGP fraction. The hydrophobic polypeptide backbone strongly adsorbs at the oil–water interface, while the attached carbohydrate units stabilize the emulsion by steric and electrostatic repulsion.

Fractionation studies show that, although emulsifying properties generally improve with increasing molecular weight and protein content, the best results are obtained with mixtures of different fractions (Ray *et al*. 1995). Also, the heterogeneous nature of the gum makes it an excellent emulsifier. Buffo *et al*. (2001) found that stability of beverage emulsions is influenced by a number of processing factors, such as pasteurization and demineralization, and by the pH of the emulsion.

2.9.1 Food uses

The use of gums in foods has to be in accordance with the FDA Code of federal regulations in USA. Gums are mainly used in the confectionery industry, where it is incorporated in a wide range of products. It has a long tradition of use in wine gums, where it produces a clarity that is higher than can be obtained with other hydrocolloids (Williams and Phillips 2000). Furthermore, it prevents sucrose crystallization, provides a controlled flavor

release, and slows down melting in the mouth, making the wine gum longlasting. It also provides the appropriate texture to these candies, which are easily deformed in the mouth but do not adhere to the teeth. It is also used in chewing gum as a coating agent and as a pigment stabilizer.

In aerated confectionery products, such as marshmallows, nougats, and meringues, gum acts as a whipping and stabilizing agent. It is also used in toffees and caramels as an emulsifier, to maintain a uniform distribution of the fat across the product. In jelly products, it is used to provide a fibrous, fruit-like texture. Gum glazes are used as coatings for nuts, dragees, and others.

Gums are widely used as an emulsifier in the manufacture of soft drinks. Due to its stability in acid conditions and its high solubility, gum is well suited for use in citrus and cola flavor oil emulsions. High levels of gum are used to ensure a complete coverage of the interface and to prevent flocculation and coalescence of oil droplets. Normally, a weighting agent is added to increase the oil-phase density, inhibiting destabilization due to creaming. Gum can also form a stable cloud in the drink, imitating the effect of added fruit pulps and juices. In beer, it is used as a foaming agent and to assist lacing.

Gum is used increasingly as a source of soluble fiber in low calorie and dietetic beverages (Phillips 1998). In powdered beverage mixes, gum is added to produce the same opacity, appearance, mouthfeel, and palatability as natural fruit juices. In microencapsulation, liquid, solid or gaseous substances are coated with a protective layer to prevent chemical deterioration and the loss of volatile compounds. It is a useful technique to convert liquid food flavors to flowable powders that can be used in dry food products. Gum is an effective encapsulation agent because of its high water solubility, low viscosity, and emulsification properties and is used in soups and dessert mixes. Gum is also used to prevent gelation in canned gravybased pet foods, as it inhibits the extraction of proteins from the meat into the gravy.

2.9.2 Non-food uses

Gum was once extensively used in the pharmaceutical industry, but is now replaced by celluloses and modified starches in many applications. It is still used as a suspending agent, emulsifier, adhesive, and binder in tabletting and in demulcent syrups. In cosmetics, gum functions as a stabilizer in lotions and

protective creams, where it increases viscosity, imparts spreading properties, and provides a protective coating and a smooth feel. It is used as an adhesive agent in blusher and as a foam stabilizer in liquid soaps.

Gum is also used in the preparation of etching and plating solutions in the lithography industry. It is used as a dispersant in paints and insecticidal emulsions, respectively keeping the pigments and active components uniformly distributed throughout the product. In the textile industry, it is used as a thickening agent in printing pastes for the coloration of knitted cellulose fabrics. (Verbeken *et al*.,2003).

Other applications are ink and pigment manufacture, ceramics, and polishes.

2.9.3 Environmental issues

Many of the areas where the *A.senegal var.senegal* and *A.seyal var.seyal* trees are found, have suffered over the years from the desertification process. The soils can be very sandy with a very poor structure highly vulnerable to erosion. The desertification process is due not only to climatic factors, but also to the presence of animals in numbers exceeding the normal carrying capacity of the land. In short spaces of time, large areas of land have been subjected to rapid desertification. In this context, the contribution of the acacia to the protection of the soil is vital.

The extensive root system of the *A.senegal var.senegal* is a precious element in the fight against wind erosion through its effect on the stabilisation of the land. The *A.senegal var.senegal* also contributes to soil improvement since, as a leguminous plant, it can fix the nitrogen in the soil. It contributes proteins through the decomposition of its leaves and pods that fall around it. Finally, the *A.senegal var.senegal* is an important source of feed for cattle, sheep and goats from its leaves and pods and of wood and charcoal for the population, in addition to the revenue derived from its gum.

2.10 Pre and post harvest gum practices

2.10.1 Seed Germination

The seeds of all *Acacia* ripen between January and April (Sahni, 1968), they are, usually, collected within this period. A seed germination rate of more than 95% can be obtained within one week after sowing, without using any pre-

treatment. Seed pre-treatment neither increases the rate of germination nor does it decreases the time required for maximum generation therefore it is not recommended, except in case of stored seeds where there is the chance of impermeability (FAO, 1995).

Farmers either use direct seeding to raise the plants or, indirectly, by raising plants in a seed bed for seedlings and then transplant them in the field. Some farmers let the seeds to spread naturally

2.10.2 Traditional agroforesty or bush fallow system

In the bush-fallow cultivation system, farmers tend to fell old gum gardens when they are between twenty and twenty five years old leaving one or two trees as seed bearers. The area is cultivated along with different field crops such as millet *(Pennisetum typhoides*), Sorghum *(Sorghum bicolor*, Sesame *(Sesamum indicum),* groundnuts *(Archis hypogaea)* and Roselle *(Hibiscus sabdariffa)*, so that farmers protect the new sapling while looking after their crops. *Acacia senegal* tree has a high coppicing capacity, thus vigorous sprouts usually, appear within a few months. These are cut back during the cropping season so they do not smother other crops; after four to six years, the farmer shifts to another plot of land leaving the tree to dominate, thus a sequential tree agricultural shifting cultivation or bush fallow system (Badi *et al.,* 1989). In over cultivated lands, the low success of coppice regeneration is attributed to be repeated cutting which weakens sprouts.

A. senegal var. *senegal* is the only variety cultivated for gum production in the Sudan, as well as in some other Sahelian countries. The species is well incorporated in the bush-fallow system of shifting cultivation, (Seif el Din, 1981). In this system the gum trees are encouraged to grow on abandoned farm plots during the fallow period, where they improve soil fertility, to ensure, adequate, crop production when cultivation is resumed. The tree, which protects the soil from erosion and improves its fertility, also provides the farmer with gum as a cash crop during the dry season. This system ensures optimum and sustainable utilization of natural resources, since both gum production and crop cultivation form productive components of the system. Added to this, is the fact that animals graze under the gum trees during the dry season without harming the trees. When the trees are felled to allow

cultivation, the wood is used as fuel, building materials and for building fences around farm plots.This agroforesty system has, however, undergone substantial deterioration, particularly in the main gum-producing areas in Kordofan and Darfur, as a result of the reoccurring droughts. Tree mortality was, severely, widespread in the northern parts of these regions, resulting in partial or total collapse of the bush fallow system.

In view of this, the government has started a project, assisted by the United Nations Sudano-Sahelian Office, to restock the gum belt in Kordofan and Darfur. In this project farmers are provided with seeds and seedlings to plant their, own, fields. Similar activities are also being carried out elsewhere in the gum belt, spearheaded by the Forest Extension Unit of the Forest National Corporation (FNC).

FNC has adopted a strategy of establishing plantations of *Acacia senegal* inside, forest reserves to act as buffer due to the prime importance of gum for The economy of Sudan. There are at present about 30000 feddans (12500ha) in Blue Nile, Kassala and Kordofan states, annually rent to gum tappers on a share-cropping basis. Furthermore, gum plantations constitute a considerable part (30-40%) of the FNC annual tree-planting programme. The government also decreed that all mechanized farming schemes should plant trees on 10-15% of their area to act as shelterbelts, using *Acacia senegal* var. *senegal* as the main species.

2.10.3 Gum tapping and collection

2.10.3.1 Farm stage

When *Acacia* trees shed their leaves and become dormant at the beginning of the dry season, is the signal to start tapping. Previously in some areas there was two tapping seasons, the first one at October/ November and the second one is the following March/April. Nowadays it was found that the two tapping cause significant affect on the health of the trees and lead the trees to die. As a result of that there is only one tapping season performed which starts in October /November and continues to April, with the collections practiced many times (Anon, GAC Company). Superficial incisions are made in the branches and bands of bark are stripped off, so that the exudates accumulate and can be collected. Bark cutting is usually carried out by using a simple axe but a more

sofisticated tool called Soonky is now available (Figure 2.7). Usually tapping is done once a year, the first collection is made after 4-6 weeks and continuous at an interval of about 2weeks, and about 4-8 collections may be made per season, depending on the weather conditions and the health of the tree (Imeson, 1992).

Yields

A tree, on average, yields 250 grams of gum per annum, although production may range from a few grams to as high as 10 kg (NAS, 1979) or 0.2 to 6.7 kg (Duke, 1981). The highest yields were reported for trees aged 7 to 12 years.

Tapping

Exuding gum

Figure 2.5: Gum tapping and exudation

In general the higher the average temperature the higher is the yield of gum. Yield per hectar per year ranges between 30 to 40 kg in case of open stands and as much as 100 kg in case of dense stands (Seif el Din, 1981).

2.10.3.2 Farmers ,middle trader, and big trader stage

After the collection of the gum farmers, usually, store the gum for a short time (3-7 days) before delivering the gum to the middle - trader. The gum is stored either in closed polyethylene bags or in a whole underground, to avoid loss in weight on drying, in this way they, highly, damage the quality of the gum. Sometimes the farmers store their gum for a long time for commercial reasons, in this case increased storage time, highly, affects the gum quality, gum being blocked together and stick to the bags (called malbook) and that lead to mold growth, colour change, and contamination with foreign materials such as sand and mud (Anon, 1970 – 2008).The farmers, normally, sell their gum to the middle trader (village merchant) as raw gum.

After the middle traders received the gum from the farmers they start packing the gum in bags, usually, jute bags 100 Kg capacity. Some of them clean and sort the gum and most of them sell the gum as crude, to the big trader or in the auction market, and then to the companies or other traders, (Anon, 1970 – 2008)

Big traders are customers of specific companies, Gum Arabic Company (GAC) or other exporting companies. GAC used to be the biggest buyer and takes most of the gum in the market, and it has many suppliers from the big traders, and some of the middle traders.

When the big traders receive the gum from middle traders and farmers, they check some physical parameters such as colour, size, quantity of siftings, and impurities. The origin of the gum and the middle trader or farmer personalities are important factors for the big traders to check the gum, accurately, to insure if it is mixed with other *Acacia* species or not, and then clean and sort the gum.

Some degree of cleaning and sorting may be undertaken by small village traders to whom the producer sells his gum, but it is, usually, undertaken by the large traders and then selling their gum to the exporting companies, where its recleaned and sorted at its, own, warehouses in the regional centers of the gum belt.

2.10.3.3 Cleaning, sorting and grading

Cleaning is done traditionally by women, who manually sort the gum according to the size of the lumps and remove foreign matter (FAO 1995). More recently, cleaning has been performed mechanically using conveyor belts and sieving machines. In Sudan, the gum from *Acacia* is presented in various grades and classified into raw gum and processed gum.

Raw gum:

- Hand-picked selected: The cleanest and largest pieces with the lightest colour. The most expensive grade.
- Cleaned: The material which remains after hand-picked selected. This grade comprises whole and broken lumps with a pale to dark amber colour and it contains siftings.
- Dust: This grade is collected after the cleaning process and comprises very fine particles of gum, sand, and dirt.

Processed gum:

- Kibbled product: in which the tears sizes are 3-3.5cm in diameter and reduced to 1-1.5mm.
- Powder product: in which the oversize and undersize particles of gum arabic are reduced to powder with 10-150 mesh sizes.
- Spray dried: in which the spray dried process condition can be adjusted to deliver physical properties such as particle size, bulk density and moisture content for buyer's requirement.
    1. Particle size 40-80 micron
    2. Bulk density 350-500kg/m3.
    3. Moisture content 6-10%

2.10.3.4 The exporting process

The companies receive the gum throughout their branches from many big traders, middle traders, and sometimes from the farmers, and classify the gum according to the origin, season, and grade (cleaned or raw gum), and then send the gum through trains or trucks to the exportation areas. These branches receive the gum and store it according to the classification of the delivered branches which are labeled on the bags; the label contains the origin of the gum, the season, and the grade.

The quality control department checks some physical parameters of the received gum such as colour, quantity of siftings…etc, then they take random samples (one bag out of any ten bags), which are checked for three physiochemical parameters, moisture content, optical rotation, and viscosity. After that, the quality control department controls all the steps of the cleaning, sorting, grading, packaging and exporting of the gum**.**

2.10.3.5 packing and exporting stage

The packing, usually, carried out either in poly propylene bags (plastic) or multilayer paper bags lined with food good polypropylene bags depending on customer request prior to exportation

2.11 Factors affecting gum production and supply

Table 2.9 shows the beneficial and adverse effect of the factors that affect gum production

The major causal factor in the reduction in tonnages involved in international gum trading in recent years has been the uncertainty of regular supply which is, primarily, caused by drought.

There is always the possibility that some of the gum can be collected will be marketable, especially if more systematic and wide spread production decrease prices. Hygiene and storage standards improve prices, research identifies new uses of natural gums, and marketing strategies of Sudan are improved with a reduction in the present high rate of export and local taxes (60%).

When the tree is planted for essential ecological reasons, and when the unique secondary products from these trees can earn essential overseas currencies, it is poor business practice if these earnings are not maximized. The recent trend in use of natural foods may also tilt the balance in favour of gum including other natural gums.

Not so long ago, sales of gums collected by nomads and villagers in Africa constituted their major single source of annual income; gum trees were treasured possessions and fights to death to retain ownership were not infrequent. However, low prices are inconducive for producers. Due to all these factors the nature and the trend of supply and, subsequently, earnings are characterized by fluctuations. For instance the experience of the Gum

Company (GAC) for the last 40 years as the biggest supplier in the international market is characterized by fluctuation trends

Table 2.9: Factors effecting gum production and supply (GAC,1999)

Factor	Beneficial Effect	Adverse Effect
Rain fall	Good rains is a signal of good gum production (400 to 900mm per annum/season)	Continuous rain fall very late or showers fall is bad for gum production
Drought	Doughtiness immediately after the end of rainy season improve production	The garden or natural stands wiped out by drought
Temperature	High temperature is conducive to good production if the trees are tapped at the right time	Low temperature at tapping time seem to slow gum exudation, sometimes the trees tapping have to be repeated
Size and age of the trees	Mature trees (15-20 years old) are high gum producers	Young trees (below 5 years) and old one over 20 years old are low gum producers
Health of the tree	Trees which have good growth during the rainy season have high production	Trees of poor growing season have low production
Injector insect (Garraha)	Farmers believe that Garraha increases production	-
Animals	Cattle and sheep are predominant grazers, keep the ground vegetation down reducing or even eliminated fire hazards	Animals graze on leafs of the trees (goats, camels)
Fire	-	The fire damage live trees and destroy substantial amount of seeds that has fallen in the ground
Expansion of agriculture	-	Resorted gum garden to expand their cash crop production areas which is cause low gum production
Locusts	-	Tree locust as well as desert locust attacks results in partial or complete failure of gum production
Shortage of water supply	-	Drinking water shortage and long distance for water supply for tappers, indirectly effects production quantity
Credit	Microfinance, One village one product	Sheil system credit
Rural poverty	-	Increased internal migration to the cities subsequently decrease gum production
Marketing and transport	Adequate marketing cycle and transportation will lead to production sustainability	Lack of adequate marketing cycle and transportation in some part of gum belt will result in unstable sustainability of supply

2.12 Structural features of gum

2.12.1 Chemical constituent of *Acacia* gum

Crude gum is a complex copolymer of polysaccharide with a high molecular mass and a complex structure (Connolly et al., 1987; 1988). It is a branched molecule (Snowden et al., 1987) with protein content about 2.0 -2.5%. The gum is present in mixed calcium, magnesium and potassium salt of polysaccharidic acid (Standford and Barid, 1983). It is composed of six carbohydratemoieties; glactopyranose, arabinpyrano arabinofuranose, ramnopyranose, glucuropyranosyluronic acid and 4-O-methylglucuropyranosyl uronic acid(Sharma,1981;Glickman,1979; Aspinal et al,.1956;Ekhadem,1956). Polysaccharides that contain arabinose and glacatose as their major constituents are called arabinogalactan(AG) (Fincher et al 1983). So all *Acacia* gum chemically are arabinogalactan - protein (AGP). And it was described as `hetropolymolecular` ,i.e., having either a variation in monomer composition and/or a variation in the mode of liking and branching of the monomer units, in addition to distribution in molecular weight (Lewis,1957;Jermyn,1962; Anderson and Stoddart, 1966).

2.12.2 Molecular structure of gum

Research studies of molecular structure of the gums have been carried out over a century (Neubauer, 1854; O`Sullivan, 1884; Butler and Gretcher, 1929; Howorth and Hirst ,1931; Smith 1939). Earlier investigation (Anderson et al., 1966) on the primary chemical structure of *A.senegal* gum have recognized the gum as an acidic polysaccharide containing D-galactose, L-arabinose, L-rhmanose , and D-glucuronic acid. Several important structural features have been deduced (Smith, 1939) from methylation study of the degraded gum resulting from the removal of the acid–labile arabinofuranose and rhamnopyranose residues by autohydrolysis. Partial acid hydrolysis have shown that 6-O-(β-D-glucopyranosyl uronic acid) –D-galactose (Challinor et al., 1931), 3-O- α-D-galactopyranosyl-L-arabinose (Smith, 1939; Jones, 1953)' 3-O-β-D-galactopyranosyl –L-arabinose (Andrews and Jones, 1955), are constituent units of the gum.

The structural interpretations from smiths experiments were limited to those based on branched frame work of 1,3-and 1,6-linked D-galactose residues.

Evidence for the mode of the distribution of the 1, 3- and 1,6-linkages between these residues in the "core "of the gum obtained by Dillon(Dillon et al.,1954) who subjected the gum to three successive Barry degradations; (Barry, 1943) further treatment of the degraded polysaccharide with periodate and phenylhydrazine gave a product in a high yield. This indicated that little degradation had taken place during the fourth Barry degradation; it was concluded that the gum contained a fundamental chain of D-galactose unit, exclusively involving 1, 3-linkages.

(Anderson and Stoddart, 1966) show that *A.senegal* contained D-galactose (39%), L-arabinose (28%), L-rhamnose (14%), D-glucuronic acid (17.5%) and 4-O-methyl-D-glucuronic acid (1.5%).

The gum molecule consist of a β-(1-3) linked galactopyranose backbone chain with numerous branches linked through β-(1-6) galactopyranose residues (Lawson,etal.,1998) and containing arabinopyranose (Satii 2004), arabinofuranose, rhamnopyranose, glucuronic acid (Figure 2.6) and 4-O-methyl- glucuronic acid (Shirely et al., 1983) the composition is shown in table 2.10 (Lawson et al.,1998).

The methylated gum was subjected to methanolysis and the mixture of methyl glycosides was analysed by gas–liquid partition chromatography ; (Aspinall,1963) the methyl glycosides of 2,3,4-tri- O-methyl-L-rhamnose , 2,3,5-and 2,3,4-tri-, 2,5 –di-O-methyl-D-galactose, and 2,3,4-tri- and 2,3-di-O-methyl-D-glucuronic acid were identified. With the exception of 2,3,4-tri-O-methyl-D-galacyose , all these O;methyl sugar were present in the methylated gum studied by Aspinall,Charlson ,Hirst, and young; (Aspinall et al.,1963) 2,3,4 -tri-O-methyl-D-galactose,2,3,4-Ttri-O-methyl-L-arabinose, and 2,4,6 tri-D-galactose were not reportedin the methylated sample investigatedby Smith(Smith,1939). The present of 2, 3, 4-tri-O-methyl-L-arabinose was not unexpected, since graded acid hydrolysis of the gum had yielded 3-O-β-L-arabino-pyranosyl-L-arabinose (Anderws,and Jones,1955). The identification of small amounts of 2,4,6-tri-O-methyl-D-galactose in the methylated whole gum indicated that a re-examination of the methylated degraded gum, obtained after autohydrolysis and methylation, was necessary .

Table2.10 Chemical compositions of gum (Lawson et al., 1998)

Compound	Composition%
Galactose	36%
Arabinose	30%
Rhamnose	12.6%
Glucuronic acid	19.2%
Protein	2.2%

Asecond Smith degradation yielded polysacchride B, which contained galactose (89%) and arabinose (11%). On methanolysis, the O-methyl derivative polysaccharide B gave the methyl glycosides of 2,3,5-tri- and 2,5-di-O-methyl-L-arabinose, and 2,3,4,6-2,4,6- and 2,3,4-tri-, and 2,6- and 2,4-di-O-methyl-D-galactose.A Smith degradation of polysaccharide B gave polysaccharide C, Which contained galactose (98%) and (2%). Methylation and methanolysis of this polysaccharide gave the methyl glycosides of 2, 3, 5-tri-O-methyl-L-arabinose and 2,6-and2,4-di-O-methyl-D-galactose. Successive Smith degradation then gave polysaccharide D and E,which were examined by methylation and partial acid hydrolysis; on methylation and methanolysis, both polysaccharide D and E gave 2,3,4,6-tetra-,2.4.6- and 2,3,4-tri-, and 2,6-and 2,4-di-O-methyl-D-galactose as their methyl glycosides. The ratio of the amounts of 2,4,6-tri-O-methyl-D-galactose to 2,3,4,6-tetra- and 2,4-di-O-methyl-D-galactose , as judged from the peak areas obtained for their methyl glycosides on gas-liquid partition chromatography ,was greater for polysaccharide E than for D. The methylation evidence indicates that polysaccharide E is not a simple linear β-1,3-galactan. Whilst 2, 4, 6-tri-O-methyl-D-glactose is the most predominant O-methyl sugar obtained from the methylated polysaccharide, the identification of some 2,4-di-methyl-D-galactose and 2,3,4,6-tetra-O-methyl-D-galactose indicate occasional branching at the C-3and C-6 position. The presence of small amounts of β-1, 6-galactobiosein the partial acid hydrolysate of polysaccharide E is further support for a branched structure (Anderson et al., 1966).

The polysaccharide entities of which the gum is comprised are polymer systems which have, in addition to a molecular weight distribution , a variation

in monosaccharide composition as well as a distribution in the mode of linking and branching of certain monosaccharide units (Smith et al., 1939). A suggested structural fragment *A.senegal* shown in Figure 2.6,Anderson et al.(1966) attempted determining the structure of gum Arabic by subjecting it to a series of Smith degradation using preiodate and then methylation of the degradation product. Further analysis using gel permeation chromatography showed that uronic acid and rahmnose residues were eliminated first indicating that they were located at the periphery of the molecule. The core was found to consist of a β-(1, 3)-galactopyranose chain with branches linked through the 1,6position. Street and Anderson (1983) later revised previous data and using computer modelling, proposed an alternative structure (Figure 6, 7).

Smith degradation studies carried out by Churms et al.(1983) allowing for reaction to proceed to completion, noted that Anderson et al. Had not allowed the reaction to reach completion after each stage of the degradation procedure. Churms et al.(1970) obtained different values for molecular size and composition of each degradation product. In the first and second of these products, two component of different molecular mass found in the molar ratio of 1:2 indicating that there were certain regularity within the structure. They proposed that the galactan core consisted of 13 β-1,3-D-galactopyranosyl residues having two branches, which would give single repeated subunits of molecular mass of 8000 within the whole molecule. Adam et al. (1977) and Churms et al.(1977) in studies on structural features of the gum exudates from some *Acacia* species, from which molecular – weighet distributions have been measured by gel-permeation chromatography (GPC), the various samples of gum of *A.podalyriaefolia* have been found to vary considerably in Mw with values ranging from 9500 to 32000 even among samples taken from different branches of the same young tree. Churms et al. (1970) in molecular – distribution studies from *A.podalyriaefolia* gel chromatography, a molecular weight of 31000 as found for the undegraded gum. Alain and McMullen (1985) carried out studies on *Acacia* to evaluate its molecular weight and its polydispersity by using a fractional coacervation method.

Defaye and Wang (1986) using Smith degradation studies and C-NMR studies. There have been numerous concerned with determination of the average

molecular mass of the gum Arabic , where values obtained range from 2.5×10^5 to 1×10^6 for *A.senegal* (Fenyo and Vandevelde,1990).

Anderson obtained a value of 5×10^5 for the number average molecular weight(Mn) using molecular sieve chromatography and 8.5×10^5 for weight average molecular weight(Mw) using light scattering technique(Anderson et al.1966).Using light scattering technique large value of weight average molecular weight were obtained. Veis and Eddenberger, (1954) reported a $Mw=1.0\times10^6$,Mukheriee and Deb (1962) reported Mw up to 5.8×10^5 ,Swenson et al.(1968) reported $Mw=3.65\times10^5$ as cited in picton et al.(2000).

The gum molecule consist (Lawson et al., 1998) of a β-(1-3) linked glactopyranose backbone chain with arabinopyranose, arabinofurnose, rhamnopyranose, glucuronic acid and 4-O-methyl-glucuronic acid. None of the previous studies took into account the portentous material, as an integral part of the structure. Anderson and Stoddart (1966) had shown that portentous material was associated with high molecular mass fraction and the remaining lower molecular mass fraction were mostly polysaccharides. Studies carried by Anderson and McDougall(1987), illustrated that portion was present in all the degradation products, although the sugar to protein ratio was quite high at the core of the molecule (11:1) compared to that at the periphery (40:1). Akiyama et al. (1984) carried out immunology studies, showed that gum interacted with Yariv antigen indicating the molecule was a kind of arabinogalactan. Their study showed the presence of hydroxyproline, oligoarabinoside and serine-carbohydrate linkage.

Duvallet et al.(1989) and Vandevelde and Fenyo(1985)showed that enzyme degradation of gum decrease the weight average molecular weight from 7.2×10^5 to 1.8×10^5 where as number average molecular weight remain unchanged at value of 1.9×10^5 , and that Mw approached Mn value.the authors then suggested that Mn is more fundamental property than Mw and hence Mn could be considered as an intrinsic property of gum.

Connly et al.and Duvallet et al. result led to the conclusion that gum had a wattle blossom type structure in which carbohydrate moieties linked to common polypeptide for AGP.

Based on this model Connolly et al. calculated the molecular mass of the blocks and found it to be of the order 2×10^5. Randall et al.(1998) fractionated gum using GPC and also fractionated gum by hydrophilic interaction chromatography (HIC) and isolated four fractions. Most of the gum was found to have low protein content and refer to as AG. The fractions rich in protein constitute 12% of the total gum and were refer to as AGP and glycoprotein (GP). The latter fraction(GP) has spartic acid as the dominating amino acid.

HIC studies carried by Osman et al.(1993, 1994), using a number of gum samples obtained similar findings. Osman et al. (1995) also fractionated two samples by ion exchange chromatography the fractions were very different from those obtained by HIC and were polydispersity depicting the high level of heterogeneity of gum.

