

1. Introduction

Gums are high molecular weight polymeric compound composed of carbon, hydrogen, oxygen and nitrogen (Somaya, 2010). Plant gums are organic substance obtained as an exudation from fruit, trunk or branches of the trees spontaneously or after mechanical injury of the plant by incision of the bark, or after the removal of the branch, or after invasion by bacteria. The exudates becomes hard nodules or ribbons on dehydration to form sheath against micro-organism. They form clear glassy masses substance with dark brown color to pale yellow.

The majority of gums dissolve in water at different concentration (e.g, gum arabic can form solution of up to 60% forming viscous solution), that makes solubility and viscosity are fundamental property of gum. Gum arabic is enjoy in applications and this is mainly due to the reduced surface tension and to extremely high solubility in water and low viscosity (Osman, 1993). The major application of gum is in food industry, the gum is also used in pharmaceutical and medical field, in addition to other industries such as cosmetic, adhesive, paint and inks.

This study is aim to explain the information that may help in understanding the interaction of gum molecule with a solvent and how it behaves when mixed with other ingredients with food, pharmaceuticals, cosmetics and other industrial formulae.

1.1- Distribution of *Anogeissus Leiocarpus*

Anogeissus leiocarpus is found in a large range of ecosystem, from dry savannah to wet forest borders, in wooded grassland and bush land, and on river banks in

Eritrea, Ethiopia, Sudan, Cameroon, Congo-Kinshasa, Gambia, Ghana, Mali, Niger and Senegal (USDA, 2010, Andary *et. al.* 2005).

Optimum growth condition are 200 – 1200 mm annual rainfall at sea- level up to an altitude of 1900m in fertile soils, it often grow gregariously on fertile soil in moist situation (Andary *et. al.*, 2005).

In Sudan *Anogeissus leiocarpus* tree is spread in Kassala and Darfur.

1.2- Description of *Anogeissus Leiocarpus*

The African birch (*Anogeissus leiocarpus*) is slow growing evergreen shrub or small to medium sized tree, reaching up to 15-30 m in height. The bark is grey to mottled pale and dark brown, scaly, flaking off in rectangular patches, fibrous, exuding a dark gum.

Leaves are alternate to nearly opposite, simple and entire covered