Qi et al. (1991) using GPC, alkaline hydrolysis for carbohydrate, they were concluded that the carbohydrate was attached the polypeptide chain in small unit of 30 sugar residues through galactose-hydroxyproline linkage. This was further supported by electron microscopic studies, which showed rode like molecule of 150 nm long. The authors suggested that the structure resemble "twisted hairy rope" Figure 2.7 in contradiction to Wattle blossom model Figure 2.6. However Osman et al argued against this conclusion reasoning that the possibility that the branched carbohydrate chain could themselves be degraded by alkali in addition to cleavage of polypeptide –carbohydrate linkage, was not taken into account. Further more the specific hydroxyproline assay used to monitor the alkaline hydrolysate following the chromatography could not detect sugar residues devoid of hydroxypyroline. Baldwin et al. using electron microscopy to study AGP found that "Wattle blossom" model provided the best description for AGP and AGP- like molecules. Their results show that AGP secreted from carrot possess an elliptical molecule with dimension 25×15 nm implying "Wottele blossom" type structure Figure 2.6.

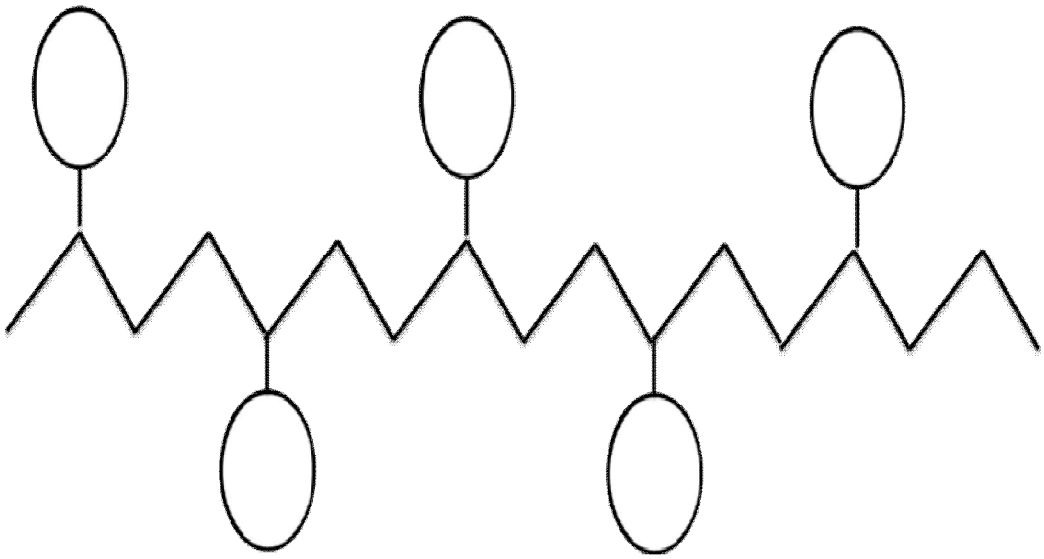

Figure 2.6: The Wattle blossom model of the arabinogalactan –protein (Fincher, 1983)

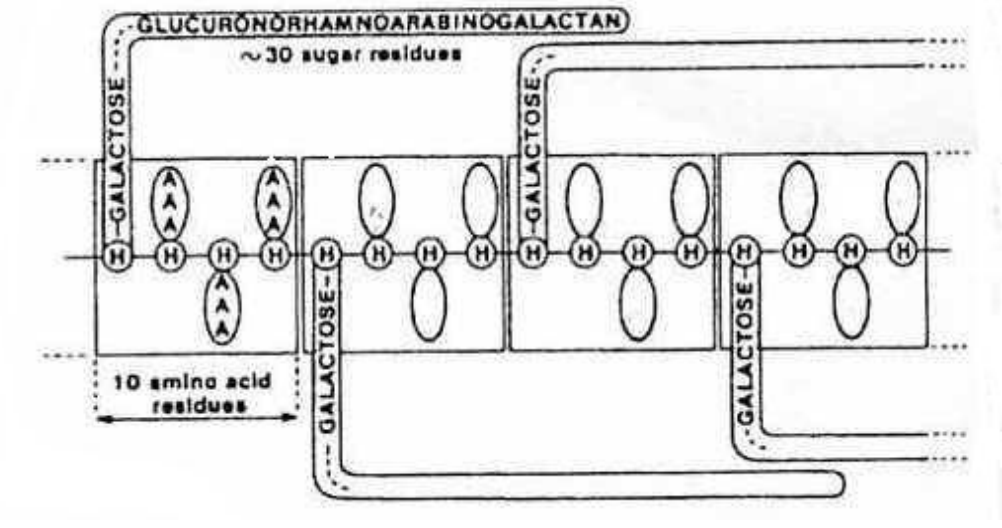

Figure 2.7: The Twisted hairy rope" model of gum glycoprotein

Hassan (2000) estimated the molecular weight of *A.seyal var.seyal* from the light scattering measurement using multi-angle laser light system.The value of Mw, Mn and Mz were found to be1.94×10^{6},1.08×10^{5}and1.11×10^{6} respectively, the author fractionated the *A.seyal var.seyal* gum by using gel permeation column coupled to a multi detector system comprising light scattering, infra red(IR) and ultra violet(UV) detectors. The resultant chromatogram showed a high molecular weight fraction associated with much of protein present in the polymer molecule, a low molecular mass fraction of much lesser amount of protein and a low molecular mass proteinaceous fraction. The molar mass fractions distribution pattern produced for *A.seyal var.seyal* resemble that obtained for gum *A.senegal var.senegal* .However the patterns of the two gums differ in the proportion of each fraction.

2.13 Factors affecting physiochemical and functional properties of gum

Gums are harvested after been tapped by producers in different sites of the gum belt in the Sudan as well as in other African countries. In these areas there were variations in botanical sources, locations, and soil types, age of trees, seasons, topographical conditions and temperature (Chikamai and Gachathi, 1994). It has been reported that the quality of gum may be influenced by geographical origin and age of the trees, climatic conditions, soil types, and even on the location of exudation on the tree (Chikamai, 1993; Idris *et al*., 1998; Islam *et al*., (1997); Karamalla *et al*., 1998). However, of soil characteristicsis the major factors that influence gum quality and production, particularly, are soil reaction, soil pH, organic carbon, nitrogen and phosphorus. Despite this wealth information describing the effect of some locations, seasons and soil types, little has been done to compare different seasons coupled with different soil types in Sudan.

For instance, gums from the natural stands of *Acacia senegal* variety *kerensis* in Merrile, Laisamis, Logologo and Marigat, Baringo district can be mixed because of their similar levels of nitrogen. The pH of gum from the natural stands of *Acacia senegal* variety *kerensis* in Sereolipi, Merrile, Laisamis and Logologo were 4.54, 4.5, 4.51 and 4.52 similar to the required international standards (pH: 4.2 - 4.8). Further research is required to determine factors

influencing the high inherent viscosity, nitrogen and specific rotation in relation to soil characteristics and varieties as stated by Churms *et al*. (1983).

Idris *et al*. (1998) concluded that the chemical and physicochemical characteristics of *A.senegal var.senegal* gum exhibit some variations depending on location and age of the tree. There are no significant differences in the characteristics of gum from Kordofan and El Daley regions. However, multi dimension GPC has proved a very powerful method to probe the molecular characteristics of the gum without the need to fractionate. It has been shown that the gum has a wide molecular mass distribution and consists of three molecular mass components of, significantly, different chemical characteristics (protein components) each of which has a highly branched globular structure typical of arabinogalactan proteins generally. Few studies on characterization of *A.senegal var.senegal* with relation to geographical locations and other factors had been done (Osman *et al.,* 1995; Siddig *et al.,* 2005). There are no, significant, differences in the characteristics of the gum from kordofan and El Daley regions although they are characterized by sandy and clay soils respectively. Fifteen years old trees yielded gum with the highest molecular mass but further work on a much larger numbers of samples is required before any firm conclusions can be drawn.

Other factors that may affect emulsion formation, emulsion stability and viscosity of the emulsion concentrate were studied to assess their significance, including chemical composition of the gum (protein content and mineral content), gum processing prior to emulsion preparation (pasteurization and demineralization), and pH of the dilute emulsion. Protein content was not related to emulsion stability, whereas minerals decreased stability presumably due to electrostatic screening effect.Both pasteurization and demineralization favored stability, most likely by promoting protein unfolding and eliminating the screening effect, respectively. Emulsions were less stable at pH=2.5 than at higher pH levels (4.5and5.5). There was a significant difference between the two gum species studied (*A.senegal var.senegal and Acacia seyal var.seyal*) in their sensitivity to these treatments. The viscosity of the emulsion concentrate was decreased by pasteurization and increased by demineralization. Protein load at the O/W interface and thickness of the adsorbed layer of emulsifier

were not related to emulsion stability.The most important colloidal interactions in dilute beverage emulsions are van der Waals, electrostatic and polymeric steric (**Buffo** *et al*., 2001). The emulsifying properties of gum, however, are directly influenced by botanical type, the nature of the growing soils and the climate, (NGARA, 2005).

2.14 Thermodynamic properties of *Acacia gums* solutions

2.14.1 Introduction

Chemical and physical processes are almost invariably accompanied by, energy changes. Chemistry can be viewed as being based on the interrelated physical factors of energetic, structure, and dynamics. In some ways, energetics can be viewed as the most fundamental parameter, since the energetic behavior of molecules determines their structure and reactivity. Thermodynamics has an immense predictive power and the thermodynamic laws can be used to predict the direction in which a process would proceed. To understand behavior of gum molecule in solutions it is necessary to measure and calculate some thermodynamic parameters and functions.

Thermodynamic of polymer solutions can be applicable to gum solutions since gum molecules are classified as biopolymer molecules. Solutions are characterized by thermodynamics parameters like the volume, internal energy, Gibbs free energy, entropy and enthalpy.

However, one usually makes use of use of differences of these quantities in two specified states of the system. In case of solution processes it is customary to refer to the difference between the thermodynamics functions of the solution and the same functions of the components before dissolving, the properties of real solutions are non-additive for example:

$$V_{sol} \neq \sum V_{comp}$$

$$G_{sol} \neq \sum G_{comp}$$

Hence, the volume, enthalpy, entropy, e t c., of components in solution differ from their values before dissolving. This made it necessary to introduce the concept of partial molar (specific) functions to characterize the thermodynamic behavior of the components in a solution (Tager, 1978).

2.14.2 Weight fraction (ω)

The weight fraction of a component is the ration of its weight to the sum of weight of all the components.

$$w_1 = \frac{g_1}{g_1 + g_2} \ldots\ldots (2.14.2.1)$$

$$w_2 = \frac{g_2}{g_1 + g_2} \ldots\ldots (2.14.2.2)$$

Where g_1 and g_2 are the weghts of component 1 and 2 respectively.

2.14.3 The molar fraction (n)

It is the most useful concentration variable for theoretical understanding of solutions of like-size molecules. The mole fraction of a component (Ni) of a binary solution is calculated from the following equation.

$$N_1 = \frac{n_1}{n_1 + n_2} \ldots\ldots (2.14.3.1)$$

$$N_2 = \frac{n_2}{n_1 + n_2} \ldots\ldots (2.14.3.2)$$

Where n_1 and n_2 are number of moles of component involved.

2.14.4 Volume fraction (Φ)

The volume fraction of a component (Φ_i) is the ratio of its partial molar (specific) volume to the total volume of the solution. For the binary system for instance (Φ_i) is given as (Tager, 1978).

$$\Phi_1 = \frac{\bar{V}_1}{\bar{V}_1 + V_2} \ldots\ldots (2.14.4.1)$$

$$\Phi_2 = \frac{\bar{V}_2}{\bar{V}_1 + V_2} \ldots\ldots (2.14.4.2)$$

Where $\bar{V}_1$ is partial molar (specific) volume of the solvent.

$\bar{V}_2$ Is partial molar (specific) volume of the solute.

2.14.5 Density of solid gum

The density and the specific volume of the gum give a good idea about the distance between the molecules. The density of the gum can be determined by pyknometer using solvent that gum is insoluble in and cannot be affected by it. Gradient tube method also used to determine the density of the polymer (Tager, 1978).

2.14.6 Partial molar (specific) volume ($\bar{V}$)

In general the partial molar volume of a substance A in a mixture is the change in volume per mole added to a large volume of the mixture. If the molecular masses of the components are not known exactly, so that their mole fractions cannot be calculated, it is more convenient to use specific partial functions, i.e., functions referred to one gram rather than to one mole of the component.

A partial specific function (Z_{isp}) equals the partial molar function (Z_{imol}) divided by the molecuylar mass (M_i) of the component:

$$Z_{isp} = \frac{Z_{imol}}{M_i} \ldots\ldots (2.14.6.1)$$

To discuss the determination of partial molar volume of liquid solution, it is convenient to write the molar volume (V_m) of a binary solution as a function of the partial molar volumes of the two components and their mole fractions (N_1,N_2).

$$Z_{M=N_1\overline{V}_1+N_2\overline{V}_2} \ldots\ldots\ldots\ldots (2.14.6.2)$$

The molar volume of a solution can be calculated from its density and composition (Karolina, 2005). For a binary solution the molar volume at constant temperature and pressure can be calculated by graphical method there are two graphical method for calculating partial molar (specific) volume (Tager, 1978).

(I) Tangent method:

The volume of the solution (V) is plotted against the number of moles (n) or grams (g) of one its components.

Evidently, the derivative ∂ v/∂ n or ∂ v / ∂ g determined at any point of the curve, equals the partial molar (specific) volume of the component in a solution of the corresponding concentration (Tager, 1978).

(II) Intercept method:

The intercept method, consist in plotting the value of volume (v) or its change (ΔV) referred to one mole of solution $\{V_{tot.}/(n_1+n_2)\}$. If the volume referred to one gram of solution (V/g_1+g_2) are plotted along the ordinate is against composition in weight fractions (ω), the tangent intercepts on the ordinate will be numerically equal to the partial specific functions (Tager, 1978).

Paijk, et al., (1990)syudied the density of aqueous solutions of some monosaccharides (D- pentoses and D-hexoses). The mean molar volumes of the solutions were found to be linearly dependent on the mole fraction of the solute. Thus, the partial molar volumes of solvent and solute, respectively, are concentration-independent; i.e, the partial molar volume of the solvent equals the molar volume of the pure solvent, and the partial molar volume of the solute is equal to its value at infinite dilution.

The graphical methods described by lewis and Randall (1923) are used in the determination of the apparent molal volume Φ_V which defined by the relation

$$\Phi_v = \frac{v - n_1 v_0}{n_2} \ldots\ldots (T, P\ constant)$$

2.14.7 Chemical potential (μ)

One of the most function characteristics in the behavior of each component in a solution is the chemical potential of the component. The chemical potential equals the change in internal energy of a solution on addition of an infinitely small number of moles of with component, referred to that amount of substance at constant volume, entropy, and quantity of each of the other component.

$$\mu_1 = \left(\frac{\partial u}{\partial n_i}\right)_{v.s.n_{j(j\neq i)}} \ldots\ldots\ldots\ldots (2.14.7.1)$$

$$\Delta G = \Delta\mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.14.7.2)$$

Since

$$\Delta G = \Delta H - T\Delta S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.14.7.3)$$

$$\Delta\mu = \Delta H - T\Delta S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.14.7.4)$$

The change in chemical potential of solvent with environmental pressure at constant temperature is given by the equation.

$$\left(\frac{\partial u}{\partial p}\right)_r \bar{V} \ldots\ldots\ldots\ldots (2.14.7.5)$$

Or

$$d\mu_i = \bar{V}\, dp \ldots\ldots\ldots\ldots (2.14.7.6)$$

Hence

$$-\int_{\mu 1}^{\mu 1^0} d\mu_1 = \int_{p^0}^{p} \bar{V}\ dp \ldots\ldots\ldots\ldots\ldots (2.14.7.7)$$

Assuming $\bar{\Gamma}$ to be constant, we obtain after integration.

$$\mu_{1^0} - \mu_1 = V(p - p^{0)= \bar{\bar{V}}_{1\pi}} \ldots\ldots\ldots\ldots (2.14.7.8)$$

$$\mu_{1^0} - \mu_1 = \bar{\bar{V}}_{1\pi} \ldots\ldots\ldots\ldots (2.14.7.8)$$

$$\mu_{1^0} - \mu_1 = \bar{\bar{V}}_\pi \ldots\ldots\ldots (2.14.7.9)$$

Where π = osmotic pressure.

V = partial molar (specific) volume of solvent.

Hence

$$\mu_{1^0} - \mu_1 = \Delta\mu_1 \ldots\ldots\ldots (2.14.7.10)$$

$$\mu_{1^0} - \mu_1 = -\bar{\bar{V}}_\pi \ldots\ldots\ldots (2.14.7.11)$$

2.14.8 Ideal and non-ideal solutions

Ideal solution are those which form with a zero heat effect ($\Delta H = 0$) and ideal entropy of mixing equals –R Ln N. consequently, in accordance with equation (2.14.7.4), the change in chemical potential of ith component in an ideal solution equals.

$$\Delta\mu_i = -T\Delta S_i = RTlnN_i \ldots\ldots\ldots (2.14.8.1)$$

i.e., depends only on the mole fraction of that component in the solution. In this case of a real solution.

$$\Delta\mu_i = \Delta G = RT \ln\left(\frac{pi}{pi^0}\right) \ldots\ldots (2.14.8.2)$$

Where P_i and p_i^0 are the partial vapour pressures of the ith component above the solution and above the pure component respectively.

2.14.9 Osmotic pressure (π)

Osmosis is the phenomenon of penetration of a solvent into a solution through a semi permeable membrane. The tendency of solvent molecules to pass spontaneously into a solution, due to the inequality of chemical potential of pure solvent and solution estimated quantitatively by osmotic pressure, which has the dimension of pressure (atm). The Osmotic pressure of a solution is equal to the additional pressure which

must be applied to the solution to make the chemical potential of the component in solution equal to the chemical potential of the pure solvent.

$$\pi = p - p^0 \ldots\ldots\ldots\ldots\ldots (2.14.9.1)$$

A comparison of equation (2.14.7.8) and equation (2.14.8.1) shows that the Osmotic pressure of an ideal solution can be given by the relation.

$$\pi = -\left(\frac{RT}{v_1^0}\right) \ln N_1 \ldots\ldots (2.14.9.2)$$

$$\pi = -\left(\frac{RT}{v_1^0}\right) \ln(1 - N_2) \ldots\ldots (2.14.9.3)$$

Expanding in (1-)N_2 in a series, and using the term of this series for high dilutions, we obtain.

$$\ln N_1 = \ln(1 - N_2) = -N_2 - \frac{N_2^2}{2} \ldots . (2.14.9.4)$$

$$\pi = -\left(\frac{RT}{v_1^0}\right) N_2 \ldots\ldots . \ldots (2.14.9.5)$$

The mole fraction of a component is

$$N_2 = \frac{n_2}{n_1 + n_2} \ldots\ldots\ldots . . (2.14.9.6)$$

Where n_1 and n_1 are the number of moles of the components. If $n_1 >> n_2$ then $N_2 \approx n_2/n_1$. Substituting this expression into equation (4.9.4), we get

$$\pi = \left(\frac{RT}{v}\right)_{n_2} = c_2 RT \ldots\ldots . \ldots (2.14.9.7)$$

Where V = volume of solution, equal to $n_1 v_1^0$

C = n_2/V = concentration of a solute in units of mole/litre.

Equation (2.14.9.7) was first derived empirically by van;t Hoff, and is known as the van;t Hoof equation.

The van;t Hoff equation π = CRT dose not apply to polymer solution, even though they are very dilute. The concentration dependence of Osmotic pressure is expressed by a more complex equation which results if the concentration C is replaced by power series (Flory, 1953):

$$\pi = RT\ (\mathrm{A_1C} + A_2C^2 + A_3C^3) \ldots\ldots\ldots (2.14.9.8)$$

$$\frac{\pi}{C} = RT\ (\mathrm{A_1C} + A_2\mathrm{C} + A_3C^2) \ldots\ldots\ldots (2.14.9.9)$$

Where C = concentration of a polymer in a solution (g/ml)

A_1, A_2, A_3, are first, second and third virial coefficients.

The first virial coefficients A1 is related directly to the molecular mass of a polymer by the relation $A_1 = \frac{1}{M_n}$ (Tager, 1978). Heence, equation (2.14.9.9) may be written in the following form.

$$\frac{\pi}{C} = RT\ \left(\frac{1}{M_n} + \mathrm{A_2C} + A_3C^2\right) \ldots\ldots\ldots (2.14.9.10)$$

Equation (2.14.9.10) can be written in the following form (Billmeyer, 1971; krigbaum and flory, 1953).

$$\frac{\pi}{C} = \frac{RT}{M_n}(1 + \Gamma^2\mathrm{C} + \mathrm{g}\Gamma^2C^2) \ldots\ldots\ldots (2.14.9.11)$$

Where Γ = A_2/A_1, and g is a slowly varying function of the polymer-solvent interaction with values near zero for solvent and near 0.25 for good solvents (krigbaum, 1952; stockmayer, 1952).

In most cases, the term C^2 may be neglected; when dependence on C^2 is significant, it may be convenient to take g=0..25 and equation (2.14.9.11) becomes.

$$\frac{\pi}{C} = \frac{RT}{M_n}\left(1 + \frac{\Gamma}{C}c\right)^2 \ldots\ldots\ldots (2.14.9.12)$$

In terms of the polymer-solvent interaction constant X_1 of the flory-Huggins theory, the osmotic pressure is given by.

$$\frac{\pi}{C} = \frac{RT}{M_n} + \left(\frac{P_1}{M_1}\, P_2^2\right)\left(\frac{1}{2} P_1 C\right) \ldots\ldots\ldots (2.14.9.13)$$

Where subscript 1 indicates the solvent, and 2 the gum.

As equation (5.1.9.11) and (5.1.9.14), it is usual to plot P_1/c vs. c. in general a straight line results whose intercept at c = 0 is $A_1 = RT/M_n$ and whose slope is the second virial coefficient (A_2) that allows evaluation of the polymer-solvent interaction constant X_1. If the solvent is good enough or the concentration is high enough then the C^2 term is significant, the points may deviate from a straight line. In such cases if is useful to plot $(\pi /c)^{1/2}$ versus C as suggested by equation (2.14.9.12) which can be written as follow.

$$\left(\frac{\pi}{C}\right)^{\frac{1}{2}} = \left(\frac{RT}{M_n}\right)^{\frac{1}{2}} \left(1 + \frac{\Gamma}{2}\, C\right) \ldots\ldots\ldots\ldots\ldots (2.14.9.14)$$

Since

$$\Gamma = \frac{A_2}{A_1}\; And\; A_1 = \frac{1}{M_n}$$

We can write

$$\left(\frac{\pi}{C}\right)^{\frac{1}{2}} = \left(\frac{RT}{M_n}\right)^{\frac{1}{2}} + \left(\frac{RT}{M_n}\right)^{\frac{1}{2}} \frac{A_2 M_n}{2}\, C \ldots. (2.14.9.15)$$

The intercept = $\left(\frac{RT}{M_n}\right)^{\frac{1}{2}} \frac{A_2 M_n}{2} \ldots\ldots\ldots\ldots (2.14.9.17)$

If the second virial coefficients equal zero, the solvent called ideal solvent.

The better solvent has the higher value of A_2 (Figure 2.8).

For an ideal solvent, $A_2 = 0$

For good solvent, $A_2 > 0$

For poor solvent, $A_2 < 0$

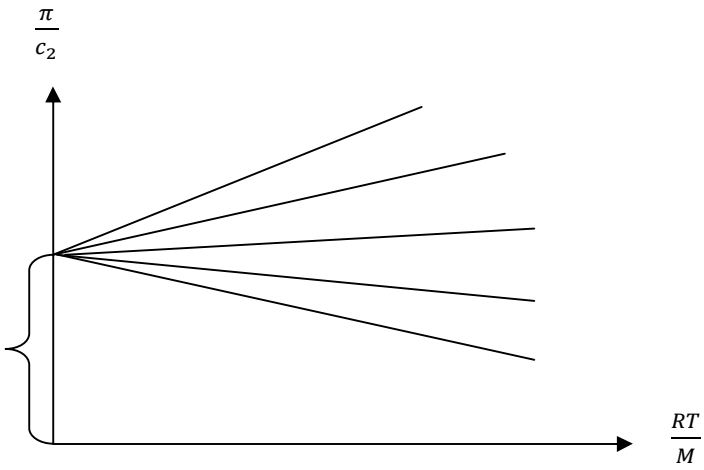

Figure 2.8 Dependence of π/C_2 on concentration of polymer solutions in various solvents.

2.14.10 free energy of mixing of polymer with a solvent

To calculate the free energy of mixing ΔG^m, it is necessary to know the chemical potential of a polymer or, to be more exact, the quantity $\Delta\mu_2$. Its value is calculated by using the Gibbs-Duhem equation for specific quantities (Tager, 1978).

$$\omega_2 d\Delta\mu_2 = -\omega_1 d\Delta\mu_1 \ldots\ldots (2.14.10.1)$$

Where ω_1 and ω_2 are weight fractions of component 1 and 2.

Hence,

$$\Delta\mu_2 = -\int \left(\frac{\omega_1}{\omega_2}\right) d\,(\Delta\mu_1) + C \ldots\ldots 2.14.10.2)$$

To solve this equation, it is necessary to plot a graph of dependence of $\omega_1/\omega_2 on\ \Delta\mu_1$ (Figure 2.9).

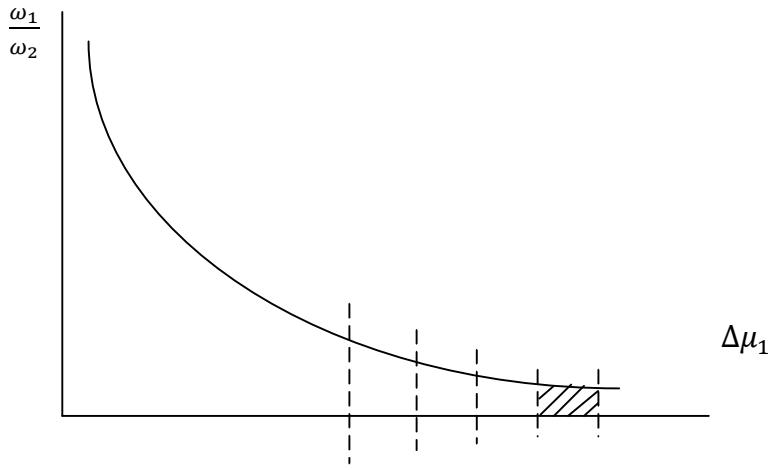

Figure 2.9 Variation of $\omega_1/\omega_2\ with\Delta\mu_1$.

For $\omega_2 = 1\ (\omega_1 = 0) the\ ration\ \omega_1/\omega_2\ = 0\ and\ \Delta\mu_1\ \rightarrow\ \infty$

For $\omega_1 = 1\ (\omega_2 = 0) the\ ratio\ \omega_1/\omega_2 =\ \infty\ and\ \Delta\mu_1 = 0$

Hence, the curve goes with both ends into infinity, and the integral may be determined within the limits ranging from – ∞ to a certain value of $\Delta\mu_1$ which corresponds to the concentration of a solution.

$$\Delta\mu_2 = \int_{-\infty}^{\Delta\mu} \left(\frac{\omega_1}{\omega_2}\right) d(\Delta\mu_1) \ldots\ldots (2.14.10.3)$$

Such an improper integral is replaced with a proper integral which is analogous to it, in this case, the finite value $\Delta\mu_1^{/}$ which conforms to concentration$\omega_1^{/}$ less than one is taken as thee lower limit . Thus, thee areas under the curve, that are bounded by ordinates corresponding to $\Delta\ \mu_1^{/}$ at $\omega_2^{/}$ and $\Delta\mu_1$at different values of ω_2 are calculated (figure 1.5). The calculated areas for $\Delta\ \mu_2^{/} = f(\omega_1)$ is plotted; in the region $\Delta\mu_2$, a graph of dependence $\Delta\mu_2 = (\omega_1)$ is plotted; in the region of concentration close to $\omega_2 = 1$, it is rectilinear. On extrapolating the straight line to $\omega_2 \rightarrow 1$, we obtain segment A. However, at $\omega_2 = 1$, $\Delta\mu_2 = 0$ it follows that the true values of $\Delta\mu_2$ differ from $\Delta\mu^{/}$*by the* length of segment A (Figure 2.10).

$$\Delta\mu_2 = \Delta\bar{\mu}_2 + A \ldots\ldots\ldots\ldots (5.1.10.4)$$

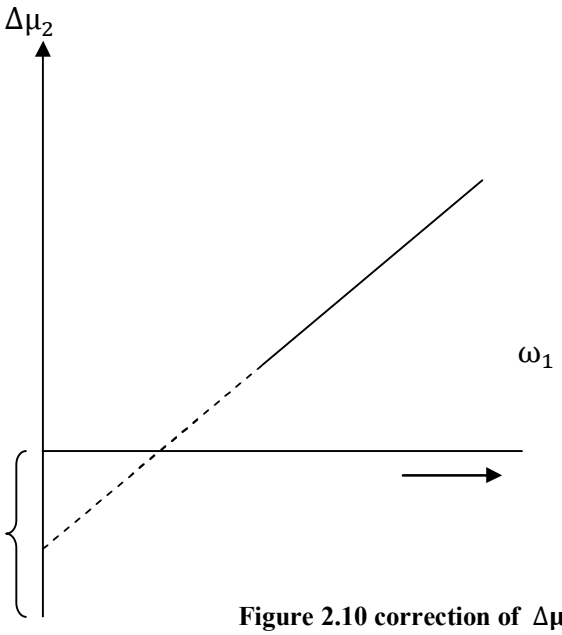

Figure 2.10 correction of $\Delta\mu_2$

This is an ordinary way of approximately calculating $\Delta\mu_2$. Knowing $\Delta\mu_1$ and $\Delta\mu_2$ the average free energy of mixing per gram of a solution can be calculated.

$$\Delta G^m = \omega_1\Delta\mu_1 + \omega_2\Delta\mu_2 \ldots\ldots\ldots 2.14.10.5)$$

Good solvents are liquids whose mixing with polymer is accompanied with great changes in the chemical potentials of components and the free energy of the entire system, and with large values of osmotic pressure and positive values of the second virtial coefficients.

MATERIALS AND METHODS

3.1 Introduction

Physiochemical methods was used to characterized the samples of *A.nilotica var.nilotica* and *A.seyal var.seyal* to determine its physical and chemical properites such as moisture content, ash content, pH value, total nitrogen content, protein content, sugar composition, specific rotation, acid equivalent weight, uronic acid, intrinsic viscosity, and cationic composition.

Thermodynamics properites to determine functions such as partial specific volume of solvent and solute, Osmotic pressure, number average molecular weight, second virial coefficient, chemical potential of solute and solvent and free energy of mixing.

3.2 Material and methods

3.2.1 Gum samples

Fourty gum samples *Acacia nilotica* var.*nilotica* and *Acacia seyal var.seyal* (Nodular gum) are located in the different parts of gum belt. These locations are of varied soil types and climatical conditions. Therefore, the sample of the gum collected represents diversity of these locations. Sandy soil samples are collected from west Kordfan and north Kordfan. Clay soil samples are collected from Gazira, Gadaref, Sinnar, and Blue Nile areas as shown in Table 3.1 and Table 3.2 which shows sample description according to location, season, soil type and rain fall distribution.

3.2.2 Preparation of the gum samples

The gum samples used in this study were dried under shade and cleaned to remove any impurities such as bark and leave fragments and the cleanest nodules were selected and made into fine powder using mortar and pestle then kept in sealed polyethylene bags. Composite samples were prepared by mixing equal weight from each sample, taken from each location.

3.2.3 Methods

The sample in the form of nodules and lumps was left to dry at room temperature, and then cleaned by manually, ground by mill, sieved and kept in labeled plastic container for analysis.

Table 3.1: Sample code, location, date of collection, soil type and rain fall of *Acacia nilotica* var. *nilotica*gum, season 2013

Code	Location		Date of collection	Type of soil	Rain fall
	State	Specific area			
A	Blue Nile	Khourdonia	Jan-03	Clay	< 400mm
Comp A 2013	is prepared by mixing equal amounts of (A1+A2+A3+A4+A5)				
B	West kurdofan	Abu zabad	Mar-08	Sandy	< 400mm
Comp B 2013	is prepared by mixing equal amounts of (B1+B2+B3+B4+B5)				
C	Sinnar	Sinnar	Feb-08	Clay	< 400mm
Comp C 2013	is prepared by mixing equal amounts of (C1+C2+C3+C4+C5)				
D	Gazira	Elremitab	Feb-02	Clay	< 400mm
Comp D 2013	is prepared by mixing equal amounts of (D1+D2+D3+D4+D5)				

Table 3.2: Sample code, location, date of collection, soil type and rain fall of *Acacia seyal* var. *seyal*gum, season 2013

Code	Location		Date of collection	Type of soil	Rain fall
	State	Specific area			
W	Blue Nile	Khourdonia	Jan-03	Clay	< 400mm
Comp W 2013	is prepared by mixing equal amounts of (W1+W2+W3+W4+W5)				
X	Sinnar	El-Dindir	Mar-11	Clay	< 400mm
Comp X 2013	is prepared by mixing equal amounts of (X1+X2+X3+X4+X5)				
Y	North kurdofan	Elobied	Feb-17	Sandy	< 400mm
Comp Y 2013	is prepared by mixing equal amounts of (Y1+Y2+Y3+Y4+Y5)				
Z	West kurdofan	Elnohoud	Mar-01	Sandy	< 400mm
Comp Z 2013	is prepared by mixing equal amounts of (Z1+Z2+Z3+Z4+Z5)				

3.2.4 Determination of moisture content

Moisture content of the gum samples was determined according to AOAC, (1980) method. One gram of gum sample was accurately weighted in a clean, dry preweighted shallow weighing dish. The weighted dish and its contents were dried in an oven (Heraeus. Function line T6- Kendro) at 105°C for five hours, then cooled in a desiccator and reweighed. The loss on drying was calculated as follows:

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

W_1 = Original weight of sample (g).

W_2 = Weight of sample after drying (g).

3.2.5 Determination of ash content

Accurately three grams of the dried sample were weighted on dry porcelain crucible and ignited at 550^{0}C in a muffle furnace (Heraeus. Function line T6- Kendro) until free from carbon, cooled in a desiccator and weighed. Then the total ash % was calculated as follows: (FAO, 1991)

$$\text{Ash (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where:

W_1 = Weight of the empty crucible (g).

W_2 = Weight of the crucible + the sample (g).

W_3 = Weight of the crucible + ash (g).

3.2.6 pH measurement

CORNING- Pinnale-555 pH meter was calibrated by using three different buffer solutions one adjusted at pH 4, 7 and other at pH 11. Then after calibration it was used to determine the pH of crude gum samples, of 1g/100 ml aqueous solution (w/v) calculated on dry weight basis.

3.2.7 Determination of specific optical rotation $[\alpha]_D^T$

The optical rotation was determined for 1.0% solution on dry weight basis. The sample was dissolved in distilled water, mixed on a roller mixer until the sample fully dissolved (approximately 5 hours), after filtration of the gum solution through whatman cellulose nitrate membrane filter paper (0.8µm), optical rotation was measured at room temperature

(25^0C) using polarimeter (AA-5 optical Activity Ltd.) with a D-line of Na (589.3nm) fitted with a cell of path length of 20.0 cm. The specific optical rotation was calculated according to the relationship:

$$\text{Specific optical rotation}[\alpha]_D^T = \frac{\alpha \ x \ 100}{L \ x \ C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots (3.3)$$

Where:

α = Observed angle of rotation.

L = the length of sample holder in decimeters (dm).

C = concentration in gm/100ml

T = Temperature 25Cº.

3.2.8 Determination of intrinsic viscosity

3.2.8.1 Theoretical consideration

Viscosity is a property common to gases and liquids (i.e. fluids). It is a measure of the frictional resistance that a layer of a fluid in motion offers to another. Viscosity is produced by the shearing effect of one layer of the fluid moving past another. In case of liquid, there are strong attractive cohesive forces between the different molecules. When a layer is moving faster than the other, there is slowing down of the faster layer i.e., viscous drag is there due to strong attractive forces.

Viscosity of a polymer solution depends on concentration and size of molecules (i.e., molecular weight) of the dissolved polymer. By measuring the solution viscosity we should be able to get an idea about molecular weight. Solution viscosity is basically a measure of the size or extension in space of polymer molecules. It is empirically related to molecular weight for linear polymers, the simplicity of the measurement and the usefulness of the viscosity-molecular weight correlation are so great that viscosity measurement constitutes an extremely valuable tool for the molecular characterization of polymer. Dilute solution viscosity is usually measured in capillary viscometer of the Ostwald-Fenske or Ubbelohde type. The latter has the advantage that the measurement is independent of the amount of solution in the viscometer, measurement at a series of concentrations can easily be made by successive dilution (Billmeyer, 1962).

The intrinsic viscosity has great practical value in molecular weight determinations of high polymers. This concept is based on the Mark-Houwink relation suggesting that the intrinsic viscosity of a dilute polymer solution is proportional to the average molecular weight of the solute raised to a power in the range of 0.5 to 0.9. Values of the proportionality constant and the exponent are well known for many polymer-solvent

combinations. Solutions viscosities are useful in understanding the behavior of some polymers.Measurements of solution viscosity are usually made by comparing the efflux time t required for a specified volume of polymer solution to flow through a capillary tube with the corresponding efflux time t_0 for the solvent. From t, t_0, and the solute concentration, several quantities whose defining equations and names are given below, are drived.

Relative viscosity $\eta_r = \frac{\eta_{sol}}{\eta_{solv}} = \frac{t}{t_o}$ ..... (3.4)

Specific viscosity $\eta_{sp} = \frac{\eta_{sol} - \eta_{solv}}{\eta_{solv}} = \eta_r - 1$ ..... (3.5)

Reduced viscosity $\eta_{red} = \frac{\eta_{sp}}{C}$ ..... (3.6)

Inherent viscosity $\eta_{inh} = ln \left[\frac{\eta_{red}}{C}\right]$ .....(3.7)

Intrinsic viscosity $[\eta] = lim \left[\frac{\eta_{sp}}{C}\right]_{c \to 0} = ln \left[\frac{\eta_{red}}{C}\right]_{c \to 0}$ .....(3.8)

In these equations, $\boldsymbol{\eta_{sol}}$ is solution viscosity, $\boldsymbol{\eta_{solv}}$ is viscosity of the pure solvent, and $\boldsymbol{C}$ is concentration g/dL. Relative viscosity is the ratio of the viscosity of the solution,$\boldsymbol{\eta_{sol}}$ to the viscosity of the solvent ,$\boldsymbol{\eta_{solv}}$.

Specific viscosity expresses the incremental viscosity due to the presence of the polymer in the solution. Normalizing η_{sp} to concentration gives $\frac{\eta_{sp}}{C}$ which expresses the capacity of a polymer to cause the solution viscosity to increase, i.e., the incremental viscosity per unit concentration of polymer. As with other polymer solution properties, the solutions used for viscosity measurements will be non-ideal and therefore $\frac{\eta_{sp}}{C}$ will depend on C. The extrapolated value of $\frac{\eta_{sp}}{C}$at zero concentration is known as the intrinsic viscosity (η).

Intrinsic viscosity (η) will be shown to be a unique function of molecular weight (for a given polymer-solvent pair) and measurements of (η) can be used to measure molecular weight. The remaining form for the viscosity is the inherent viscosity. Likeη_{sp}, ln η_{red} is zero for pure solvent and increases with increasing concentration, thus ln η_{red} also

expresses the incremental viscosity due to the presence of the polymer in the solution. Normalizing lnη_{red} to concentration or ln $\frac{\eta_{red}}{C}$ gives the inherent viscosity in the limit of zero concentration, η_{red} extrapolates the same as $\frac{\eta_{sp}}{C}$ and becomes equal to the intrinsic viscosity.

The intrinsic viscosity (η) is a measure of the hydrodynamic volume occupied by a macromolecule, which is closely related to the size and conformation of the macromolecular chains in a particular solvent (Higiro*et al*., 2007).

Experimental results with polymer solutions has revealed that the slope of the $\frac{\eta_{sp}}{C}$ vs.C curve, k, depends on molecular weight of the polymer. Huggins found that a plot of k versus $(\eta)^2$ was linear and passed through the origin.

3.2.8.1.1 Huggins equation

The equation describing the dependence of the reduced viscosity on□□the mass concentration of a polymer, *c*, for dilute polymer solutions of the form:

$$\frac{\eta_{sp}}{C} = (\eta) + k^{\backslash}(\eta)^2 c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.9)$$

where$k^{\backslash}$is the Huggins coefficient and (□) is the intrinsic viscosity.

For very dilute solutions, however, Equation (3.9) can be shortened by retaining only the first-order term, and (η) can be determined from the slope of a plot of c against$\frac{\eta_{sp}}{C}$.

To measure intrinsic viscosity it requires extrapolation of $\frac{\eta_{sp}}{C}$to zero concentration.The simplest approach is to do a simple linear extrapolation:

$\frac{\eta_{sp}}{C} = (\eta) + k^{\backslash}c$ ……..…….. (3.10)

The constant, $k^{\backslash}$, is a function of the polymer/solvent/temperature of the system, but is independent of molecular weight. The Huggins coefficient is accepted as a parameter relating polymer–solvent interactions. It describes the resulting interaction from the point of view of existing differences between the chemical structures of solvent and macromolecule. Low $k^{\backslash}$ values ranging from 0.25 to 0.5 are assigned to good solvatation, while higher values are due to poor solvents. (Curvale*et al*., 2008). Morris, (1995) stated that the Huggins constant theoretically should lie between 0.3 and 0.8 indicating a non-aggregation, and values larger than 1 imply polymer–polymer aggregation. In addition, McMillan (1974) reported that the intrinsic viscosity could be obtained from the Kraemer equation (Kraemer, 1938) by extrapolation to zero concentration.

$$ln\left[\frac{\eta_{red}}{c}\right] = (\eta) + k^{\backslash\backslash}(\eta)^2 c \text{ .... } (3.11)$$

where $k^{\backslash\backslash}$ is the Kraemer constant. For very dilute solutions, however, Equation (3.11) can be shortened by retaining only the first-order term, and (η) can be determined from the slope of a plot of c againstln η_{red}. (Higiro *et al.*, 2007).

The intrinsic viscosity is related to the molecular mass according to the Mark-Houwink equation (1938, 1941).

$$[\eta] = K\, M_W^{\alpha} \text{ ....} (3.12)$$

Where

Mw = Molecule weight

K and α Mark- Houwink constant

3.2.8.1.2 Salt tolerance (S) and relative stiffness parameter (B)

Salt tolerance is a property that is related to the stiffness of polymer chains. The more flexible the chain, the higher the response, as observed from intrinsic viscosities, to changing ionic strengths.(Anthonsen*et al.*, 1993). Based on this fact, Smidsrødand Haug (1971) suggested an empirical parameter, *B,* that provides a relative measure of chain stiffness of polyelectrolytes. A necessary and useful feature of *B* is that it is independent of molecular weight, so that the comparison with polyelectrolytes of different chemical structure is possible. Also, *B* is estimated without molecular weight determinations. Smidsrød and Haug concluded that within a relatively broad range of stochiometric charge densities, *B* was solely dependent upon chain stiffness.

Smidsrød and Haug proposed that the salt tolerance parameter (*S*) can be determined from the slope of (η) at various ionic strengths vs. the inverse square root of ionic strength ($I^{0.5}$) plot according to the following equation:

$$(\eta) = (\eta)^{\infty} + S.\, I^{-0.5} \text{ .... } (3.13)$$

Where $(\eta)^{\infty}$ is the intrinsic viscosity at infinite ionic strength. The relative stiffness parameter (*B*) was then obtained from the intercept of a double logarithmic plot of the salt tolerance vs. the intrinsic viscosity at an ionic strength of 0.1 M ($(\eta)_{0.1}$) according to the following equation:

$$S = B.((\eta)_{0.1})^{\upsilon} \quad \text{.....(3.14)}$$

Where υ was found to vary only in a narrow range (1.2–1.4) for most polyelectrolytes (Lapasin*et al.*, 1995). And an average value of 1.3 is widely used. Low values of *B* areassociated with stiff polymer backbones and vice versa.

Another stiffness index that is commonly used is the persistence length q, which is a measure of the length over which the chain persists'in the direction of the first bond of the chain. The persistence length is related to the stiffness parameter *B* by the expressionproposed by Smidsrød*et al.*, (1991) and Mohammadifar*et al.*, (2006).

$$q = 0.26/B \quad \text{..... (3.15)}$$

Higher rigidity of the polyelectrolyte chain implies higher persistence length (Cristóbal*et al.*, 2008).

This method is very simple and easy to use, and the chain stiffness parameter *B* can be estimated only from the intrinsic viscosity data. A number of studies showed that Smidsrød 'B-value' method is accepted widely, and even applicable to characterize biopolymers such as xanthan, hyaluronate, pectin, alginate, and cellulose derivatives. (Xiaojuan*et al.*,2009). From these examples, it can be seen that this '*B*-value' method is not only applicable to homopolymers but also to heteropolymers.

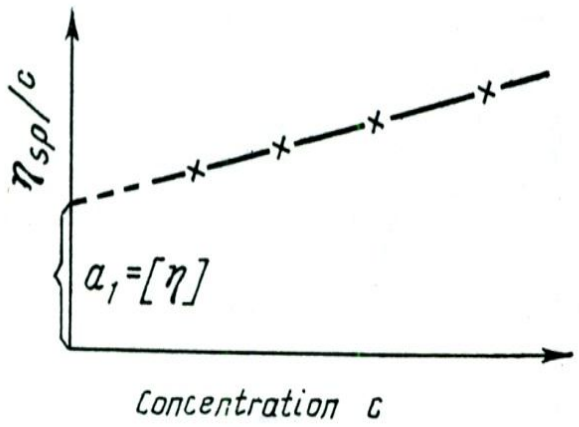

Figure 3.1: Dependence of reduced viscosity of a dilute polymer solution on concentration

3.2.8.2 Method

Intrinsic viscosity was determined using Cannon- ubbelohde semi- micro dilution viscometer, type (75 N 94). Gum sample was dissolved in 0.2M NaCl solution to give solution with concentration of 4%. The solution was filtered through whatman cellulose nitrate membrane filter paper 0.8µm into clean container. The viscometer

was cleaned by washing with distilled water and dried in acetone. The viscometer was immersed in a water bath (Cannon CT-500 series II) adjusted at 25^{o}C ±1 and left to attain equilibrium.The efflux time of solvent and that of the test solution was measured by inserting exactly 2 ml in to the reservoir of the viscometer using glass pipette. The test solution in the viscometer was successively diluted by adding 0.3, 0.4, 0.5, 0.8, 1.2 and 1.8 ml of solvent and the efflux time of the diluted solution was measured. The readings were taken in duplicate using an accurate millisecond timer. The same method was repeated using 0.5M NaCl, 0.1M NaCl ,0.05M NaCl, 0.01M NaCl, 0.005M NaCl, 0.2M NaCl in water (4ml of 5% gum solution + 1 ml of 1 M NaCl), 0.05M NaCl in water (4ml of 5% gum solution + 1 ml of 0.25M NaCl) and pure distilled water. The intrinsic viscosity is, therefore, obtained by extrapolating of reduced viscosity to the value at zero solute concentration by using a linear regression. Salt tolerance parameter (*S*) was determined from the slope of (η) at various ionic strengths vs.the inverse square root of ionic strength ($I^{-0.5}$) plot. The relative stiffness parameter (*B*) was then obtained from the intercept of a double logarithmic plot of the salt tolerance vs. the intrinsic viscosity at an ionic strength of 0.1 M ($(\eta)_{I\,0.1}$).

3.2.9 Nitrogen and protein Content

The Kjeldahl method was used to determine the total nitrogen in gum samples according to AOAC (1990). The method consists of three basic steps: (1) digestion of the sample in sulfuric acid with a catalyst, which results in conversion of nitrogen to ammonia, (2) distillation of the ammonia into a trapping solution, and (3) quantification of the ammonia by titration with a standard solution. The reactions involved in these steps can be shown as follows:

- Sample + H_2SO_4 (conc.) catalyst +Heat → $(NH_4)_2SO_4$
- $(NH_4)_2SO_4$ + 2 Na OH → $2NH_3 + Na_2SO_4 + 2H_2O$
- $NH_3 + H_3BO_3 \rightarrow NH_4^+ + H_2BO_3^-$
- $H_2BO_3^- + HCl \rightarrow H_3BO_3 + Cl^-$

3.2.9.1 Method

0.5 gram of each sample (in duplicate) was weighed and transferred to Kjeldahl digestion flasks and Kjeldahl tablet (copper sulphate-potassium sulphate catalyst) was added to each. 10 cm^3 concentrated, nitrogen free, sulphuric acid was added. The tube was then mounted in the digestion heating system which was previously set to 240^{o}C and capped with an aerated manifold. The solution was then heated at the above

temperature until a clear pale yellowish-green color was observed which indicates the completion of the digestion. The tubes were then allowed to attain room temperature. Their contents were quantitatively transferred to kjeldahl distillation apparatus followed by addition of distilled water and 30% (w/v) sodium hydroxide. Steam distillation was then started and the released ammonia was absorbed in 25 cm^3 of 2% boric acid. Back titration of the generated borate was then carried out versus, 0.02M, hydrochloric acid using methyl red as an indicator. Blank titration was carried in the same way.

$$\%N = \frac{14.01\ x\ M\ x\ (\ volume\ of\ titrant - volume\ of\ blank) x\ 100}{weight\ of\ sample\ (grams)} \quad \text{..... (3.16)}$$

Where:

M is the molarity of hydrochloric acid.

Protein content was calculated using nitrogen conversion factor resulting from amino acid analysis as follows:

% protein = % N x 6.51 ..... (3.17)

3.2.10 Determination of acid equivalent weight and uronic acid

Acid equivalent weight was determined according to the method reported in encyclopedia of chemical technology (1966) with some modification. A cation exchange column was packed with Amberlite IR (120 H^+) resin. 2 molar sulphuricacid was passed through the column until the resin was thoroughly washed with the acid. Then this was followed by distilled water until the column was free from sulphate. 50 ml of 3% w/v gum solution was allowed to pass through the column under gravity action, followed by distilled water until a volume of 250 ml of the eluent and washing were collected and titrated against 0.1N NaOH. The apparent equivalent weight of the acid was calculated by:

$$Acid\ equivalent\ weight\ = \frac{weight\ of\ sample\ x\ 1000}{volume\ of\ titrant\ x\ normality\ of\ alkali} \text{..... (3.18)}$$

$$\%\ Uronic\ acid\ anhydride\ = \frac{194\ x\ 100}{Acid\ equivalent\ weight} \text{..... (3.19)}$$

Where:

194 Molecular weight of uronic acid.

3.2.11 Determination of cationic composition

Atomic absorption spectrometry is a technique which can be applied effectively to determine about 70 elements. It is based on the absorption of radiations by the atoms of a particular element in the ground state, raising them to exited states. Excitation is produced by radiation energy at a wavelength equivalent to the energy needed to lift an atom from its ground state to higher level, the energizing radiation is thus absorbed and the amount of absorption is directly dependent on the population of the ground state atoms in the flame. The sample solution is aspirated in the gaseous state by vaporization and dissociation of molecules. A hollow cathode lamp, which consists of a cathode of the element of interest or coated with it and anode at a low pressure of neon or argon, is used as a source of radiation. A monochromator is used in conjunction with the hollow cathode lamp to isolate the desired spectrum. The radiation that finally reaches the detector system is amplified.

3.2.11.1 Method

Dry ashing method was used in sample preparation; two grams of gum sample were placed in a well-glazed porcelain dish. Started in a cold furnace, and then heated to 550^0C, the temperature was maintained for 4 hours. The sample was cooled and 10 ml of 3N HCl were added. The dish was covered with watch glass, and the sample was boiled gently for 10 minutes. The sample was cooled, filtered into a 100 cm^3 volumetric flask, and diluted to the volume with deionized water.

Atomic absorption spectrometer (SensAA-Dual-GBC Scientific equipment) was used to determine the elements.

3.2.12 Determination of sugar composition

HPLC is widely considered to be a technique mainly for biotechnological, biomedical, biochemical research, and for the pharmaceutical industry, is as well widely used in a lot of fields such as cosmetics, energy, environmental, and food industries (Marcrae, 1985).

3.2.12.1 Sample preparation

The samples were hydrolysed to liberate the sugar residues. Sample was weighed out (100 mg, taking into account the moisture content) and added to 10 cm^3 of 4% H_2SO_4 and incubated at 100 ^{0}C for 6 hours. Following this, 1g of $BaCO_3$ was added to the solution and left overnight (minimum of 12 hours) to neutralise the solution. After $BaCO_3$ treatment, universal indicator strips were used to ensure that the sample was neutral before proceeding to the next stage. The solution was then centrifuged at 2500

rpm for 10 minutes to allow the Barium Sulphate (formed from neutralising the H_2SO_4) to settle. The supernatant was removed and filtered through a 0.45 µmWhatman nylon filter and then diluted 1:1 with 70/30 Acetonitrile/buffer. This constituted the final solution of which 1ml was put in a vial (filtered via 0.45 µm filter) prior to injection into HPLC column.

3.2.12.2 Method

The purpose of analysing the gum samples by HPLC was to determine the relative concentration of each sugar residue present in the sample, namely rhamnose (Rha), arabinose (Ara), galactose (Gal) and glucuronic acid (GlcA).

Before analysis of the gum samples, calibration curves of these sugars were prepared. Stock concentrations of 5 mg cm^{-3} for each sugar were made up by hydrating in 70/30 acetonitrile/buffer for 2 hours. Dilutions of the stock solution achieved six different concentrations for each sugar over a range of 2.5–0.5 mg cm^{-3}. This allowed six levels for the calibration curve and an average of 3 replicates for each level was used to ensure accuracy. This calibration allowed the determination of the unknown sugar content for the gum samples. The concentration of each sugar was calculated by peak height and expressed as a % of the total sugar content.

3.2.13 Determination of number average molecular weight

An important group of absolute methods allowing the determination of the molecular weight of macromolecules is based on the measurement of colligative properties. Here, the activity of the solvent is measured in a polymer solution via determination of the osmotic pressure π_{os}. The value of π_{os} required to determine the number-average molecular weight can be obtained using a membrane osmometer. Here, in a measuring cell having two chambers separated by a semi permeable membrane, one chamber contains the pure solvent and the second one the polymer solution in the same solvent (a membrane is called semi permeable if only the solvent can pass through but not the polymer molecules). Due to the lower activity (lower chemical potential) of the solvent in the polymer solution as compared to the pure solvent, solvent molecules migrate through the membrane from the solvent chamber into that of the polymer solution and dilute it. There fore, the volume of the polymer solution increases until an equilibration is reached between the osmotic pressure $\pi_{os}$and the hydrostatic pressure generated by the diluted polymer solution.

$$\pi_{os= \sigma \, g \, \Delta h} \quad (3.21)$$

where σ is the density of the solvent and *g* is the acceleration of gravity. Following Van't Hoff, it is

$$\pi_{os\,V=nRT} \ldots\ldots\ldots\ldots \text{(3.22)}$$

For diluted solutions, with *V* being the volume of the polymer solution and *n*the number of moles of the dissolved polymer. Since $n = m/M_n$ (*m* is the mass (in g) of dissolved polymer) and $c = m/V$ it follows that:

$$\pi_{os} = \frac{mRT}{VM_n} = \frac{cRT}{M_n} \ldots\ldots\ldots\ldots \text{(3.23)}$$

Since Van's Hoff's law is valid only for infinitely diluted solutions, one develops $^{\pi_{os}}/_{c}$in power law series (break after the linear term in c)

$$\frac{\pi_{os}}{c} = \frac{RT}{M_n} + A_2.c \ldots\ldots\ldots\ldots \text{(3.24)}$$

Thus, the osmotic pressure is first measured at different polymer concentrations, $^{\pi_{os}}/_{c}$is then plotted vs. c, the values are linearly extrapolated to $c \to 0$, and the value of $M_n$is determined from the *y* axis intercept. A_2 is the second virial coefficient of the osmotic pressure.

If the solvent is good enough or the concentration is high enough then the c^2 term is significant, the points may deviate from a straight line. In such cases It is useful to plot $(\pi/c)^{½}$versus c as suggested by equations:

$$(^{\pi}/_{c})^{1/2} = \left(^{RT}/_{M_n}\right)^{1/2}\left(1 + {^{\Gamma}/_{2}}\,c\right) \ldots\ldots\ldots\ldots \text{(3.25)}$$

Since

$$\Gamma = {^{A_2}/_{A_1}} \; and \; A_{1=} {^{1}/_{M_n}}$$

We can write

$$(^{\pi}/_{c})^{1/2} = \left(^{RT}/_{M_n}\right)^{1/2} + \left(^{RT}/_{M_n}\right)^{1/2} A_2\, {^{M_n}/_{2}}\, c \ldots\ldots\ldots\ldots \text{(3.26)}$$

The intercept = $\left(RT/M_n\right)^{1/2}$ ……..……..….(3.27)

The slope = $\left(RT/M_n\right)^{1/2} A_2 M_n/2$ ……..…..(3.28)

If the second virial coefficients equal zero, the solvent is called ideal solvent. The better solvent has the higher value of A_2.

For an ideal solvent, $A_2 = 0$

For good solvent, $A_2 > 0$

For poor solvent, $A_2 < 0$ (Tager, 1978).

According to statistical mechanical solution theory, A_2 represents the interaction of a single solute particle with the solvent, and higher order virial coefficients are associated with correspondingly larger number solute particle cluster interactions with the solvent. For membrane Osmometry (as well as for all other techniques of molecular weight determination via colligative properties) it is very important that the samples to be analyzed are very pure. In particular low-molecular-weight impurities have to be removed reliably. Otherwise, they will migrate through the semi permeable membrane and lower the chemical potential of the solvent in the reference chamber. An overestimation of the molecular weight will follow. The same effect applies when there are very small oligomers in the test sample.

3.2.14 Partial specific volume of solvent

Tangent method was used (Tager, 1987) by dissolving a constant weight of gum sample in different weights of water.The density of solution was determining by pyknometer and then the total volume of the solution was calculated.Then volume of solution was plotted against weight of solutions. The partial specific volume of water is equal to the ∂ v / ∂ g was then found from graph slope.

3.2.15 Partial specific volume of gum

Tangent method was used in which different weights of gum were dissolving a constant weight of water.The density of solution was determining by pyknometer and then the total volume of the solution was calculated.A graph of the volume solution versus the weight of gum was plotted. The partial specific volume of gum sample is equal to the ∂ v / ∂ g which can be calculated from graph given.

3.2.16 Density of solid gums

The density of gums can be determined by weighting out a certain weight of the gum sample with a certain weight of acetone in density bottle. The density of acetone was being determined, and the volume occupied by gum is calculated. From the volume and weight of gum, its density can be calculated.

3.2.17 Osmotic pressure

Osmotic pressures of gums solutions were measured using osmomat^{R} 050 colloidal osmometer at 21◦C.

3.2.17.1 Method

The colloid osmotic pressure is measured by means of an osmotic cell (Osmomat 050). The lower half of the osmotic cell, which is closed off to the outside, is filled with electrolyte containing ringer's solution. The upper half of the cell, which is open to the outside, is filled with a colloid-containing solution. The two halves of the cell are separated from each other by a semi permeable. This membrane possesses defined pores, through which only water and electrolyte can pass. Due to osmotic pressure differential of the two solutions, solvent permeates from the lower into the upper half of the measuring cell until equilibrium is reached between the pressure in lower half of the cell and the osmolal concentration.

Results and discussion

4.1 Physiochemical properties

physicochemical and chemical methods were applied to characterize *Acacia nilotica var.nilotica* and *Acacia seyal var.*seyal gum. The characterization of gums is very important when we need to establish their use for industrial applications. The study of chemical and physical properties of gum is used to ensure thier purity and hence to a void mixed samples and to report the specification of the samples under study. Tables (4.1 and 4.2) show analytical data of *Acacia nilotica* var. *nilotica* and *Acacia seyal* var. seyal gum samples seasons 2012/2013 respectively.

4.1.1 Moisture content

The moisture content of the gum is usually affected by the season of collection, the prevailing climate conditions and the storage condition.

The moisture content of *Acacia nilotica var.nilotica* gum samples collected in season 2012/2013, ranged between 9.57-11.68% with an average value of 10.87% as shown in Table (4.1). The results show higher moisture contents compared to those reported by Kapoor *et al*., (1991) and Karamallah (1999).but agree with the results obtained by A.satti (2012).*Acacia seyal var.seyal* gum samples of season 2012/2013 had moisture contents in the range of 10.00-12.6% with an average value of 11.3% as shown in Table (4.2).The moisture content of *A.seyal var.seyal* agrees with the results those were reported in the literature in different seasons (karamallah et al.,1998; Siddig 2003). The moisture content of *A.seyal var.seyal* were found to be more than the average value reported in the literature (Hassan, 2000), but agree with the results obtained by Anderson and Herbich(1963).

4.1.2 Ash content

Tables (4.1 and 4.2) show the ash content of *A. nilotica var.nilotica* gum and *Acacia seyal var.seyal* gum samples collected on seasons 2012/2013.The ash content of *A.nilotica var.nilotica* gum was found to be ranged between 1.60% - 2.10% and which is almost similar to those results obtained by Anderson (1977) and Kapoor *et al*., (1991) which fell in the range of 1.98- 2.48%, but far less than those obtained by Andreson, et. al., (1966) and Karamallah (1999) which were reported as 0.02 % and 0.03%.

Table 4.2 shows the ash content of *A.seyal var.seyal* was found to be ranged between 2.11% - 3.19% with an average value 2.82% which agree with the results mentioned in the literature (Anderson and Herbich, 1963),(Anderson and Weiping, 1991),

(Karamallah et al.,1998) and (Malik,2008). The average value also agree with the results obtained by (Ibrahim, 2006), but these average was less than the average values of *A.seyal var.seyal* obtained by (Hassan, 2000).

Ash content of *A.nilotica var.nilotica* is less than that reported in the literature for *Acacia senegal* (Anderson, 1977, Anderson, 1991, Jurasek *et al*., 1993, Osman, 1993, Karamallah *et al*., 1998, Karamallah, 1999, Omer, 2006, Abdelrahman, 2008 and Younes 2009). Also the results were less than the values mentioned for *Acacia seyal var.seyal* by Karamallah (1999), Omer (2006), Malik (2008) and Younes (2009).

4.1.3 pH value

Tables (4.1 and 4.2) show the pH values for *A. nilotica var.nilotica* gum and *A.seyal var.seyal* season 2012/2013. The average values were found to be 5.1, and 3.4 respectively. The pH value of *A. nilotica var.nilotica* is significantly higher than that obtained by Karamalla (1999), which was found to be 4.10 it is also higher than that reported for *A.esnegal var.senegal* (Karamalla 1998, 1999) and *A.seyal var.seyal* by the same author (1999) and Younes (2009). The pH values for *A.nilotica var.nilotica* gum is significantly similarly to that reported by Satti (2012).

The pH values for *A.seyal var.seyal* average values were found to be 3.4 is a good agreement to that reported by karamallah (1999), which was found to be 4.35 but it is lower than that reported by younes,(2009).

4.1.4 Specific optical rotation

The specific optical rotation is regarded as one of the most important parameters by means of which an *Acacia* species gums can be distinguished from other *Acacia* species gums. *Acacia nilotica* has a positive specific optical rotation and it belongs to *Gummeferae* series which contains *A.syeal, A.siberiana, A.tortilis, A.Oerfota* ...etc. whereas *A.senegal var.senegal* has negative specific optical rotation and belong to *Vulgares* series that contains *A.Leata, A.polyacantha, A.mellifera*….etc.

The highest value of specific optical rotation of *Acacia nilotica var.nilotica* was +98.4 whereas the lowest was +88.6. The average values were found to be +92.6, for season 2012/2013, (Table4.1). These results agree well with those reported by Anderson *et al*., (1966), Anderson(1977) and Karamalla (1999). Interestingly, they are far more than those obtained by an FAO study for Nigerian gum, (Al-Assaf *et al*., 2005) where a value of +21 was reported.

Specific optical rotation value of *A.nilotica var.nilotica* is higher than that reported in the literature for *A.seyal var.seyal* (Anderson *et al*., 1963, 1977, Jurasek *et al*, 1993, Karamallah, 1999, Hassan, 2000, Hassan *et al*., 2005, Siddig *et al*., 2005, Omer, 2006, Abdelrahman, 2008 and Younes, 2009).

Table 4.2 shows that the average value of specific rotation value of aqueous solutions of the samples was found to be +55.25 of *A.seyal var.seyal* was fall in the range reported in the literature (Hassan 2000) and Osman.,et al (1993a). And also the result was fall in the range obtained by (AndersonandHerbich, 1963) and (Malik, 2008).

4.1.5 Viscosity

Since *A.nilotica var.nilotica* belongs to *Gummeferae* series, it is characteristed by its low viscosity (Anderson *et al*., 1963, 1966). The intrinsic viscosities of *A.nilotica* var. *nilotica* for season 2012/2013 was found to be ranged between 8.56 to 11.13 cm^3g^{-1} with the average 10.1cm^3g^{-1} as shown in Tables (4.1) . These results agreed with those mentioned in the literature (Anderson *et al*., 1966 and Anderson, 1977) which was 9.5cm^3g^{-1}, but is far less than that obtained by an FAO study for Nigerian gum which was reported as 35cm^3g^{-1} (Al-Assaf *et al*., 2005).

The low specific optical rotation value and extremely high intrinsic viscosity value cited in the FAO study may lead to a conclusion that the studied gum material did not belong to *A.nilotica var.nilotica* specially when considering the many variants of this species.

The intrinsic viscosities of *A.seyal var.seyal* for season 2012/2013 was found to be ranged between 11.36 to 13.08cm^3g^{-1} with the average 12.12cm^3g^{-1} as shown in Tables (4.2).

Both *A.senegal var.senegal* and *A.seyal var.seyal* have higher value of intrinsic viscosity compared with *A.nilotica var.nilotica*. (Anderson, 1977, Duvallet *et al*., 1989, Jurasek *et al*., 1993, Idris *et al*., 1998,Karamallh *et al*., 1998, 1999, Hassan *et al*., 2005, Siddig *et al*., 2005, Omer, 2006, Abdelrahman, 2008, Elmanan *et al*., 2008 and Younes, 2009).

Table 4.1: Physicochemical properties of *Acacia nilotica var. nilotica* gum season 2012/2013

Sample code	Moisture %	Ash%	pH	Optical rotation $[\alpha]_D^T$ (+)	Intrinsic viscosity cm^3g^{-1}	Nitrogen %	Protein %	Acid equivalent weight	Glucuronic acid%
Comp A-bn12/13	11.68	2.10	5.13	+98.4	8.56	0.029	0.189	1887.00	10.28
Comp B-gd12/13	11.28	1.60	5.05	+90.1	11.13	0.024	0.156	1813.82	10.70
Comp C-wk12/13	9.57	1.81	5.21	+88.6	10.49	0.019	0.124	1996.26	9.72
Comp D-gz12/13	10.96	1.93	5.00	+93.4	10.22	0.021	0.137	1769.95	10.96
Average	**10.87**	**1.86**	**5.1**	**+92.6**	**10.1**	**0.023**	**0.151**	**1866.76**	**10.42**

Table 4.2: Physicochemical properties of *Acacia seyal var.seyal* gum season 2012/2013

Sample code	Moisture %	Ash%	pH	Optical rotation $[\alpha]_D^T$ (+)	Intrinsic viscosity cm^3g^{-1}	Nitrogen %	Protein %	Acid equivalent weight	Glucuronic acid%
Comp W-bn12/13	12.2	2.81	3.4	+48	11.36	0.144	0.95	1363.32	14.23
Comp X-sn12/13	12.6	2.11	3.3	+59	12.24	0.141	0.93	1316.15	14.74
Comp Y-nk12/13	10.0	3.17	3.5	+51	11.78	0.131	0.86	1704.75	11.38
Comp Z-wk12/13	10.2	3.19	3.3	+63	13.08	0.117	0.77	1470.81	13.19
Average	**11.3**	**2.82**	**3.4**	**+55.25**	**12.12**	**0.133**	**0.88**	**1449.93**	**13.38**

4.1.6 Nitrogen and protein content

The mean percentages of nitrogen and protein content using kjeldahl method are shown in Tables (4.1) for *A. nilotica* var. *nilotica* for seasons 2012/2013.

The mean percentages of nitrogen and protein of *A. nilotica* var. *nilotica* ranged between 0.023% and 0.151%. The total protein content was calculated using nitrogen conversion factor (NCF) of 6.51 resulting from amino acid analysis. From literature, the nitrogen conversion factor (NCF) of *A. senegal* was found to be 6.6 (Anderson, 1986 cited in Osman *et al*., 1993). The percentage of nitrogen content of *A. nilotica* var. *nilotica* is typical with the result obtained by Anderson *et al*., (1966), Anderson, (1977) and Satti (2012) but slightly less than the value reported by Karamallh (1999) which was 0.06%. The protein content obtained from this study is far less than that indicated by Kapoor, *et al*., (1991) and a FAO study for Nigerian gum. (Al-Assaf *et al*., 2005). These values were 1.9% and 4.7% respectively. Both *A. senegal* and *A. seyal* have higher nitrogen and protein content compared with *A. nilotica* var. *nilotica* (Anderson *et al*., 1963, Anderson, 1977, Jurasek *et al*., 1993, Osman, 1993, Idris *et al*., 1998, Karamallh *et al*., 1998, 1999, Hassan *et al*., 2005, Siddig *et al*., 2005, Omer, 2006, Malik, 2008, Elmanan *et al*., 2008 and Younes, 2009).

Table 4.2 shows the nitrogen and protein percentage using Kjeldal method. A conversion factor 6.6 use to the total nitrogen percentage to total protein percentage.

The nitrogen and protein content of *A. seyal* var.*seyal* was in the range obtain by Malik (2008) and Hassan et al(2005) using Kjeldal method from 0.11% to 0.19% w/w for the nitrogen content and from 0.73% to 1.12% for the protein content. Results of *A.seyal* (Table 4.2) are agree with comparative analytical data for *A.seyal* gums reported in the literature karamallah (1999), and it is also similar to that obtained by Malik (2008).

4.1.7 Acid equivalent weight and uronic acid

The acid equivalent weight and corresponding calculated uronic acid content of *A.nilotica var.nilotica* gum are given in Tables (4.1) for seasons 2012/2013. The mean of acid equivalent weights were 1866.76, with the corresponding uronic acid having the mean value of 10.42%. This range is in agreement with that previously obtained by (Anderson *et al*., 1966, Anderson, 1977), but uronic acid is far less than that obtained from a FAO study (21%) for Nigerian gum (Al-Assaf *et al*., 2005). These results are different from the results obtained for *A.senegal var.senegal* by Osman *et al*., (1993) and Siddig *et al*. (2005), they reported a range of 1153 to 1500 for acid equivalent weight and a range of 12.93 % to 16.33 % for uronic acid content.

Table (4.2) shows the acid equivalent weight and corresponding calculated uronic acid content of *A.seyal var.seyal* gum for seasons 2012/2013.The average value of acid equivalent weight and corresponding calculated uronic acid were found to be 1449.93 and 13.38% respectively.The results agree with that reported by (Anderson 1963) and (Malik 2008), but the results significantly higher than that reported by (karamallah 2000), (Omer 2003) and (Hassan 2005).

4.1.8 Cationic composition

Table 4.3: Cationic composition of*Acacia nilotica var.nilotica* gum season 2012/2013

Sample code	Na w/w (%)	K w/w (%)	Ca w/w (%)	Mg w/w (%)	Fe w/w (%)	Zn w/w (%)×10^{4-}	Pb w/w (%)
Comp A-bn12/13	0.0018	0.286	0.141	0.0170	0.0022	0.0024	0.0021
Comp B-gd12/13	0.0714	0.0411	0.121	0.0146	0.0019	0.0036	0.0040
Comp C-wk12/13	0.0345	0.256	0.098	0.0134	0.0016	0.0019	0.0062
Comp D-gz12/13	0.0506	0.0583	0.048	0.0162	0.0048	0.0023	0.0081
Average	**0.0396**	**0.1604**	**0.102**	**0.0153**	**0.0026**	**0.0025**	**0.0051**

Table 4.4: Cationic composition of *Acacia seyal* var. *seyal* gum season 2012/2013

Sample code	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)	Zn (ppm)	Pb (ppm)
Comp W-bn12/13	113.71	2961.36	9598.21	1230.40	41.39	7.88	7.41
Comp X-sn12/13	111.67	2901.02	9567.18	1224.60	39.98	7.56	7.86
Comp Y-nk12/13	111.03	2889.25	9581.10	1226.18	41.07	7.51	4.82
Comp Z-wk12/13	111.45	2864.17	9588.90	1229.70	41.59	7.83	7.54
Average	**111.97**	**2903.95**	**9583.85**	**1227.72**	**41.00**	**7.69**	**6.91**

Cationic composition of *A.nilotica var.nilotica* gum samples was determined using atomic absorption spectrophotometric technique and the average values are dipicted in Table (4.3).The major elements were in the order: K>Ca>Mg>Na >Pb >Fe >Cu > Zn. Potassium, calcium and magnesium recorded high values, indicating that the gum is a salt of potassium, calcium and magnesium.The major elements in *Acacia senegal var.senegal* obtained by Younes (2009) have the order: Ca > Mg > K > Na. However, the ratios of cationic composition of *A.nilotica var.nilotica* gum were less than those reported for *A.senegal var.senegal* and *A.seyal var.seyal* (Siddig *et al*., 2003, Omer,

2006, Malik, 2008 and Younes, 2009). The results show insignificant differences in gum samples obtained from different locations.

Cationic compositions of *Acacia seyal var.seyal* Table (4.4) agree with the results reported in the literature (Buffo et al.2001) and (Malik 2008) when we compare the results obtained we found that they were in ranges reported for all elements. The results obtained in this study show that potassium,calcium and magnesium recorded high values this indicates that the gum contain high ratio of calcium, this results agree with the results reported by (Malik 2008) and (Siddig 2003) we found that potassium,calcium and magnesium recorded high values.

4.1.9 Sugar composition

Table 4.5: Sugar composition of *Acacia nilotica* var. *nilotica* gum season 2012/2013

Sample code	Arabinose%	Galactose%	Rhamnose%
Comp A-bn12/13	37.67	16.78	11.28
Comp B-gd12/13	43.91	14.73	12.54
Comp C-wk12/13	47.18	18.63	11.21
Comp D-gz12/13	45.84	15.23	6.27
Average	**45.90**	**16.34**	**10.33**

Table 4.6: Sugar composition of *Acacia seyal* var. *seyal* gum season 2012/2013

Sample code	Arabinose%	Galactose%	Rhamnose%
Comp W-bn12/13	42.54	38.46	3.71
Comp X-sn12/13	42.73	37.94	3.83
Comp Y-nk12/13	41.89	37.68	3.54
Comp Z-wk12/13	42.16	38.14	3.59
Average	**42.33**	**38.06**	**3.67**

The sugar contents of *Acacia nilotica var.nilotica* gum which were measured using HPLC technique and the average were found to be 45.90% arabinose, 16.34% galactose and 10.33% rhamnose (Table 4.5).*Acacia nilotica var.nilotica* gum belongs to *gummiferae* series according to Bentham classification (Anderson.1974), in which arabinose had a higher percentage than galactose, and the lowest percentage of rhamnose. The results agree with that reported in literature for *Acacia nilotica var.nilotica* gum. Anderson *et al*., (1966) reported sugar composition of 47%

arabinose and 41% galactose, and also the result agree with that reported by (Satti, 2012) sugar composition of41.20% arabinose and 17.43% galactose and 10.68% rhamnose.

Anderson, (1977) found that the sugar content was 46% arabinose 44% galactose and 0.4% rhamnose. Indian *A.nilotica var.nilotica* gums showed negligible amount of rhamnose according to Kapoor *et al*., (1991). He found arabinose ranged from 45.9% to 65.7% and galactose from 23.1% to 36.6%. Karamalla, (1999) reported a value of 42% and 1.8% for arabinose and rhamnose respectively.

Arabinose represents the highest percentage for sugars in *A.seyal var.seyal* gum while galactose represents the highest percentage in *A.senegal var.senegal* (Osman *et al*., 1993, Siddig *et al*., 2005, Malik, 2008).

Table (4.6) shown the average values of the sugar content of *Acacia seyal var.seyal* gum.Rhaamnose is the lowest percentage value in all samples.Arabinose is highest percentage values of sugars. The results agree with the results obtained by Karamallah (2000) reported analytical data for *A.seyal var.seyal* gum collected between 1960 and 1999 in Sudan, he reported sugar composition 37-38% galactose, 41-45% arabinose, 3-4% rhamnose and 11-12% glucuronic acid.

4.2 Thermodynamic properties

4.2.1 Partial specific volume of the solvent and solute

The partial specific volume of the solvent and solute could be calculated using the tangent method. From the results is possible to construct Figures and from the intercepts of these Figures partial specific volumes of solvent and solute are to be obtained. The partial specific volume of water and *A.nilotica var.nilotica* gum in *A.nilotica* gum solution was obtained from the intercepts of Figures 4.1, to 4.8 composite samples A,B,Cand D the values found to be 0.997,0.999,0.998,0.998 cm^3g^{-1} and 0.655,0.618,0.642,0.653 cm^3g^{-1} respectively.

For *A.seyal var.seyal* gum solution the specific partial molar volume of water and *A.seyal var.* gum in *A.seyal var.seyal* gum solution Figures 5.١٢, to 5.١٩ composite samples W,X,Yand Z were found to be were 0.998,0.998,0.998,0.999 cm^3g^{-1} for water and 0.643,0.655,0.659,0.633 cm^3g^{-1} for *A.seyal* gum respectively.

The partial specific volume of *A.seyal var.seyal* are almost the same of that *A.nilotica var.nilotica* although there is noticeably different between their molecular masses this may be due to the compactness of *A.nilotica* molecules is greater than the *A.seyal* molecules, the results of partial specific volume of gum also show that *A.seyal* molecule expands in water more than *A.nilotica* molecule.

The results show that the sequences of the specific volume of the gums under study are in the order of decreasing molecular weight of these gums i. e., *A.nilotica* and *A.seyal*. The partial specific volume of water and gum in *A.seyal* is so close to that of *A.nilotica,* Although there is noticeably difference between their molecular masses this is may be due to the compactness of *A.seyal* molecules which is greater than the *A.nilotica* molecules, the results of partial specific volume of gums also show that *A.seyal* molecules expands in water more than *A.nilotica* molecules.

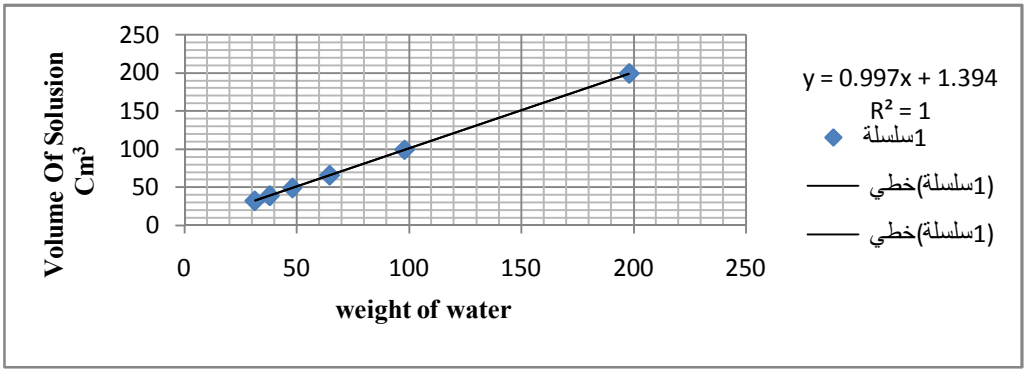

Fig (4.1): Partial Specific Volume of water (Comps. Sample A) ***Acacia nilotica***

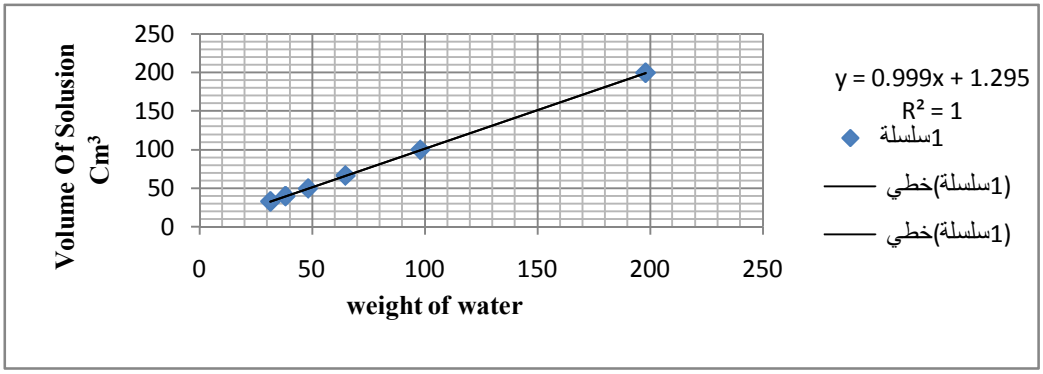

Fig (4.2): Partial Specific Volume of water (Comps. Sample B) ***Acacia nilotica***

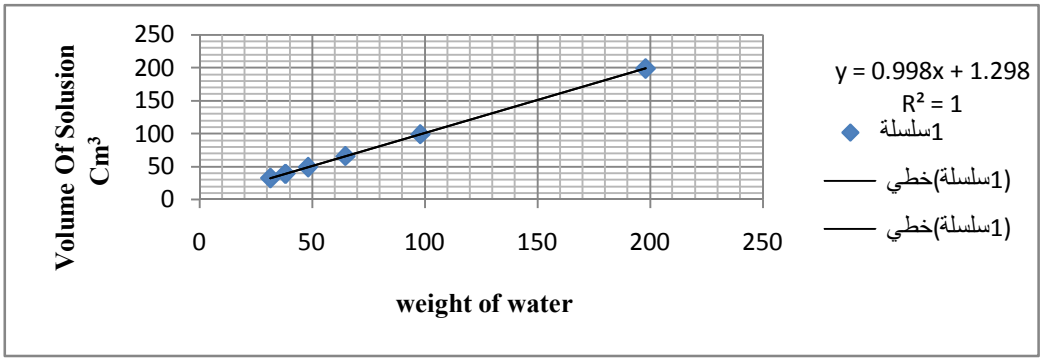

Fig (4.3): Partial Specific Volume of water (Comps. Sample C) ***Acacia nilotica***

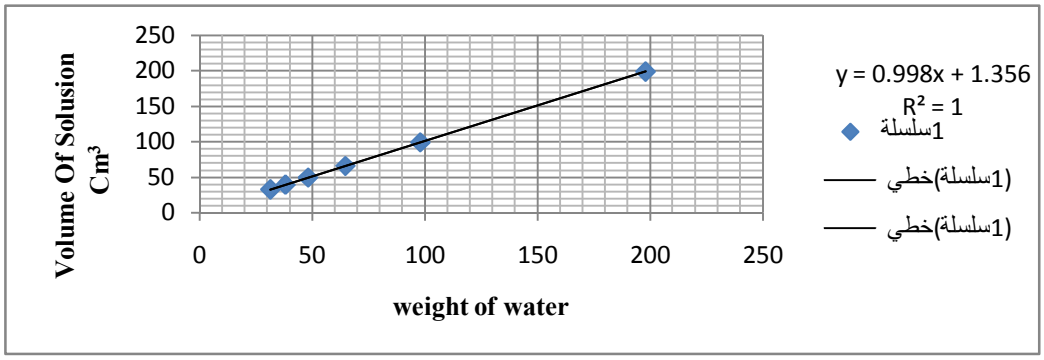

Fig (4.4): Partial Specific Volume of water (Comps. Sample D) ***Acacia nilotica***

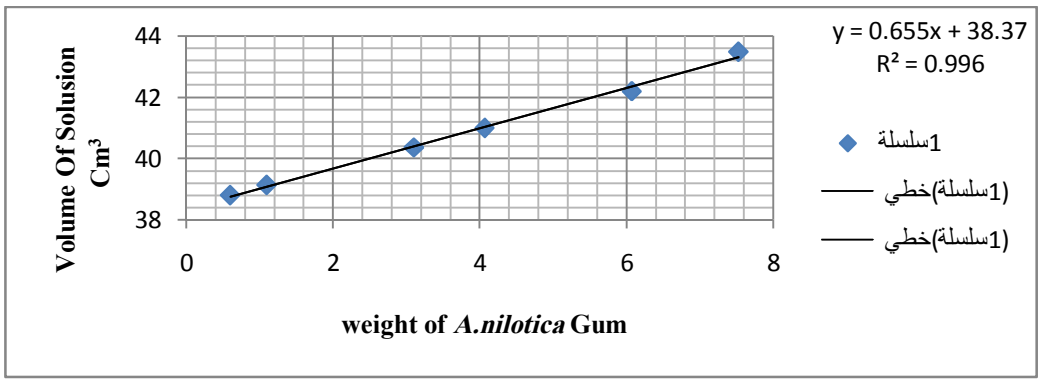

Fig (4.5): Partial Specific Volume of Gum (A) *Acacia nilotica* in *Acacia nilotica* solution

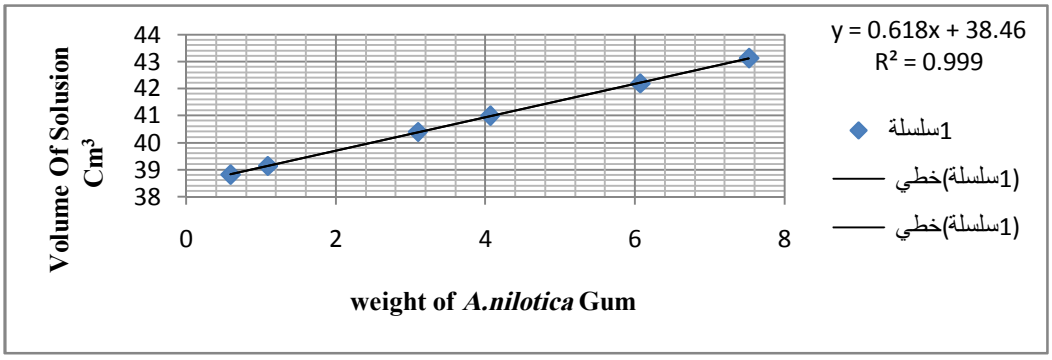

Fig (4.6): Partial Specific Volume of Gum (B) *Acacia nilotica* in *Acacia nilotica* solution

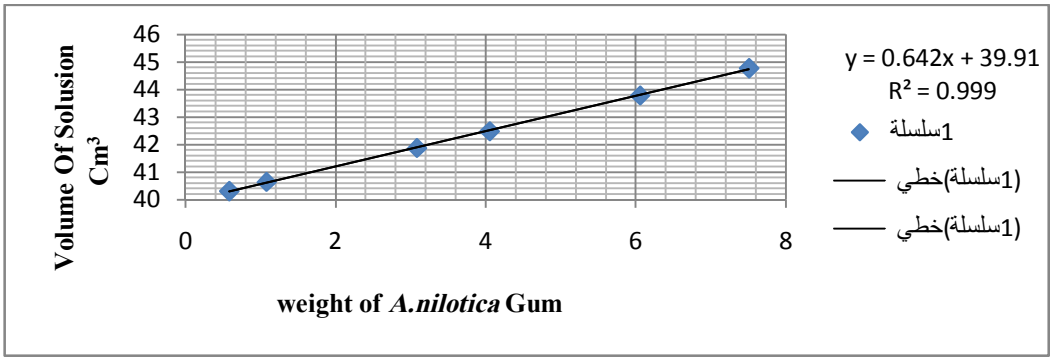

Fig (4.7): Partial Specific Volume of Gum (C) *Acacia nilotica* in *Acacia nilotica* solution

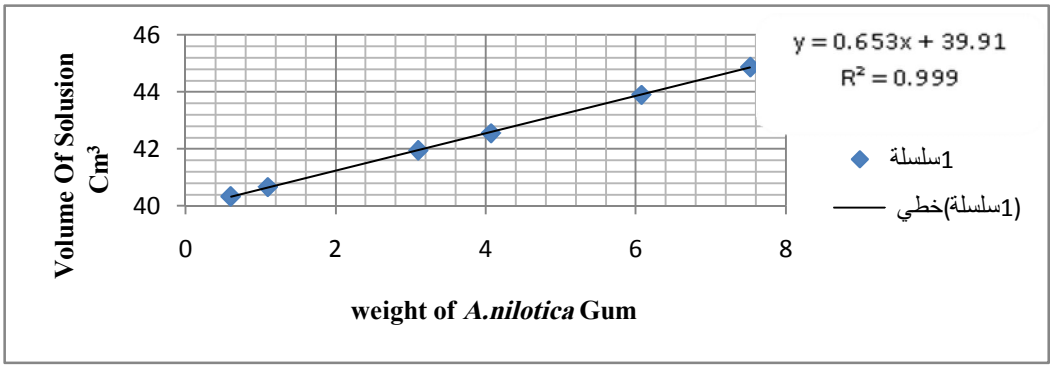

Fig (4.8): Partial Specific Volume of Gum (D) *Acacia nilotica* in *Acacia nilotica* solution

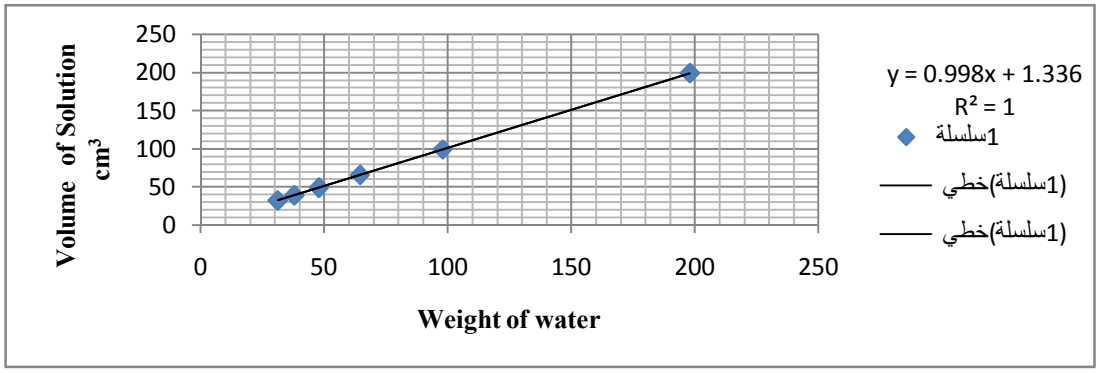

Fig (4.9): Partial Specific Volume of water (Comps. Sample W) ***Acacia Seyal***

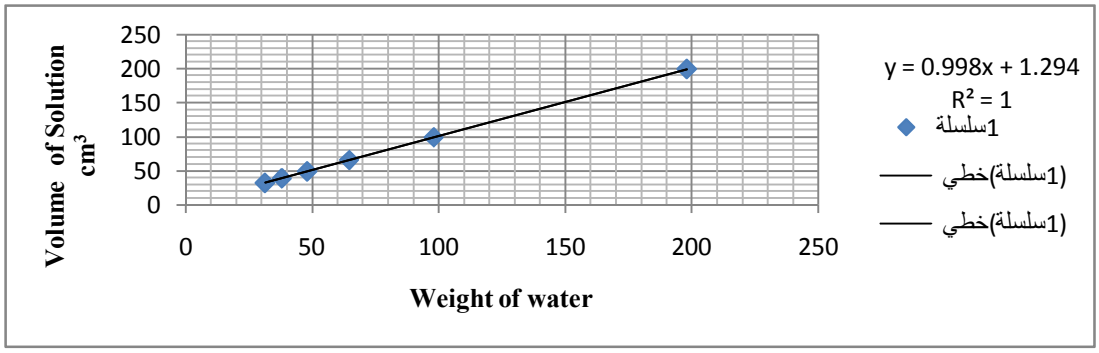

Fig (4.10): Partial Specific Volume of water (Comps. Sample X) ***Acacia Seyal***

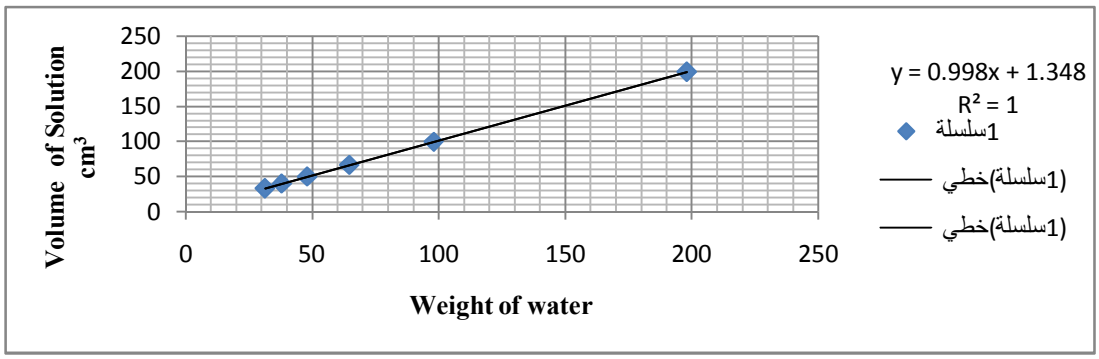

Fig (4.11): Partial Specific Volume of water (Comps. Sample Y) ***Acacia Seyal***

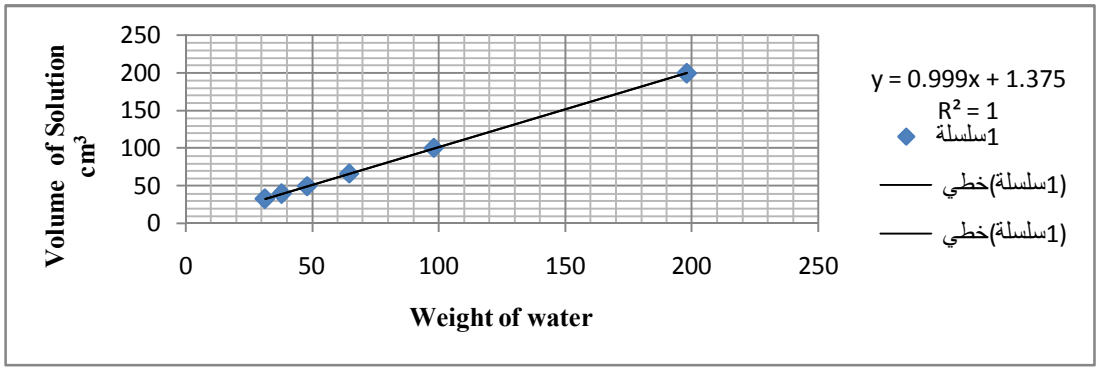

Fig (4.12): Partial Specific Volume of water (Comps. Sample Z) ***Acacia Seyal***

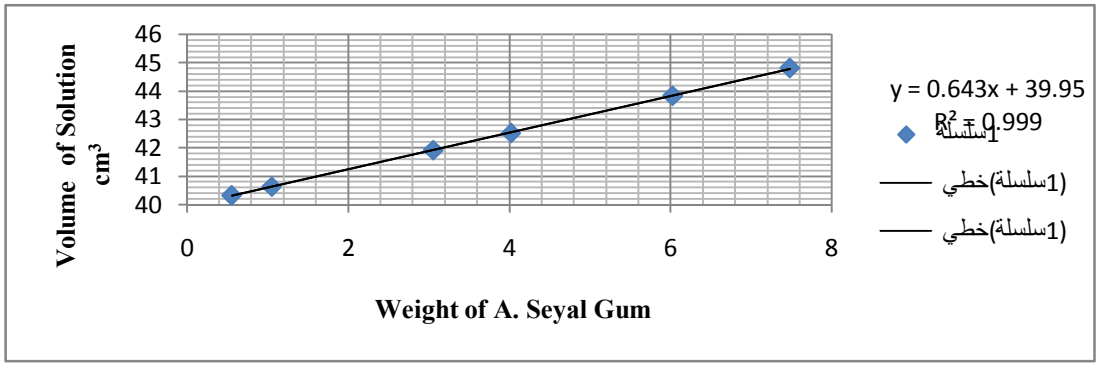

Fig (4.13): Partial Specific Volume of Gum (W) *Acacia Seyal* in *Acacia Seyal* solution

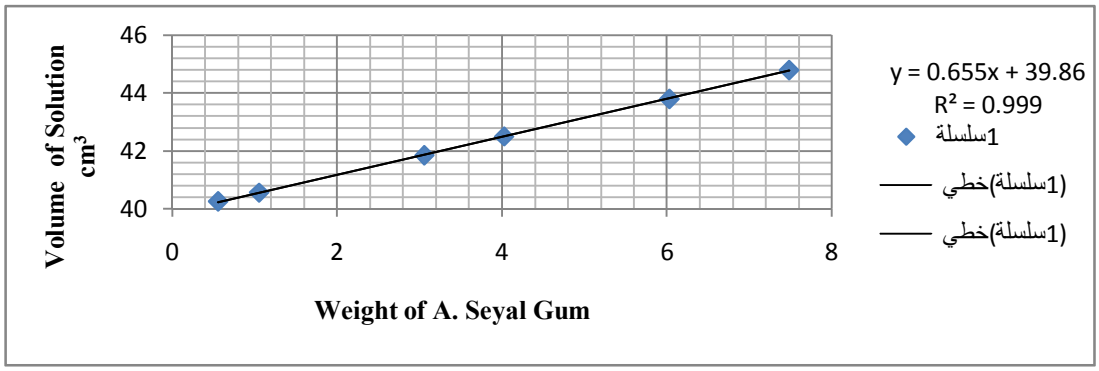

Fig (4.14): Partial Specific Volume of Gum (X) *Acacia Seyal* in *Acacia Seyal* solution

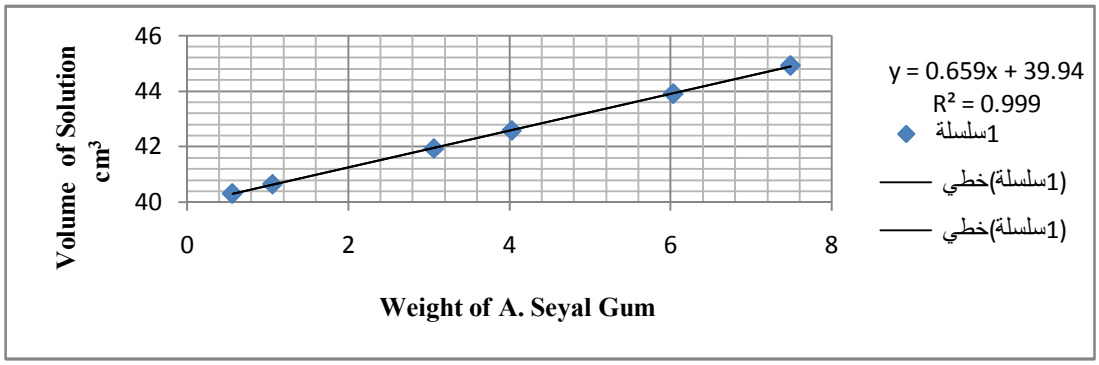

Fig (4.15): Partial Specific Volume of Gum (Y) *Acacia Seyal* in *Acacia Seyal* solution

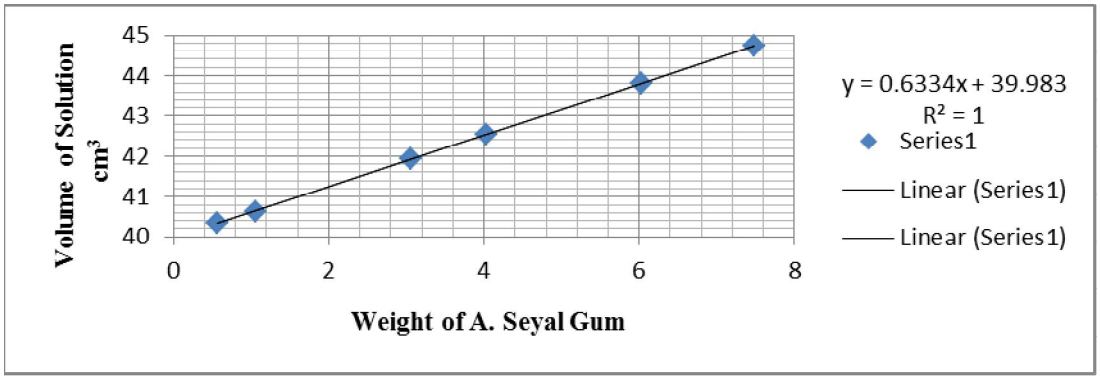

Fig (4.16): Partial Specific Volume of Gum (Z) *Acacia Seyal* in *Acacia Seyal* solution

Table (4.7): Partial specific volume of water (V_1), of gum (V_2), volume fraction of water (φ_1), of gum (φ_2) for composite samples of *A. nilotica var.nilotica* and *A.seyal var.seyal* gums aqueous solution

Gum sample	V_1(cm^3 g^{-1})	V_2 (cm^3 g^{-1})	φ_1	φ_2
A.nilotica (A)	0.997	0.655	0.6383	0.3965
A.nilotica (B)	0.999	0.618	0.6178	0.3823
A.nilotica (C)	0.998	0.642	0.6085	0.3915
A.nilotica (D)	0.998	0.653	0.6038	0.3962
Average	**0.998**	**0.642**	**0.6171**	**0.3916**
A.seyal (W)	0.998	0.643	0.6081	0.3918
A.seyal (X)	0.998	0.655	0.6037	0.3950
A.seyal (Y)	0.998	0.659	0.6022	0.3977
A.seyal (Z)	0.999	0.633	0.6121	0.3878
Average	**0.998**	**0.648**	**0.6065**	**0.3931**

4.2.2 Volume fractions of water φ_1 and gums φ_2

The volume fractions of water φ_1 and that of gums φ_2 in gums solutions of different concentrations was calculated using equations 2.14.4.1 and 2.14.4.2 results are shown in Table 4.7.

A.nilotica var.nilotica has the larger volume fraction than *A.seyal var.seyal* The sequence of the volume fraction was related to the sequence of weight average molecular weight and partial specific volume of the samples of gums studied.

Figures 5.٢٠ to 5.٢٧ show osmotic pressure of different concentrations of aqueous *A.nilotica var.nilotica* and *A.seyal var.seyal* gum solution. The results obtained show that at the same concentration of *A.seyal var.seyal* have high value of osmotic pressure than the *A.nilotica,* this mean that they interact with water more than *A.nilotica var.nilotica* and this due to the structural variation

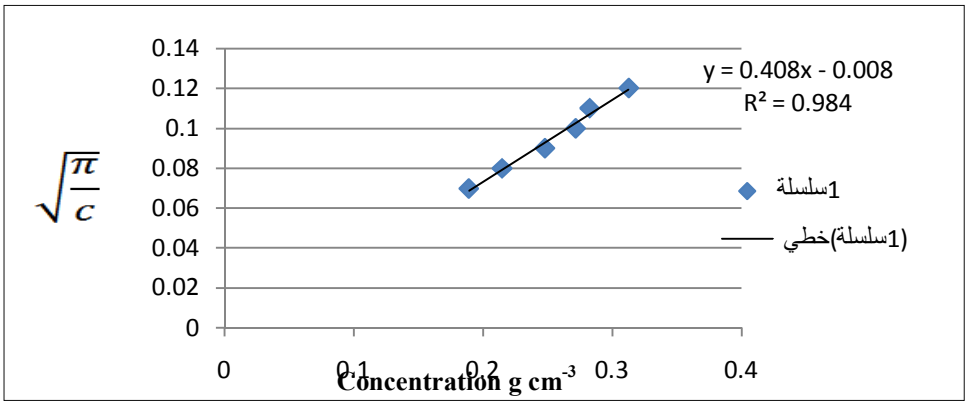

Figure 4.17 Osmotic pressure Concentration profile of *Acacia nilotica* (A)

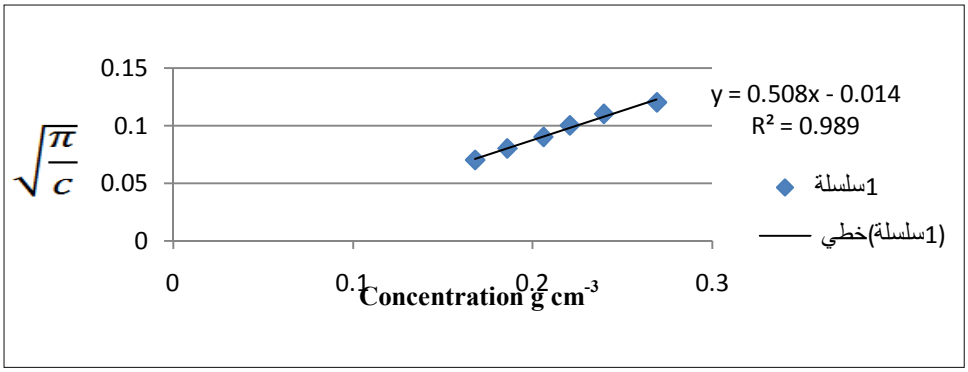

Figure 4.18 Osmotic pressure Concentration profile of *Acacia nilotica*(B)

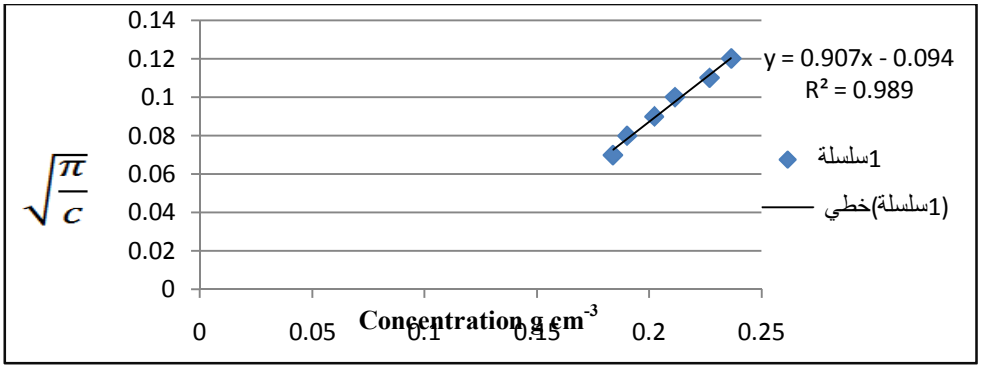

Figure 4.19 Osmotic pressure Concentration profile of *Acacia nilotica*(C)

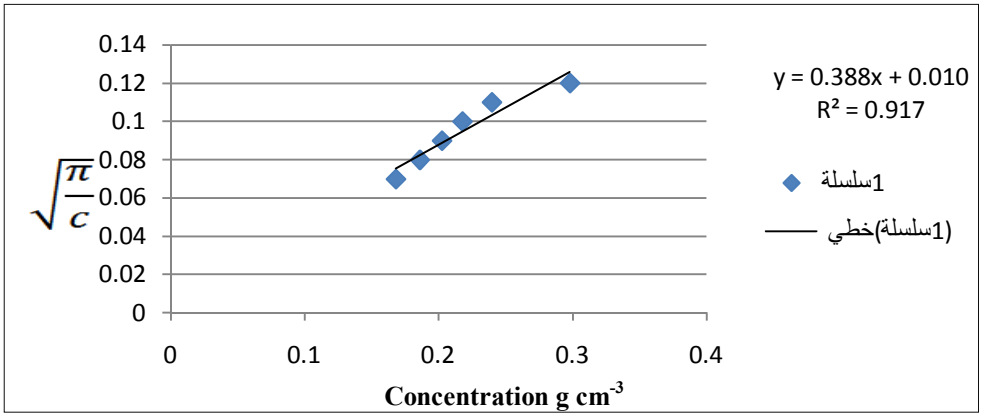

Figure 5.٢٣ Osmotic pressure Concentration profile of *Acacia nilotica* (D)

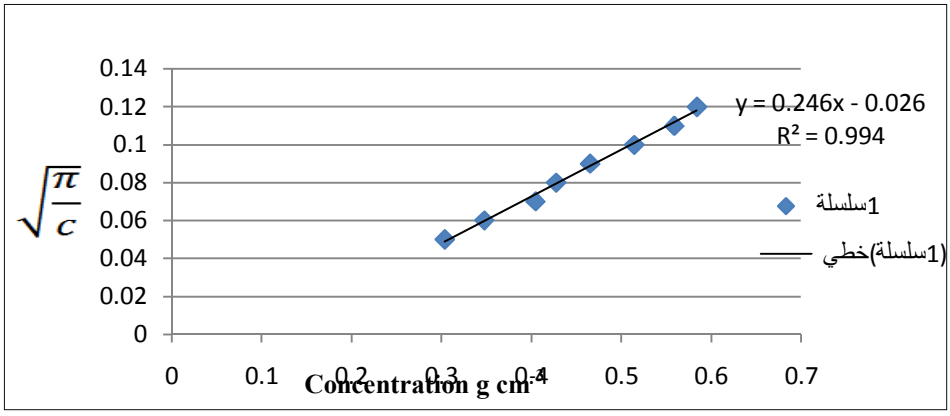

Figure 4.٢1 Osmotic pressure Concentration profile of *Acacia Seyal* (W)

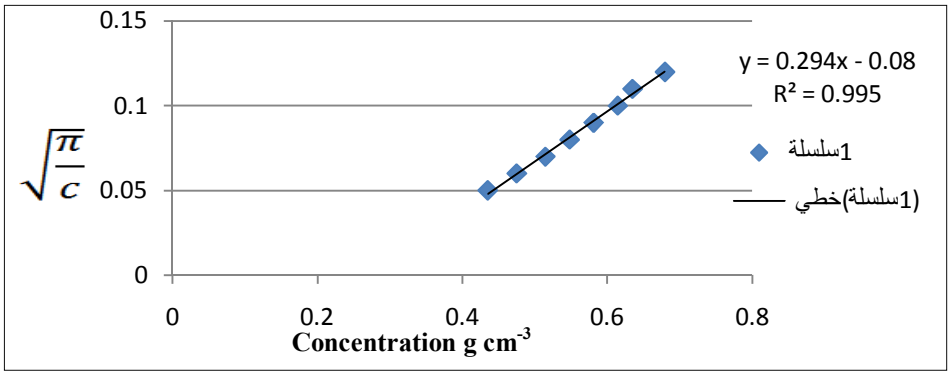

Figure 4.٢2 Osmotic pressure Concentration profile of *Acacia Seyal* (X)

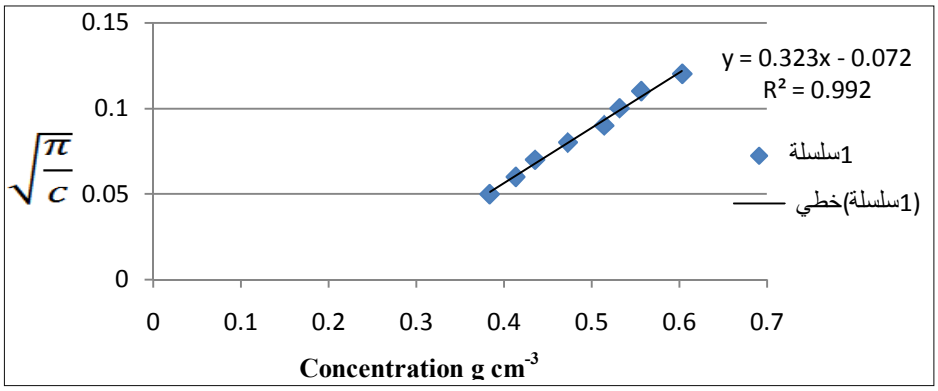

Figure 4.٢3 Osmotic pressure Concentration profile of *Acacia Seyal* (Y)

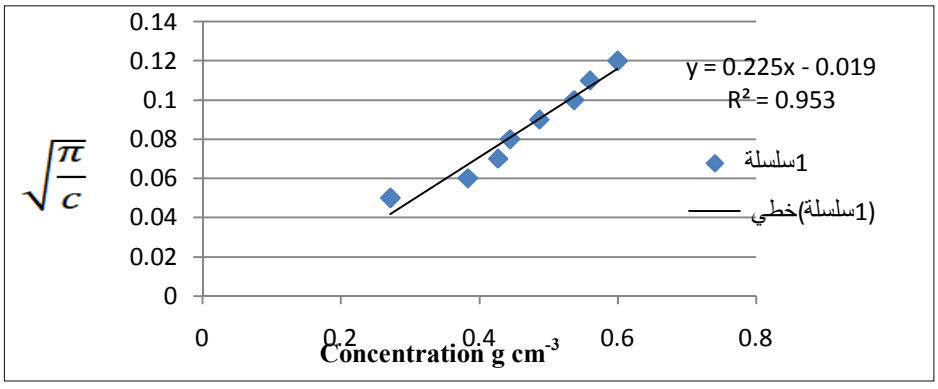

Figure 4.٢4 Osmotic pressure Concentration profile of *Acacia Seyal* (Z)

4.2.3 The second virial coefficient (A_2)

The second virial coefficient (A_2) and obtained from the slope of the graph of osmotic pressure (equation 2.14.9.15) of different *Acacia* gum samples by plotting ($\sqrt{\pi}/c$) versus concentration g cm^{-3}. The number average molecular weight can obtain from the intercept o the same graph of (Figures 4.17, to 4.٢4)

The second virial coefficient of *A.nilotica var.nilotica* (composite samples A, B, CandD) was found to be 0.78×10^{-3}, 0.97×10^{-3}, 1.93×10^{-3} and 0.76×10^{-3} respectively. For *A.seyal var.seyal* the second virial coefficient of (composite samples W, X, Y and Z) was found to be 2.09×10^{-3}, 4.84×10^{-3}, 4.35×10^{-3} and 2.74×10^{-3}respectively (Table 4.8) this result explained that water is good solvent for the two types of gums, also the result explained that *A.seyal var.seyal* gum have closed and higher than these values of second virial coefficient than *A.nilotica var.nilotica* this indicate that was interact with water more than the *A.nilotica var.nilotica* gum.

4.2.4 Number average molecular weight

The number average molecular weight (Mn) of *A. nilotica* var. *nilotica* was obtained by osmotic pressure measurements and calculated from the intercept of plot of $\sqrt{\pi}/c$ versus concentration as shown in Figures (4.17- 4.24) and reflected using equation (3.27). The values of number average molecular weight (Mn) obtained by osmotic pressure measurements. The result obtained for *A.nilotica var.nilotica* is consistent with the observation that *Gummiferae* series possesses usually high molecular weight that reach an order of magnitude of 6 (10^6). It also agrees with Al- Assaf *et al*., (2003) findings

Table 4.8: Number average molecular weight (Mn) and second virial coefficient (A_2) of *A. nilotica* and *A. seyal* season 2012/2013 by osmotic method

Sample code	Mn	A_2
A.nilotica (A)	1.386×10^5	0.78×10^{-3}
A.nilotica (B)	1.886×10^5	0.97×10^{-3}
A.nilotica (C)	2.598×10^5	1.93×10^{-3}
A.nilotica (D)	2.54×10^5	0.76×10^{-3}
A.seyal (W)	1.67×10^5	2.09×10^{-3}
A.seyal (X)	1.14×10^5	4.84×10^{-3}
A.seyal (Y)	3.94×10^5	4.35×10^{-3}
A.seyal (Z)	5.14×10^5	2.74×10^{-3}

4.2.5 Chemical Potential

According to equation 2.14.7.11, it was possible to determine the chemical potential of water as a solvent different gums solution (Tables 4.9 to4.10). The results show that the change in chemical potential of water in A.seyal var.seyal gum solution was greater than the change in chemical potential of water in A.nilotica var.nilotica gum solution, and the results also show that A.seyal var.seyal values are closed to values of A.nilotica var.nilotica.

The chemical potential of A.nilotica var.nilotica andA.seyal var.seyal calculated by plotting ω1/ω2 versus Δμ1 Figures (4.25, 4.27, 4.29, 4.31, 4.33, 4.35, 4.37, 4.39) using results in Tables (4.9 to 4.16). the areas under the curve, that are bounded by ordinates corresponding to Δμ2/ which less than the true areas values obtained of Δμ2, to correct these areas a graph of dependence $\Delta\mu_2$/ versus ω1 was plotted to obtain segment A Figures (4.26, 4.28, 4.30, 4.32, 4.34, 4.36, 4.38, 4.40) ,and obtained the true values of Δμ2. The chemical potential of A.nilotica var.nilotica and A.seyal var.seyal was reported in Tables (4.17, 4.18) show that A.seyal gum have great changes in chemical potential this mean interact with water more than A.nilotica var.nilotica.

Tables 4.17, 4.18 and 4.19 show the change in chemical potential of A.nilotica var.nilotica gum, A.seyal var.seyal gum, A.Oefota gum, A.senegal gum and A.polyacantha gum at different concentrations. The change in chemical potential was the order A.polyacantha gum >A.senegal gum >A.seyal gum >A.nilotica gum >A.Oerfota this indicate that A.polyacantha interact with water more than the other four types.

Table (4.9) Chemical potential $\Delta\mu_1$ and weight fractions of water in *A.nilotica var. nilotica* gum solutions (composite sample A)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHgcm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.997	1.9	-1.8943	-2525.670	0.93	0.07	13.2857
0.08	0.997	2.8	-2.7916	-3722.040	0.92	0.08	11.50
0.09	0.997	4.2	-4.1874	-5583.060	0.91	0.09	10.1111
0.1	0.997	5.6	-5.5832	-7444.080	0.90	0.1	9.0000
0.11	0.997	6.6	-6.5802	-8773.380	089	0.11	8.0909
0.12	0.997	8.9	-8.8733	-11830.770	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

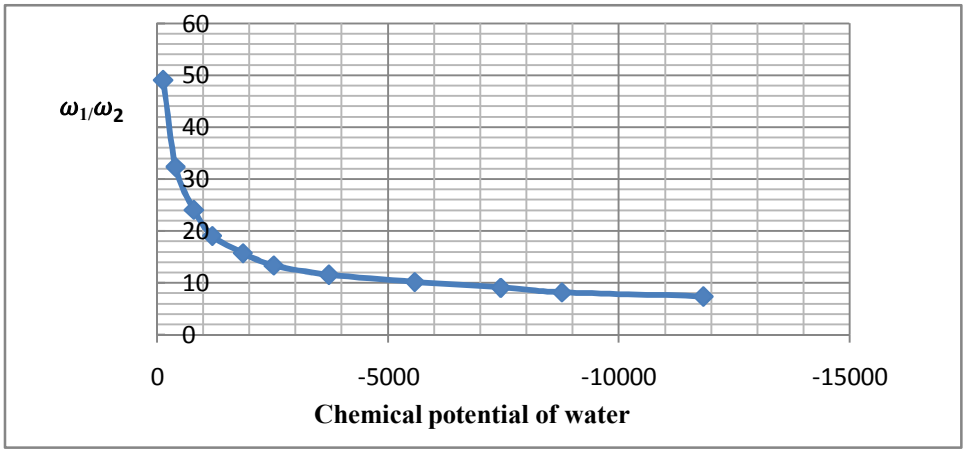

Figure (4.25) variation of $\omega_1/\omega_2$with the chemical potential of water (sample A)

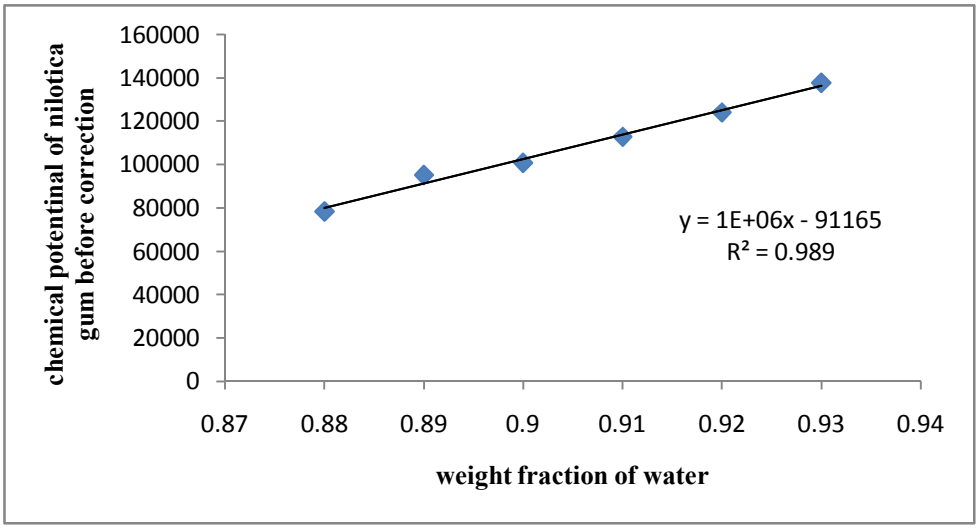

Figure (4.26) Segment A to correct the chemical potential of *Acacia nilotica var. nilotica* ($\Delta\mu_2$)(composite sample A)

Table (4.10) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia nilotica var. nilotica* gum solutions (Composite sample B)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHg cm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.999	1.5	-1.4985	-1997.95005	0.93	0.07	13.2857
0.08	0.999	2.1	-2.0979	-2797.13007	0.92	0.08	11.50
0.09	0.999	2.9	-2.8971	-3982.7004	0.91	0.09	10.1111
0.1	0.999	3.7	-3.6963	-4928.2767	0.90	0.1	9
0.11	0.999	4.8	-4.7952	-6393.4401	0.89	0.11	8.0909
0.12	0.999	6.6	-6.5943	-8790.9802	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water and gum

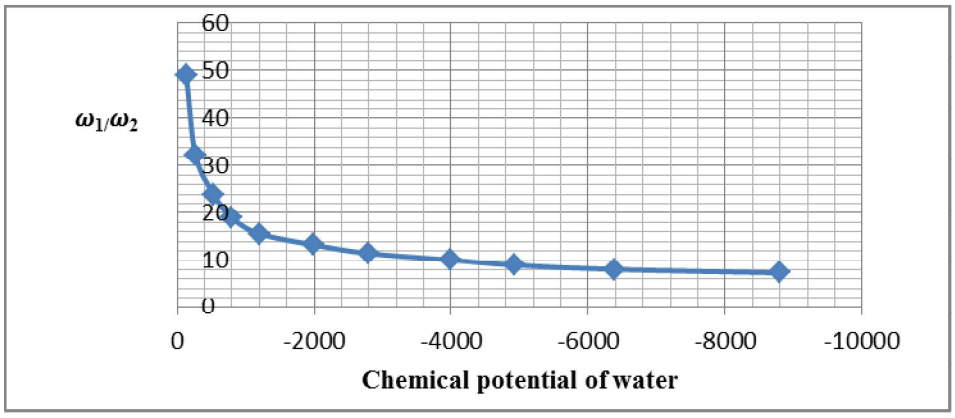

Figure (4.27) variation of $\omega_1/\omega_2$with the chemical potential of water (sample B)

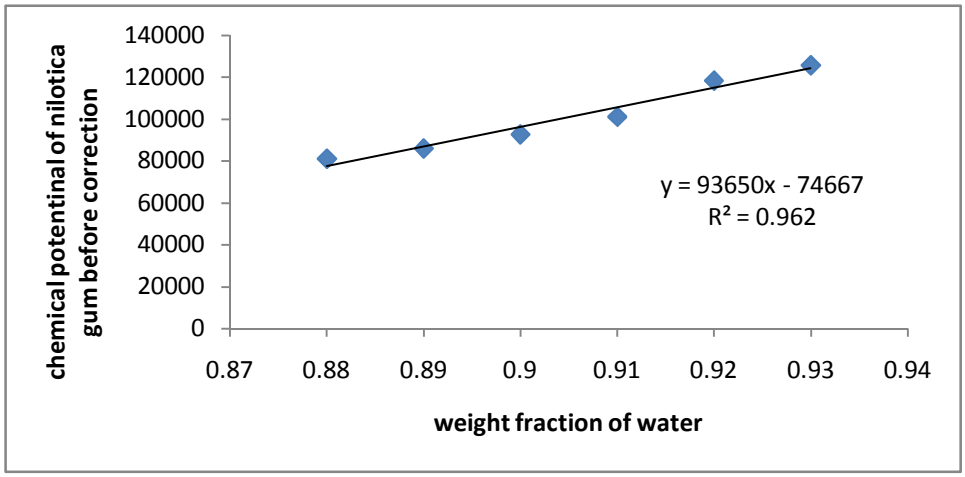

Fig (4.28) segment A to correct the chemical potential of *Acacia nilotica var. nilotica* ($\Delta\mu_2$) (composite sample B)

Table (4. 11) chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia nilotica var. nilotica* gum solutions (composite sample C)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmhg	$\Delta\mu_1$mmhgcm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.998	1.8	-1.7964	-2392.47352	0.93	0.07	13.2857
0.08	0.998	2.2	-2.1956	-2927.34348	0.92	0.08	11.50
0.09	0.998	2.8	-2.7944	-3725.77352	0.91	0.09	10.1111
0.1	0.998	3.4	-3.3932	-4524.15356	0.90	0.1	9
0.11	0.998	4.3	-4.2914	-5721.72362	0.89	0.11	8.0909
0.12	0.998	5.1	-5.0898	-6786.23034	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

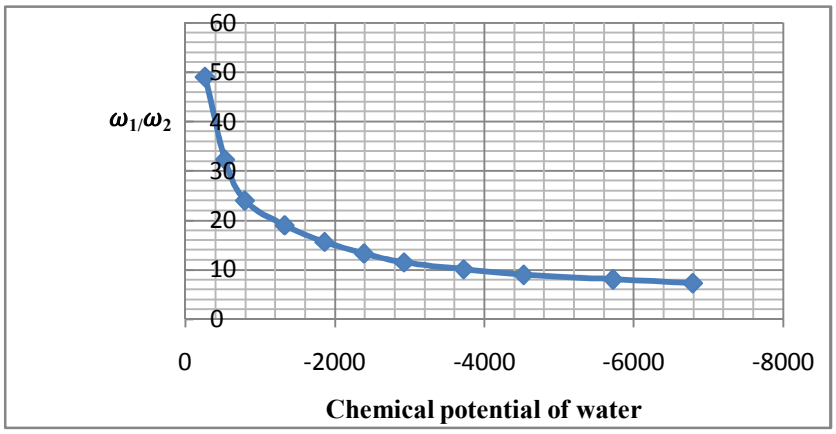

Figure (4.29) variation of $\omega_1/\omega_2$with the chemical potential of water (sample C)

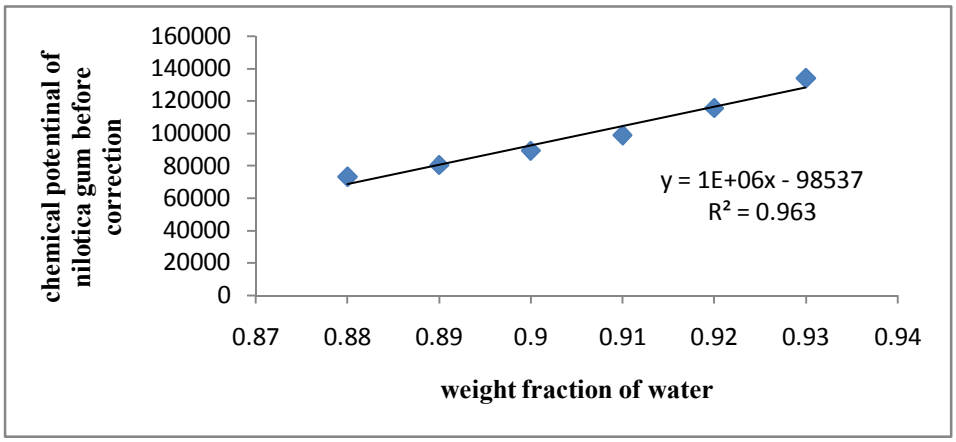

Fig (4.30) segment A to correct the chemical potential of *Acacia nilotica var. nilotica* ($\Delta\mu_2$) (sample C)

Table (4.12) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia nilotica var. nilotica* gum solutions (composite sample D)

Con.gcm^{-3}	V_1cm g^{-1}	πmmHg	$\Delta\mu_1$mmHgcm$^3g^{-1}$	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.998	1.5	-1.497	-1995.9501	0.93	0.07	13.285
0.08	0.998	2.1	-2.0958	-2794.3301	0.92	0.08	11.50
0.09	0.998	2.8	-2.7944	-3725.7735	0.91	0.09	10.111
0.01	0.998	3.6	-3.5928	-4790.2802	0.90	0.1	9
0.11	0.998	4.8	-4.7904	-6387.0403	0.89	0.11	8.0909
0.12	0.998	8.1	-8.0833	-10778.1305	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

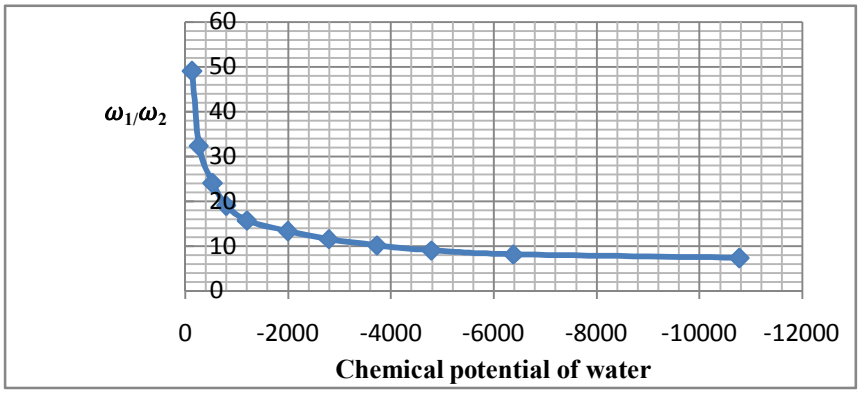

Figure (4.31) variation of $\omega_1/\omega_2$with the chemical potential of water (sample D)

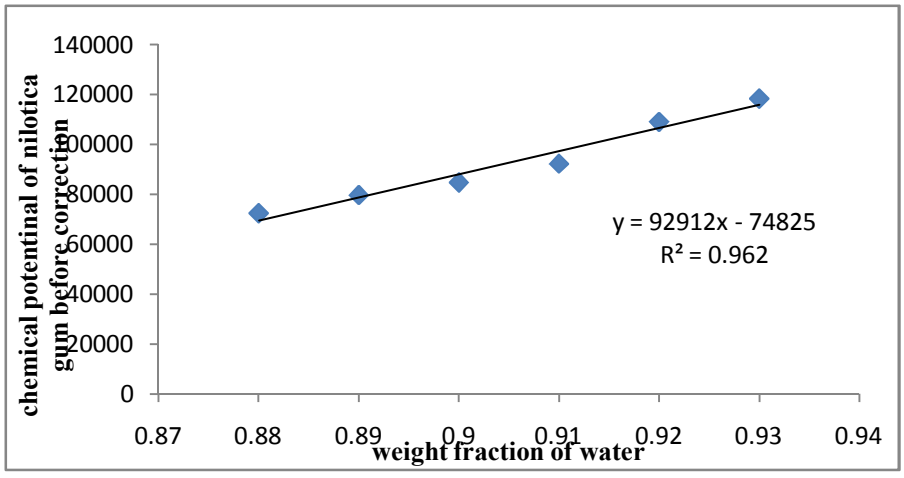

Fig (4.32) Segment A to correct the chemical potential of *Acacia nilotica var. nilotica*($\Delta\mu_2$) (sample D)

Table (4.13) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia seyal var. seyal* gum solutions (composite sample W)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHgcm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.998	8.7	-8.6826	-11576.511	0.93	0.07	13.2857
0.08	0.998	11.1	-11.0778	-14770.031	0.92	0.08	11.50
0.09	0.998	14.8	-14.7704	-19693.374	0.91	0.09	10.1111
0.1	0.998	20.1	-20.0598	-26745.731	0.90	0.1	9
0.11	0.998	26.1	-26.0478	-34729.532	0.89	0.11	8.0909
0.12	0.998	31.1	-31.037	-41382.699	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

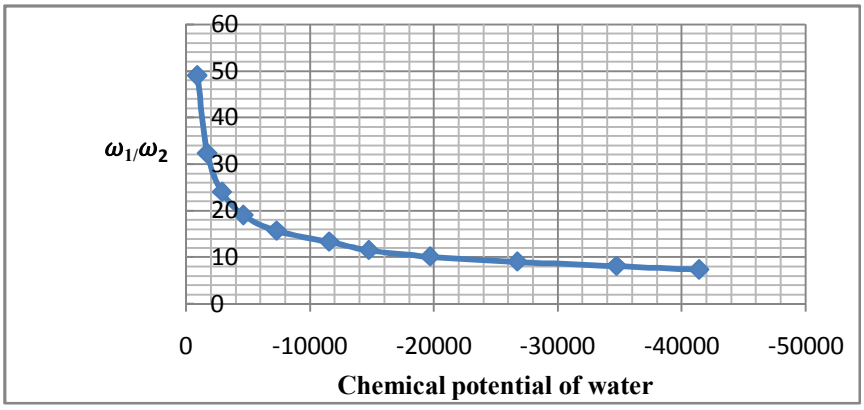

Figure (4.33) variation of $\omega_1/\omega_2$with the chemical potential of water (sample W)

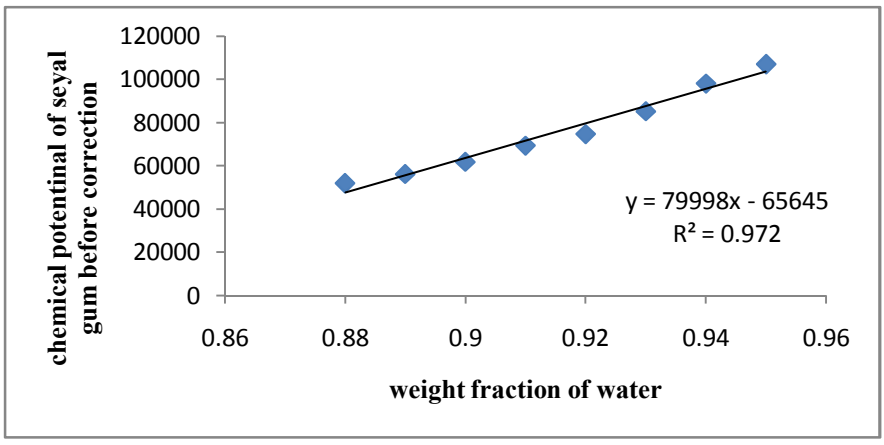

Figure (4.34) Segment A to correct the chemical potential of *Acacia seyal var. seyal* ($\Delta\mu_2$)(composite sample W)

Table (4.14) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia seyal var. seyal* gum solutions (composite sample X)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHg cm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.998	14.1	-14.0718	-18761.931	0.93	0.07	13.2857
0.08	0.998	18.3	-18.2634	-24350.591	0.92	0.08	11.50
0.09	0.998	23.1	-23.0538	-30737.632	0.91	0.09	10.1111
0.1	0.998	28.7	-28.6426	-38189.179	0.90	0.1	9.0000
0.11	0.998	33.7	-33.6326	-44842.346	0.89	0.11	8.0909
0.12	0.998	42.1	-42.0158	-56019.666	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

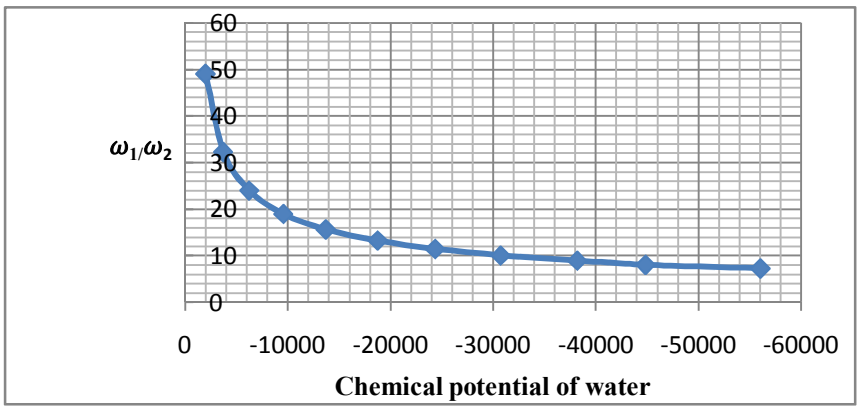

Figure (4.35) variation of $\omega_1/\omega_2$with the chemical potential of water (sample X)

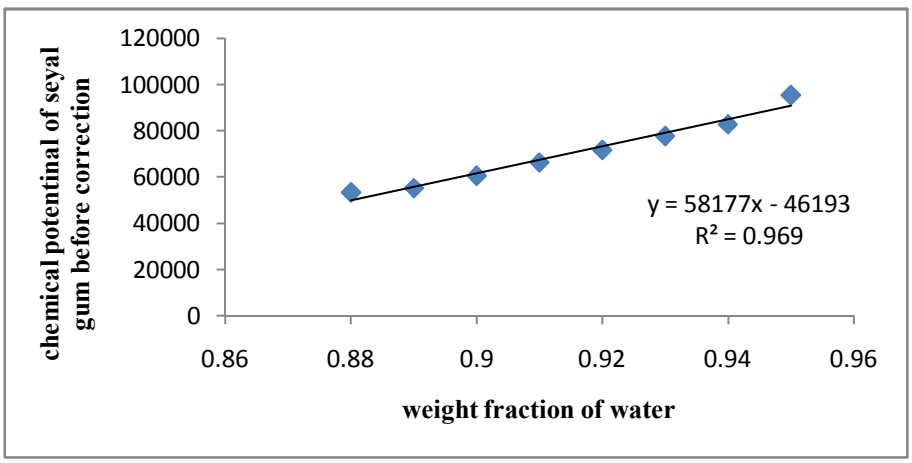

Figure (4.36) Segment A to correct the chemical potential of *Acacia seyal var. seyal* gum ($\Delta\mu_2$)(composite sample X)

Table (4. 15) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia seyal var. seyal* gum solutions (composite sample Y)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHg cm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.998	10.1	-10.0798	-13439.397	0.93	0.07	13.2857
0.08	0.998	13.6	-13.5728	-18096.614	0.92	0.08	11.50
0.09	0.998	18.1	-18.0638	-24084.465	0.91	0.09	10.1111
0.1	0.998	21.5	-21.457	-28608.618	0.90	0.1	9.0000
0.11	0.998	25.9	-25.8482	-34463.405	0.89	0.11	8.0909
0.12	0.998	33.2	-33.1336	-44177.029	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

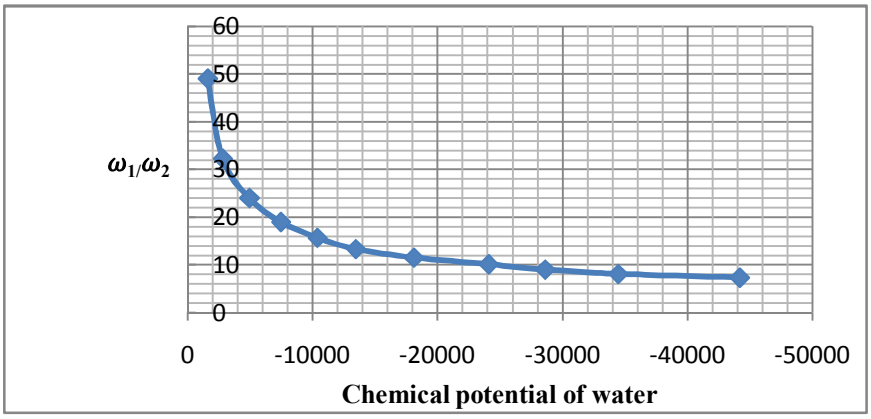

Figure (4.37) variation of $\omega_1/\omega_2$with the chemical potential of water (sample Y)

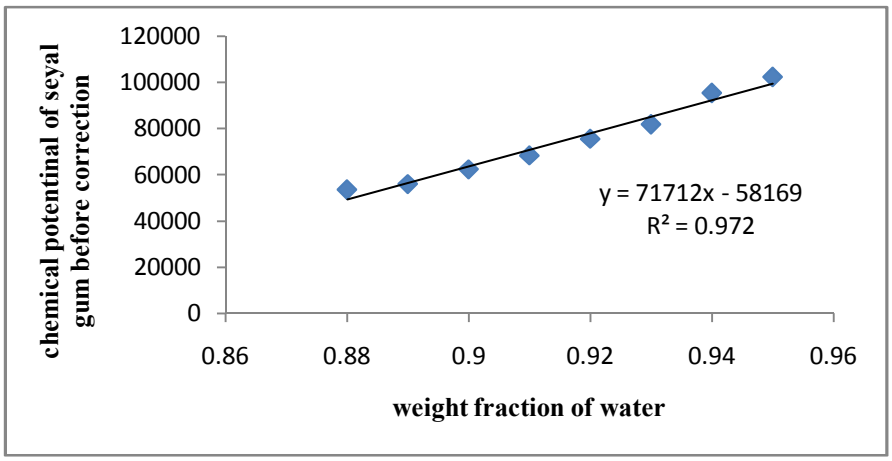

Figure (4.38) Segment A to correct the chemical potential of *Acacia seyal var.seyal* gum ($\Delta\mu_2$)(composite sample Y)

Table (4.16) Chemical potential $\Delta\mu_1$ and weight fractions of water in *Acacia seyal var. seyal* gum solutions (composite sample Z)

Conc.gcm^{-3}	V_1cm^{3}g^{-1}	πmmHg	$\Delta\mu_1$mmHgcm^{3}g^{-1}	$\Delta\mu_1$erg g^{-1}	ω_1	ω_2	ω_1/ω_2
0.07	0.999	8.7	-8.6913	-11588.11	0.93	0.07	13.2857
0.08	0.999	12	-11.988	-15983.6	0.92	0.08	11.50
0.09	0.999	16.2	-16.1838	-21577.861	0.91	0.09	10.1111
0.1	0.999	21.9	-218781	-29170.071	0.90	0.1	9.0000
0.11	0.999	26.2	-26.1738	-34897.528	0.89	0.11	8.0909
0.12	0.999	32.8	-32.7672	-43688.508	0.88	0.12	7.3333

* Where ω_1 and ω_2 weight fractions of water gum

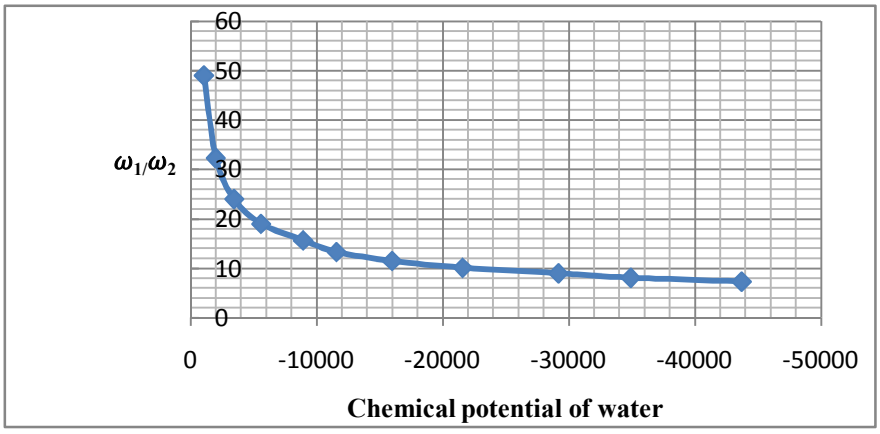

Figure (4.39) variation of $\omega_1/\omega_2$with the chemical potential of water (sample Z)

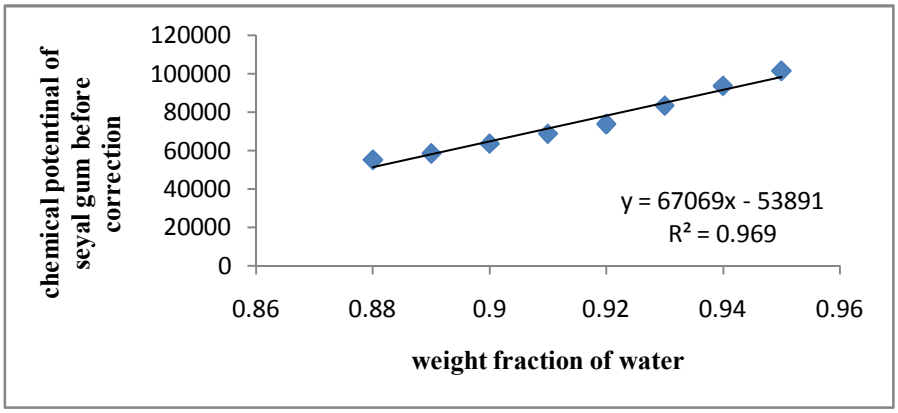

Figure (4.40) Segment A to correct the chemical potential of *Acacia seyal var. seyal* gum ($\Delta\mu_2$)(composite sample Z)

Table (4.17) Chemical potential of composite samples of *A. nilotica var.nilotica* in joule g^{-1}

Conc % g cm^{-3}	$\Delta\mu_2$ joule g^{-1}			
	***A.nilotica* Sample A**	***A.nilotica* Sample B**	***A.nilotica* Sample C**	***A.nilotica* Sample D**
7%	-1.69563×10^{-3}	-1.55865×10^{-3}	-1.71735×10^{-3}	-1.47123×10^{-3}
8%	-1.86363×10^{-3}	-1.60665×10^{-3}	-1.78935×10^{-3}	-1.54323×10^{-3}
9%	-1.91962×10^{-3}	-1.67465×10^{-3}	-1.87735×10^{-3}	-1.59423×10^{-3}
10%	-2.03962×10^{-3}	-1.75798×10^{-3}	-1.97335×10^{-3}	-1.66923×10^{-3}
11%	-2.16152×10^{-3}	-1.93064×10^{-3}	-2.14134×10^{-3}	-1.83722×10^{-3}
12%	-2.28762×10^{-3}	-2.00314×10^{-3}	-2.32534×10^{-3}	-1.93022×10^{-3}

Table (4.18) Chemical potential of composite samples of *Acacia seyal var.seyal* in joule g^{-1}

Conc % g cm^{-3}	$\Delta\mu_2$ joule g^{-1}			
	***A.seyal* Sample W**	***A.seyal* Sample X**	***A.seyal* Sample Y**	***A.seyal* Sample Z**
7%	-1.26943×10^{-3}	-1.06791×10^{-3}	-1.20567×10^{-3}	-1.17480×10^{-3}
8%	-1.34943×10^{-3}	-1.12491×10^{-3}	-1.26567×10^{-3}	-1.22580×10^{-3}
9%	-1.40343×10^{-3}	-1.17891×10^{-3}	-1.33767×10^{-3}	-1.27680×10^{-3}
10%	-1.50843×10^{-3}	-1.23891×10^{-3}	-1.40066×10^{-3}	-1.37279×10^{-3}
11%	-1.63742×10^{-3}	-1.28990×10^{-3}	-1.53566×10^{-3}	-1.47479×10^{-3}
12%	-1.72742×10^{-3}	-1.41590×10^{-3}	-1.60466×10^{-3}	-1.55279×10^{-3}

Table (4.19) Chemical potential of *A. Oerfota, A. senegal* and *A. polyacantha* in joule g^{-1}

Conc % g cm^{-3}	ΔG^m joule g^{-1}		
	A.Oerfota	***A.senegal***	***A.polyacantha***
3%	ND	-1.410909×10^{-3}	-2.359673×10^{-3}
4%	ND	-1.396364×10^{-3}	-2.335347×10^{-3}
5%	ND	-1.381818×10^{-3}	-2.311020×10^{-3}
6%	ND	-1.367273×10^{-3}	-2.286694×10^{-3}
7%	-8.87637×10^{-3}	-1.352727×10^{-3}	-2.262367×10^{-3}
8%	-9.5991×10^{-3}	-1.338182×10^{-3}	-2.238040×10^{-3}
9%	-9.98799×10^{-3}	ND	ND
10%	-1.13366×10^{-3}	ND	ND

4.2.6 Free energy of mixing

Free energy of mixing of A.nilotica var.nilotica and A.seyal var.seyal calculated using equation (2.14.11.5) was reported in Tables (4.20 to4.27). A.seyal var.seyal has high value (joule/g) compared to that of A.nilotica var.nilotica values, this mean that A.seyal var.seyal interact with water more than A.nilotica var.nilotica.

The two gums under studies have large values of osmotic pressure, great changes in chemical potential and free energy of mixing of the entire system and positive values of second virial coefficient this indicates that water is a good solvent for both types of gums. The order of the interaction of gum with water is that A.seyal var.seyal > A.nilotica var.nilotica.

The free energy of mixing of A.nilotica var.nilotica gum, A.seyal var.seyal gum, A.Oefota gum, A.senegal gum and A.polyacantha gum at different concentrations was show in tables 4.28, 4.29 and 4.30 these result show that A.polyacantha gum has change in free energy of mixing values, followed by A.senegal gum, A.seyal gum, A.nilotica gum and A.Oerfota.This indicate that the order of interaction of the gum decreases from A.polyacantha gum >A.senegal gum >A.seyal gum >A.nilotica gum >A.Oerfota.

Table (4.20) Calculating the free energy of mixing of *Acacia nilotica va.niloticar* gum (A)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-2525.670	0.93	-2348.8731	-169563.04	0.07	-11869.4128	-14218.2859
-3722.040	0.92	-3424.2768	-186362.6	0.08	-14909.008	-18333.2848
-5583.060	0.91	-5080.5846	-191962.48	0.09	-17276.6232	-22357.2078
-7444.060	0.90	-6699.672	-203962.18	0.1	-20396.218	-27095.89
-8773.380	0.89	-7808.3082	-215161.9	0.11	-23667.809	-31476.1172
-11830.770	0.88	-10411.0776	228761.56	0.12	-27451.3872	-37862.4648

Table (4.21) Calculating the Free energy of mixing of *Acacia nilotica var.nilotica* gum (B)

$\Delta\mu_1$erg $^{-1}$	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-1997.95005	0.93	-1858.093547	-155864.97	0.07	-10910.5479	-12768.64145
-2797.13007	0.92	-2573.359664	-160664.85	0.08	-12853.188	-15426.54766
-3982.7004	0.91	-3624.257364	-167464.68	0.09	-15071.8212	-18696.07856
-4928.2767	0.90	-4435.44903	-175797.81	0.1	-17579.781	-22015.23003
-6393.4401	0.89	-5690.161689	-193064.04	0.11	-21237.0444	-26927.20609
-8790.9802	0.88	-7736.062579	-200313.87	0.12	-24037.6644	-31773.72698

Table (4.22) Calculating the Free energy of mixing of *Acacia nilotica var.nilotica* gum (C)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-2392.4735	0.93	-2225.000374	-171735.17	0.07	-12021.4619	-14246.46227
-2927.39348	0.92	-2693.202002	-1788934.99	0.08	-14314.7992	-17008.0012
-3725.77352	0.91	-3390.453903	-187734.77	0.09	-16896.1077	-20286.5616
-4524.15356	0.90	-4071.738204	-197334.53	0.1	-19733.453	-23805.1912
-5721.72362	0.89	-5092.334022	-214134.11	0.11	-23554.7521	-28647.08612
-6786.23034	0.88	-5971.882699	-232533.65	0.12	-27904.038	-33875.9207

Table (4.23) Calculating the Free energy of mixing of *Acacia nilotica var. nilotica* gum (D)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-1995.9501	0.93	-1856.233593	-147123.19	0.07	-10298.6233	-12154.85689
-2794.33014	0.92	-2570.783729	-154323.01	0.08	-12345.8408	-14916.62453
-3725.77352	0.91	-3390.453903	-159422.88	0.09	-14348.0592	-17738.5131
-4790.28024	0.90	-4311.252216	-166922.69	0.1	-16692.228	-21003.48022
-6387.04032	0.89	-5684.465885	-183722.28	0.11	-2029.4508	-25893.91669
-0778.13054	0.88	-9484.754875	-193022.05	0.12	-23162.646	-32647.40088

Table (4.24) Calculating the Free energy of mixing of *Acacia seyal var.seyal* gum solutions (W)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-11576.511	0.93	-10766.15523	-126943.26	0.07	-8886.0282	-19625.18343
-14770.031	0.92	-13588.42852	-134943.26	0.08	-10795.4608	-24383.88932
-19693.374	0.91	-17920.97034	-140343.13	0.09	-12630.8817	-30551.85204
-26745.371	0.90	-24071.1579	-150842.55	0.1	-15084.255	-39155.4129
-34729.532	0.89	-30909.28348	-163742.55	0.11	-18011.6805	-48920.96398
-41382.699	0.88	-36416.77512	-172742.32	0.12	-20729.0784	-57145.58352

Table (4.25) calculating the free energy of mixing of *Acacia seyal var.seyal* gum solutions (X)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-18761.931	0.93	-17448.59583	-106791.48	0.07	-7475.4036	-24923.99943
-24350.591	0.92	-22402.54372	-112491.34	0.08	-8999.3072	-31401.85092
-30737.632	0.91	-27971.24512	-117891.06	0.09	-10610.1954	-38581.44052
-38189.179	0.90	-34370.2611	-123891.06	0.1	-12389.106	-46759.3671
-44842.346	0.89	-39909.68794	-128990.93	0.11	-14189.0023	-54098.69024
-56019.666	0.88	-49297.30608	-141590.62	0.12	-16990.8744	-66288.18048

Table (4.26) calculating the free energy of mixing of *Acacia seyal var.seyal* gum solutions (Y)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-13439.397	0.93	-12498.63921	-120567.44	0.07	-8439.7208	-20938.36001
-18096.614	0.92	-16648.88488	-126567.29	0.08	-10125.3832	-26774.26808
-24084.465	0.91	-21916.86315	-133767.11	0.09	-12039.0399	-33955.90305
-28608.618	0.90	-25747.7562	-140066.95	0.1	-14006.695	-39754.4512
-34463.405	0.89	-30672.43045	-153566.62	0.11	-16892.3282	-47564.75865
-44177.029	0.88	-38875.78552	-160466.44	0.12	-19255.9728	-58131.75832

Table (4.27) calculating the free energy of mixing of *Acacia seyal var.seyal* gum solutions (Z)

$\Delta\mu_1$erg g^{-1}	ω_1	$\Delta\mu_{1\times}\,\omega_1$	$\Delta\mu_2$erg g^{-1}	ω_2	$\Delta\mu_{2\times}\,\omega_2$	$\Delta G^m=\Delta\mu_1\times\omega_1+\Delta\mu_2\times\omega_2$
-11588.11	0.93	-14704.9423	-117480.41	0.07	-8223.6287	-19000.571
-15983.6	0.92	-14704.912	-122580.28	0.08	-9806.4224	-24511.3344
-21577.861	0.91	-19635.85351	-127680.15	0.09	-11491.2135	-31127.06701
-29170.861	0.90	-26253.0639	-137279.92	0.1	-13727.992	-39981.0559
-34897.528	0.89	-31058.79992	-147479.66	0.11	-16222.7626	-47281.56252
-43688.508	0.88	-38445.88704	-155279.47	0.12	-18633.5364	-57079.42344

Table (4.28) Free energy of mixing composite samples of *A. nilotica var. nilotica* with water in joule g^{-1}

Conc % g cm^{-3}	ΔG^m joule g^{-1}			
	***A.nilotica* Sample A**	***A.nilotica* Sample B**	***A.nilotica* Sample C**	***A.nilotica* Sample D**
7%	-1.42182×10^{-3}	-1.27686×10^{-3}	-1.42465×10^{-3}	-1.21548×10^{-3}
8%	-1.83333×10^{-3}	-1.54265×10^{-3}	-1.70080×10^{-3}	-1.49166×10^{-3}
9%	-2.23572×10^{-3}	-1.86961×10^{-3}	-2.02865×10^{-3}	-1.77385×10^{-3}
10%	-2.70958×10^{-3}	-2.20152×10^{-3}	-2.38052×10^{-3}	-2.10035×10^{-3}
11%	-3.14761×10^{-3}	-2.69272×10^{-3}	-2.86471×10^{-3}	-2.58939×10^{-3}
12%	-3.78624×10^{-3}	-3.17737×10^{-3}	-3.38876×10^{-3}	-3.26474×10^{-3}

Table (4.29) Free energy of mixing composite samples of *A. seyal var.seyal* with water in joule g^{-1}

Conc % g cm^{-3}	ΔG^m joule g^{-1}			
	***A.seyal* Sample W**	***A.seyal* Sample X**	***A.seyal* Sample Y**	***A.seyal* Sample Z**
7%	-1.96522×10^{-3}	-2.49239×10^{-3}	-2.09383×10^{-3}	-1.90005×10^{-3}
8%	-2.43839×10^{-3}	-3.14018×10^{-3}	-2.67742×10^{-3}	-2.45113×10^{-3}
9%	-3.05514×10^{-3}	-3.85144×10^{-3}	-3.39559×10^{-3}	-3.11271×10^{-3}
10%	-3.91554×10^{-3}	-4.67593×10^{-3}	-3.97544×10^{-3}	-3.99811×10^{-3}
11%	-4.89209×10^{-3}	-5.40986×10^{-3}	-4.75647×10^{-3}	-4.72815×10^{-3}
12%	-5.71458×10^{-3}	-6.62881×10^{-3}	-5.81318×10^{-3}	-5.70794×10^{-3}

Table (4.30) Free energy of mixing of *A. Oerfota, A. senegal* and *A. polyacantha* with water in joule g^{-1}

Conc % g cm^{-3}	ΔG^m joule g^{-1}		
	A.Oerfota	***A.senegal***	***A.polyacantha***
3%	ND	-0.5075×10^{-2}	-0.8090×10^{-2}
4%	ND	-0.6957×10^{-2}	-1.0983×10^{-2}
5%	ND	-0.9091×10^{-2}	-1.4220×10^{-2}
6%	ND	-1.1518×10^{-2}	-1.7393×10^{-2}
7%	-0.20016608×10^{-2}	-1.3617×10^{-2}	-2.0983×10^{-2}
8%	-0.2547507×10^{-2}	-1.6615×10^{-2}	-2.4786×10^{-2}
9%	-0.30367833×10^{-2}	ND	ND
10%	-0.36877722×10^{-2}	ND	ND

CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

4.3.1 Conclusions

Composite samples of both A.nilotica var. nilotica and A.seyal var.seyal gums (8 samples) were evaluated to characterize their physiochemical properites. The date obtained that A.nilotica var.nilotica gum belongs to Gummiferae series. These properties can be summarize as follow:

A. nilotica var.nilotica gum contains a lower proportion of nitrogen and hence a lower protein contents compared to Acacia senegal var.senegal. It possessed positive optical rotation in contrast to Acacia senegal var.senegal which has a negative optical rotation. Also A.nilotica var.nilotica gum has lower rhamnose and glucuronic acid contents, higher arabinose and lower viscosity than that of Acacia senegal var.senegal.

Different physiochemical properties of samples tested agree with previously reported studies of A.nilotica var.nilotica and A.seyal var.seyal from the gummeferae species.

The partial specific volume of A.seyal var.seyal are the same of that A.nilotica var.nilotica although there is noticeably different between their molecular masses this may be due to the compactness of A.nilotica molecules is greater than the A.seyal molecules, the results of partial specific volume of gum also show that A.seyal molecule expands in water more than A.nilotica molecule.

The results show that the sequences of the specific volume of the gums under studies are in the order of decreasing molecular weight of these gums i. e., A.nilotica and A.seyal. The partial specific volume of water and gum in A.seyal is so close to that of A.nilotica, Although there is noticeably different between their molecular masses these may be due to the compactness of A.seyal molecules is greater than the A.nilotica molecules, the results of partial specific volume of gums also show that A.seyal molecules expands in water more than A.nilotica molecules.

A.nilotica var.nilotica has the larger volume fraction than A.seyal var.seyal The sequence of the volume fraction was related to the sequence of weight average molecular weight and partial specific volume of the samples of gums studied.

Osmotic pressure of different concentrations of aqueous A.nilotica var.nilotica and A.seyal var.seyal gum solution. The results obtained show that at the same concentration of A.seyal var.seyal have high value of osmotic pressure than the A.nilotica, this mean that they interact with water more than A.nilotica var.nilotica and this due to the structural variation.

The second virial coefficient of A.nilotica var.nilotica (composite samples A, B, CandD) was found to be 0.78×10^{-3}, 0.97×10^{-3}, 1.93×10^{-3} and 0.76×10^{-3} respectively. For A.seyal var.seyal the second virial coefficient of (composite samples W, X, Y and Z) was found to be 2.09×10^{-3}, 4.84×10^{-3}, 4.35×10^{-3} and 2.74×10^{-3}respectively. this result explained that water is good solvent for the two types of gums, also the result explained that A.seyal var.seyal gum have closed and higher than these values of second virial coefficient than A.nilotica var.nilotica this indicate that was interact with water more than the A.nilotica var.nilotica gum.

The results show that the change in chemical potential of water in A.seyal var.seyal gum solution was greater than the change in chemical potential of water in A.nilotica var.nilotica gum solution, and the results also show that A.seyal var.seyal values are closed to values of A.nilotica var.nilotica.

Free energy of mixing of A.seyal var.seyal has high value (joule/g) compared to that of A.nilotica var.nilotica values, this mean that A.seyal var.seyal interact with water more than A.nilotica var.nilotica.

The two gums under studies have large values of osmotic pressure, great changes in chemical potential and free energy of mixing of the entire system and positive values of second virial coefficient this indicates that water is a good solvent for both types of gums. The order of the interaction of gum with water is that A.seyal var.seyal > A.nilotica var.nilotica.

Different thermodynamic parameters have been calculated were used to compare and contrast the two types of gums A.nilotica var.nilotica and A.seyal var.seyal which fall within the range of the gummeferae species.

4.3.2 Suggestions for further work

More detailed information about the exact gum molecular structure are required to understand and interpret functional properties based on physiochemical and thermodynamic properties. This could be achieved by:

- Determination of the enthalpy of mixing by using differential scanning calorimetery and mixing vessel or other technique. This will lead to predicting entropy of mixing and others thermodynamic parameters.
- Fractionation of gel permination of the gum.
- Further study should be carried out to investigate the cause of the excellent emulsifying stability of *Acacia nilotica var.nilotica* gum compared to *A.senegal var.senegal* although it has lower protein content. evaluation of the gum emulsification and stabilization qualities in true system models also should be carried out.

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APPENDIX

Table (1) Partial specific volume of water (Comps. Sample A) in *Acacia nilotica*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.1151	198	198.961
2	2.1151	98	99.172
3	2.1151	64.66	65.905
4	2.1151	48	49.302
5	2.1151	38	39.309
6	2.1151	31.33	32.654

Table (2) Partial specific volume of water (Comps. Sample B)in *Acacia nilotica*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.1095	198	199.074
2	2.1095	98	99.236
3	2.1095	64.66	65.951
4	2.1095	48	49.291
5	2.1095	38	39.145
6	2.1095	31.33	32.367

Table (3) Partial specific volume of water (Comps. Sample C)in *Acacia nilotica*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.0985	198	199.905
2	2.0985	98	99.117
3	2.0985	64.66	65.836
4	2.0985	48	49.164
5	2.0985	38	39.235
6	2.0985	31.33	32.581

Table (4) Partial specific volume of water (Comps. Sample D)in *Acacia nilotica*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.1169	198	199.160
2	2.1169	98	99.214
3	2.1169	64.66	65.919
4	2.1169	48	49.327
5	2.1169	38	39.330
6	2.1169	31.33	32.662

Table (5) Partial specific volume of (Comps. Sample A) *A. nilotica* in *A. nilotica* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.6012	40	38.808
2.2	1.0981	40	39.141
6.4	3.1031	40	40.358
8.3	4.0701	40	40.995
12	6.0741	40	42.188
14.5	7.5261	40	43.474

Table (6) Partial specific volume of (Comps. Sample B) *A. nilotica* in *A. nilotica* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5956	40	38.817
2.2	1.0925	40	39.135
6.4	3.0975	40	40.391
8.3	4.0645	40	40.990
12	6.0685	40	42.183
14.5	7.5205	40	43.122

Table (7) Partial specific volume of (Comps. Sample C) *A. nilotica* in *A. nilotica* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5846	40	40.302
2.2	1.0815	40	40.634
6.4	3.0865	40	41.872
8.3	4.0535	40	42.481
12	6.0575	40	43.780
14.5	7.5095	40	44.778

Table (8) Partial specific volume of (Comps. Sample D) *A. nilotica* in *A. nilotica* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.603	40	40.324
2.2	1.0999	40	40.652
6.4	3.1049	40	41.943
8.3	4.0719	40	42.540
12	6.0759	40	43.890
14.5	7.5279	40	44.862

Table (9) Partial specific volume of water (Comps. Sample W) in *Acacia seyal*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.070	198	199.082
2	2.070	98	99.240
3	2.070	64.66	65.925
4	2.070	48	49.281
5	2.070	38	39.280
6	2.070	31.33	32.614

Table (10) Partial specific volume of water (Comps. Sample X) in *Acacia seyal*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.072	198	198.977
2	2.072	98	99.149
3	2.072	64.66	65.875
4	2.072	48	49.186
5	2.072	38	39.247
6	2.072	31.33	32.587

Table (11) Partial specific volume of water (Comps. Sample Y) in *Acacia seyal*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.078	198	199.098
2	2.078	98	99.220
3	2.078	64.66	65.933
4	2.078	48	49.284
5	2.078	38	39.303
6	2.078	31.33	32.637

Table (12) Partial specific volume of water (Comps. Sample Z) in *Acacia seyal*

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1	2.074	198	199.157
2	2.074	98	99.900
3	2.074	64.66	65.916
4	2.074	48	49.280
5	2.074	38	39.276
6	2.074	31.33	32.627

Table (13) Partial specific volume of (Comps. Sample W) *A. seyal* in *A. seyal* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5561	40	40.338
2.2	1.053	40	40.638
6.4	3.058	40	41.917
8.3	4.025	40	42.523
12	6.029	40	43.828
14.5	7.481	40	44.801

Table (14) Partial specific volume of (Comps. Sample X) *A. seyal* in *A. seyal* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5581	40	40.252
2.2	1.055	40	40.556
6.4	3.06	40	41.846
8.3	4.027	40	42.497
12	6.031	40	43.797
14.5	7.483	40	44.795

Table (15) Partial specific volume of (Comps. Sample Y) *A. seyal* in *A. seyal* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5641	40	40.334
2.2	1.061	40	40.664
6.4	3.066	40	41.946
8.3	4.033	40	42.591
12	6.037	40	43.911
14.5	7.489	40	44.915

Table (16) Partial specific volume of (Comps. Sample Z) *A. seyal* in *A. seyal* gum solutions

Gum Concentration w/w%	Weight of gum W_2(g)	Weight of water W_1(g)	Solution volume V(cm^3)
1.1	0.5601	40	40.351
2.2	1.057	40	40.642
6.4	3.062	40	41.921
8.3	4.029	40	42.531
12	6.033	40	43.803
14.5	7.485	40	44.729

Table (17) Osmatic pressure of *A.nilotica* of different concentration (comp. sample A)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.07	1.3	0.0017105	0.024435	0.156319
0.08	1.5	0.0019737	0.024671	0.157071
0.09	4.8	0.0063158	0.070175	0.264906
0.1	5.9	0.0077632	0.077632	0.278625
0.11	6.6	0.0086842	0.078947	0.280975
0.12	8.9	0.0117105	0.097587	0.31238

Table (18) Osmatic pressure of *A.nilotica* of different concentration (comp. sample B)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.07	1.1	0.0014474	0.0206771	0.143795
0.08	1.3	0.0017105	0.0213813	0.146223
0.09	1.9	0.0025	0.0277778	0.166666
0.1	2.4	0.0031579	0.031579	0.177704
0.11	4.3	0.0056579	0.0514355	0.226793
0.12	6.6	0.0086842	0.0723683	0.269013

Table (19) Osmatic pressure of *A.nilotica* of different concentration (comp. sample C)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.07	1.7	0.0022368	0.0319543	0.178757
0.08	2.0	0.0026316	0.32895	0.181369
0.09	2.4	0.0031579	0.0350878	0.187317
0.1	2.7	0.0035526	0.035526	0.188483
0.11	4.3	0.0056579	0.0514355	0.226793
0.12	5.1	0.0067105	0.0559208	0.236475

Table (20) Osmatic pressure of *A.nilotica* of different concentration (comp. sample D)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.07	1.2	0.0015789	0.0225557	0.150185
0.08	1.7	0.0022368	0.02796	0.167212
0.09	2.0	0.0026316	0.02924	0.170997
0.1	2.6	0.0034211	0.034211	0.184962
0.11	3.1	0.0040789	0.0370809	0.192564
0.12	8.1	0.0106579	0.0888158	0.298019

Table (21) Osmatic pressure of *A.seyal* of different concentration (comp. sample W)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.05	3.5	0.0046053	0.092106	0.303489
0.06	5.5	0.0072368	0.120613	0.347293
0.07	8.7	0.0114474	0.163534	0.404393
0.08	11.1	0.0146053	0.182566	0.427277
0.09	14.8	0.0194737	0.216374	0.465160
0.1	20.1	0.0264474	0.264474	0.514270
0.11	26.1	0.0343421	0.312200	0.558749
0.12	31.1	0.0409211	0.341009	0.583959

Table (22) Osmatic pressure of *A.nilotica* of different concentration (comp. sample X)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.05	7.2	0.0094737	0.189474	0.435286
0.06	10.3	0.0135526	0.225876	0.475264
0.07	14.1	0.0185526	0.265037	0.514817
0.08	18.3	0.0240789	0.300986	0.548621
0.09	23.1	0.0303947	0.337718	0.581135
0.1	28.7	0.0377632	0.377632	0.614517
0.11	33.7	0.0443421	0.40311	0.634909
0.12	42.1	0.0553947	0.46162	0.679427

Table (23) Osmatic pressure of *A.seyal* of different concentration (comp. sample Y)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.05	5.6	0.0073684	0.147368	0.383885
0.06	7.8	0.0102632	0.171053	0.413585
0.07	10.1	0.0132895	0.18985	0.435717
0.08	13.6	0.0178947	0.223683	0.472951
0.09	18.1	0.0238158	0.26462	0.514412
0.1	21.5	0.0282895	0.282895	0.531878
0.11	25.9	0.0340789	0.309808	0.556603
0.12	33.2	0.0436842	0.364035	0.603353

Table (24) Osmatic pressure of *A.nilotica* of different concentration (comp. sample Z)

Conc. g/cm^3	Osmatic pressure mmHg	$\pi\ atm$	π/c	$\sqrt{\pi}/c$
0.05	4.2	0.0036842	0.073684	0.271447
0.06	6.7	0.0088158	0.14693	0.383314
0.07	8.7	0.0127632	0.182331	0.427002
0.08	12	0.0157895	0.197368	0.444262
0.09	16.2	0.0213158	0.236842	0.486664
0.1	21.9	0.0288158	0.288158	0.536803
0.11	26.2	0.0344737	0.313397	0.559818
0.12	32.8	0.0431579	0.359649	0.599707

Table (25) chemical potential Δμ1 and weight fractions of water in A.nilotica gum different units

Conc.gcm^{-3}	**$\Delta\mu_1$ (erg g^{-1})**	**$\Delta\mu_1$ (joule g^{-1})**
0.07	-2525.670	-2.525670 $\times10^{-4}$
0.08	-3722.040	-3.722040 $\times10^{-4}$
0.09	-5583.060	-5.583060 $\times10^{-4}$
0.1	-7444.080	-7.444080 $\times10^{-4}$
0.11	-8773.380	-8.773380 $\times10^{-4}$
0.12	-11830.770	-1.1830770 $\times10^{-3}$

Table (26) data for plotting Δμ1 versus ω1/ω2 acacia nilotrica gum solutions (composite sample A)

ω_1/ω_2	**$\Delta\mu_1$erg g^{-1}**
13.2857	-2525.670
11.50	-3722.040
10.1111	-5583.060
9.0000	-7444.080
8.0909	-8773.380
7.3333	-11830.770

Table (27) chemical potential and weight fractions of water in A.nilotica gum different units (composite sample B)

Conc.gcm^{-3}	$\Delta\mu_1$ (erg g^{-1})	$\Delta\mu_1$ (joule g^{-1})
0.07	-1997.95005	-1.99795005×10^{-4}
0.08	-2797.13007	-2.79713007×10^{-4}
0.09	-3982.7004	-3.9827004×10^{-4}
0.1	-4928.2767	-4.9282767×10^{-4}
0.11	-6393.4401	-6.3939802×10^{-4}
0.12	-8790.9802	-8.79598022×10^{-4}

Table (28) data for plotting $\Delta\mu_1$ versus ω_1/ω_2 acacia nilotrica($\Delta\mu_2$) gum solutions (composite sample B)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
13.2857	-1997.95005
11.50	-2797.13007
10.1111	-3982.7004
9.0000	-4928.2767
8.0909	-6393.4401
7.3333	-8790.9802

Table (29) chemical potential and weight fractions of water in A.nilotica gum different units (composite sample C)

Conc.gcm^{-3}	$\Delta\mu_1$ (joule g^{-1})	$\Delta\mu_1$ (erg g^{-1})
0.07	-2392.47352	-2.39247352×10^{-4}
0.08	-2927.34348	-2.92739348×10^{-4}
0.09	-3725.77352	-3.72577352×10^{-4}
0.1	-4524.15356	-4.52415356×10^{-4}
0.11	-5721.72362	-5.72172362×10^{-4}
0.12	-6786.23034	-6.78623034×10^{-4}

Table (30) data for plotting $\Delta\mu_1$ versus ω_1/ω_2 acacia nilotrica($\Delta\mu_2$) gum solutions (composite sample C)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
13.2857	-2392.47352
11.50	-2927.39348
10.1111	-3725.77352
9.0000	-4524.15356
8.0909	-5721.72362
7.3333	-6786.23034

Table (31) chemical potential and weight fractions of water in A.nilotica gum different units (composite sample D)

Conc.gcm^{-3}	$\Delta\mu_1$ (erg g^{-1})	$\Delta\mu_1$(joule g^{-1})
0.07	-1995.9501	$-1.9959501 \times 10^{-4}$
0.08	-2794.33014	$-2.79433014\times 10^{-4}$
0.09	-3725.77352	$-3.72577352\times 10^{-4}$
0.1	-4790.28024	$-4.79028024\times 10^{-4}$
0.11	-6387.04032	$-6.38704032\times 10^{-4}$
0.12	-10778.13054	$-1.077813054\times 10^{-3}$

Table (32) data for plotting $\Delta\mu_1$ versus ω_1/ω_2 acacia nilotrica($\Delta\mu_2$) gum solutions (composite sample D)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
13.2857	-1995.9501
11.50	-2794.33014
10.1111	-3725.77352
9.0000	-4790.28024
8.0909	-6387.04032
7.3333	-10778.13054

Table (33) chemical potential and weight fractions of water in A. seyal gum different units (composite sample W)

Conc.gcm^{-3}	$\Delta\mu_1$(joule g^{-1})	$\Delta\mu_1$(erg g^{-1})
0.05	-4657.2169	-4.6572169×10^{-4}
0.06	-7318.4837	-7.3184837×10^{-4}
0.07	-11576.511	-1.1576511×10^{-3}
0.08	-14770.031	-1.4770031×10^{-3}
0.09	-19693.374	-1.9693374×10^{-3}
0.1	-26745.731	-2.6745731×10^{-3}
0.11	-34729.532	-3.4729532×10^{-3}
0.12	-41382.699	-4.1382699×10^{-3}

Table (34) data for plotting $\Delta\mu_1$ versus ω_1/ω_2 acacia seyal($\Delta\mu_2$) gum solutions (composite sample W)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
19	-4657.2169
15.6666	-7318.4837
13.2857	-11576.511
11.50	-14770.031
10.1111	-19693.374
9.0000	-26745.731
8.0909	-34729.532
7.333	-41382.699

Table (35) chemical potential of water in A. seyal gum solutions in different units (composite sample X

Conc.gcm^{-3}	$\Delta\mu_1$ (erg g^{-1})	$\Delta\mu_1$ (joule g^{-1})
0.05	-9580.5605	-9.5805605 $\times10^{-4}$
0.06	- 13705.524	-1.3705524 $\times10^{-3}$
0.07	-18761.931	-1.8761931 $\times10^{-3}$
0.08	-24350.591	-2.4350591 $\times10^{-3}$
0.09	-30737.632	-3.0737.632 $\times10^{-3}$
0.1	-38189.179	-3.8189179 $\times10^{-3}$
0.11	-44842.346	-4.4842346 $\times10^{-3}$
0.12	-56019.666	-5.6019666 $\times10^{-3}$

Table (36) data for plotting $\Delta\mu_1$ versus $\omega_{1/}\omega_2$ acacia seyal($\Delta\mu_2$) gum solutions (composite sample X)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
19	-9580.5605
15.6666	-13705.524
13.2857	-18761.931
11.50	-24350.591
10.1111	-30737.632
9.0000	-38189.179
8.0909	-44842.346
7.3333	-56019.666

Table (37) chemical potential of water in A. seyal gum solutions in different units (composite sample Y)

Conc.gcm^{-3}	$\Delta\mu_1$(erg g^{-1})	$\Delta\mu_1$(joule g^{-1})
0.05	-7451.547	-7.451547×10^{-4}
0.06	-10378.941	-1.0378941×10^{-3}
0.07	-13439.614	-1.343614×10^{-3}
0.08	-18096.614	-1.8096614×10^{-3}
0.09	-24084.465	-2.4084465×10^{-3}
0.1	-28608.618	-2.860618×10^{-3}
0.11	-34463.405	-3.4463405×10^{-3}
0.12	-44177.029	-4.4177029×10^{-3}

Table (38) data for plotting $\Delta\mu_1$ versus ω_1/ω_2 acacia seyal($\Delta\mu_2$) gum solutions (composite sample Y)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
19.000	-7451.547
15.6666	-10378.941
13.2857	-13439.614
11.50	-18096.614
10.1111	-24084.465
9.0000	-28608.618
8.0909	--34463.405
7.3333	-44177.029

Table (39) chemical potential of water in A. seyal gum solutions in different units (composite sample Z)

Conc.gcm^{-3}	$\Delta\mu_1$(erg g^{-1})	$\Delta\mu_1$(joule g^{-1})
0.05	-5594.2601	-5.5942601 $\times10^{-4}$
0.06	-8924.1769	-8.9241769 $\times10^{-4}$
0.07	-11588.11	-1.158.11 $\times10^{-3}$
0.08	-15983.6	-1.59836 $\times10^{-3}$
0.09	-21577.861	-2.1577861 $\times10^{-3}$
0.1	-29170.071	-2.9170071 $\times10^{-3}$
0.11	-34897.528	-3.4897528 $\times10^{-3}$
0.12	-43688.508	-4.3688508 $\times10^{-3}$

Table (40) data for plotting $\Delta\mu_1$ versus $\omega_{1/}\omega_2$ acacia seyal gum solutions (composite sample Z)

ω_1/ω_2	$\Delta\mu_1$erg g^{-1}
19.0000	-5594.2601
15.6666	-8924.1769
13.2857	-11588.11
11.50	-15983.6
10.1111	-21577.861
9.0000	-29170.071
8.0909	-34897.528
7.3333	-43688.508

Table (41) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia nilotrica var.nilotica* gum solutions (Composite sample A)

$\Delta\mu_2^-(erg\ g^{-1})$	ω_1
78398.04	0.88
95197.60	0.89
100797.48	0.90
112797.118	0.91
123996.90	0.92
137596.56	0.93

Table (42) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia nilotica var.nilotica* gum solutions (Composite sample B)

$\Delta\mu_2^-(erg\ g^{-1})$	ω_1
81197.97	0.88
85997.85	0.89
92797.68	0.90
101130.81	0.91
118397.04	0.92
125646.87	0.93

Table (43) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia nilotrica var. nilotica* gum solutions (Composite sample C)

$\Delta\mu_2$ erg g^{-1}	ω_1
73198.17	088
80397.99	0.89
89197.77	0.90
98797.53	0.91
115597.11	0.92
133996.65	0.93

Table (5.44) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia nilotrica var. nilotica* gum solutions (composite sample D)

$\Delta\mu_2$ erg g^{-1}	ω_1
72298.19	0.88
79498.01	0.89
84579.88	0.90
92097.69	0.91
108897.28	0.92
118197.05	0.93

Table (45) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia seyal var. seyal* gum solutions (composite sample W)

$\Delta\mu_2$ erg g^{-1}	ω_1
51898.70	0.88
56098.27	0.89
61798.45	90
69298.26	0.91
74698.13	0.92
85197.87	0.93
89097.55	0.94
107097.32	0.95

Table (46) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia seyal var.seyal* gum solutions (composite sample X)

$\Delta\mu_2$ erg g^{-1}	ω_1
53398.66	0.88
55198.62	0.89
60598.48	0.90
66298.34	0.91
71698.21	0.92
77698.06	0.93
82797.93	0.94
95397.62	0.95

Table (47) data for plotting $\Delta\mu_2^-$ versus ω_1 Acacia seyal var.seyal gum solutions (composite sample Y)

$\Delta\mu_2$ erg g^{-1}	ω_1
53698.65	0.88
56098.59	0.89
62398.44	0.90
68398.29	0.91
75598.11	0.92
81897.95	0.93
95397.62	0.94
102297.44	0.95

Table (48) data for plotting $\Delta\mu_2^-$ versus ω_1 *Acacia seyal var. seyal* gum solutions (composite sample Z)

$\Delta\mu_2$ erg g^{-1}	ω_1
55198.62	0.88
58498.53	0.89
63598.41	0.90
68698.28	0.91
73798.15	0.92
83397.92	0.93
93597.66	0.94
101397.66	0.95

Table (5.49) Chemical potential of *Acacia nilotica var. nilotica* gum solutions after correction (composite sample A)

ω_1/ω_2	$\Delta\mu_2^-$ (erg g^{-1})	A	$\Delta\mu_2$ (erg g^{-1})
٧.٣٣٣٣	-78398.04	-91165	-99004.04
8.0909	-95197.60	-91165	-186362.6
9.0000	-100797.48	-91165	-191962.48
10.1111	-112797.118	-91165	-203962.18
11.50	-123996.90	-91165	-215161.9
13.2857	-137596.56	-91165	-228761.56

Table (5.50) chemical potential of *Acacia nilotica var. nilotica* gum solutions after correction (Composite sample B)

ω_1/ω_2	$\Delta\mu_2^-$ (ergg^{-1})	A	$\Delta\mu_2$ (erg g^{-1})
7.3333	-81197.97	-74667	-155864.97
8.0909	-85997.85	-74667	-160664.85
9.0000	-92797.68	-74667	-167464.68
10.1111	-1011.30.81	-74667	-175797.81
11.50	-118397.04	-74667	-193064.04
13.2857	-125646.87	-74667	-200313.87

Table (5.51) Chemical potential of *Acacia niloticavar. nilotica* gum solutions after correction (Composite sample C)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-73198.17	-98537	-171735.17
8.0909	-80397.99	-98537	-178934.99
9.0000	-89197.77	-98537	-187734.77
10.1111	-98797.53	-98537	-197334.53
11.50	-115597.11	-98537	-214134.11
13.2857	-133996.65	-98537	-232533.65

Table (5.52) Chemical potential of *Acacia nilotica var. nilotica* gum solutions after correction (composite sample D)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-72298.19	-74825	-147123.19
8.0909	-79498.01	-74825	-154323.01
9.0000	-84579.88	-74825	-159422.88
10.1111	-92097.69	-74825	-166922.69
11.50	-108897.28	-74825	-183722.28
13.2857	-118197.05	-74825	-193022.05

Table (5.53) Chemical potential of *Acacia seyal var. seyal* gum solutions after correction (Composite sample W)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-51898.70	-65645	-117543.7
8.0909	-56098.27	-65645	-121743.27
9.0000	-61798.45	-65645	-126943.26
10.1111	-69298.26	-65645	-134943.26
11.50	-74698.13	-65645	-140343.13
13.2857	-85197.87	-65645	-150842.55
15.6666	-89097.55	-65645	-163742.55
19	-107097.32	-65645	-172742.32

Table (5.54) Chemical potential of *Acacia seyal var. seyal* gum solutions after correction (composite sample X)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-53398.66	-46193	-99591.66
8.0909	-55198.62	-46193	-101391.62
9.0000	-60598.48	-46193	-106791.48
10.1111	-66298.34	-46193	-112491.34
11.50	-71698.21	-46193	-117891.06
13.2857	-77698.06	-46193	-123891.06
15.6666	-82797.93	-46193	-128990.93
19	-95397.62	-46193	-141590.62

Table (5.55) Chemical potential of *Acacia seyal var. seyal* gum solutions after correction (composite sample Y)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-53698.65	-58169	-111867.65
8.0909	-56098.59	-58169	-114267.59
9.0000	-62398.44	-58169	-120567.44
10.1111	-68398.29	-58169	-126567.29
11.50	-75598.11	-58169	-133767.11
13.2857	-81897.95	-58169	-140066.95
15.6666	-95397.62	-58169	-153566.62
19.000	-102297.44	-58169	-160466.44

Table (5.56) Chemical potential of acacia seyal gum solutions after correction (composite sample Z)

ω_1/ω_2	$\Delta\mu_2^-$ erg g^{-1}	A	$\Delta\mu_2$ erg g^{-1}
7.3333	-55198.62	-538912	-109380.62
8.0909	-58498.53	-538912	-112380.53
9.0000	-63598.41	-538912	-117480.41
10.1111	-68698.28	-538912	-122580.28
11.50	-73798.15	-538912	-127680.15
13.2857	-83397.92	-538912	-137279.92
15.6666	-93597.66	-538912	-147479.66
19.0000	-10197.66	-538912	-155279.66

Table (5.57) Free energy of mixing of *Acacia nilotica var. nilotica* gum solutions in different units (Composite sample A)

Conc.gcm^{-3}	ΔG^m(erg g^{-1})	ΔG^m(joule g^{-1})
0.07	-14218.2859	$-9.2791559 \times 10^{-4}$
0.08	-18333.2848	$-1.83332848 \times 10^{-3}$
0.09	-22357.2078	$-2.23572078 \times 10^{-3}$
0.1	-27095.89	-2.709589×10^{-3}
0.11	-31476.1172	$-3.14761172 \times 10^{-3}$
0.12	-37862.4648	$-3.786214648 \times 10^{-3}$

Table (5.58) Free energy of mixing of *Acacia nilotica var. nilotica* gum solutions in different units (Composite sample B)

Conc.gcm^{-3}	ΔG^m(erg g^{-1})	ΔG^m(joule g^{-1})
0.07	-12768.64145	$-1.276864145\times10^{-3}$
0.08	-15426.54766	$-1.542654766\times10^{-3}$
0.09	-18696.07856	$-1.869607856\times10^{-3}$
0.01	-22015.23003	$-2.201523003\times10^{-3}$
0.011	-26927.20609	$-2.692720609\times10^{-3}$
0.012	-13773.72698	$-3.177372698\times10^{-3}$

Table (5.59) Free energy of mixing of *Acacia nilotica var. nilotica* gum solutions in different units

Conc.gcm^{-3}	ΔG^m(erg g^{-1})	ΔG^m(joule g^{-1})
0.07	-14246.46227	$-1.424646227\times10^{-3}$
0.08	-17008.0012	$-1.7008.0012\times10^{-3}$
0.09	-20286.5616	-2.02865616×10^{-3}
0.1	-23805.1912	-2.38051912×10^{-3}
0.11	-28647.08612	$-2.864708612\times10^{-3}$
0.12	-33875.9207	-3.38759207×10^{-3}

Table (5.60) Free energy of mixing of *Acacia nilotica var. nilotica* gum solutions in different units (composite sample D)

Conc.gcm^{-3}	ΔG^m(erg g^{-1})	ΔG^m(joule g^{-1})
0.07	-12154.85689	$-1.215485689\times10^{-3}$
0.08	-14916.62453	$-1.491662453\times10^{-3}$
0.09	-17738.5131	-1.77385131×10^{-3}
0.1	-21003.48022	$-2.100348022\times10^{-3}$
0.11	-25893.91669	$-2.589391669\times10^{-3}$
0.12	-32647.40088	$-3.264740088\times10^{-3}$

Table (5.61) Free energy of mixing of *Acacia seyal var. aseyal* gum solutions in different units (Composite sample W)

Conc.gcm^{-3}	ΔG^m (erg g^{-1})	ΔG^m (joule g^{-1})
0.05	-10301.54106	-1.030154106 $\times 10^{-3}$
0.06	-14183.97088	-1.418397088 $\times 10^{-3}$
0.07	-19625.18343	-1.1962518343 $\times 10^{-3}$
0.08	-24383.88932	-2.438388932 $\times 10^{-3}$
0.09	-30551.85204	-3.055185204 $\times 10^{-3}$
0.1	-39155.4129	-3.91554129 $\times 10^{-3}$
0.11	-48920.96398	-4.892096398 $\times 10^{-3}$
0.12	-57145.58352	-5.714558352 $\times 10^{-3}$

Table (5.62) Free energy of mixing of *Acacia seyal var.seyal* gum solutions in different units (composite sample X)

Conc.gcm^{-3}	ΔG^m (erg g^{-1})	ΔG^m (joule g^{-1})
0.05	-14081.11548	-1.408111548$\times 10^{-3}$
0.06	-18966.68976	-1.896668976$\times 10^{-3}$
0.07	-24923.99943	-2.492399943$\times 10^{-3}$
0.08	-31401.85092	-3.140185092$\times 10^{-3}$
0.09	-38581.44052	-3.858144052$\times 10^{-3}$
0.1	-46759.3671	-4.67593671$\times 10^{-3}$
0.11	-54098.69024	-5.409869024$\times 10^{-3}$
0.12	-66288.18048	-6.628818048$\times 10^{-3}$

Table (5.63) Free energy of mixing of *Acacia seyal var.seyal* gum solutions in different units (composite sample Y)

Conc.gcm^{-3}	ΔG^m(erg g^{-1})	ΔG^m(joule g^{-1})
0.05	-12672.35215	-1.267235215 $\times 10^{-3}$
0.06	-16612.25994	-1.661225994 $\times 10^{-3}$
0.07	-20938.36001	-2.093836001 $\times 10^{-3}$
0.08	-26774.26808	-2.677426808 $\times 10^{-3}$
0.09	-33955.90305	-3.395590305 $\times 10^{-3}$
0.1	-39754.4512	-3.97544512 $\times 10^{-3}$
0.11	-47564.75865	-4.756475865 $\times 10^{-3}$
0.12	-58131.75832	-5.813175832 $\times 10^{-3}$

Table (5.64) Free energy of mixing of *Acacia seyal var. seyal* gum solutions in different units (composite sample Z)

Conc.gcm^{-3}	ΔG^{m}(erg g^{-1})	ΔG^{m}(joule g^{-1})
0.05	-10783.5781	-1.07835781×10^{-3}
0.06	-15131.55809	$-1.513155809\times10^{-3}$
0.07	-19000.571	-1.9000571×10^{-3}
0.08	-24511.3344	-2.45113344×10^{-3}
0.09	-31127.06701	$-3.112706701\times10^{-3}$
0.1	-39981.0559	-3.99810559×10^{-3}
0.11	-47281.56252	$-4.728156252\times10^{-3}$
0.12	-57079.42344	$-5.707942344\times10^{-3}$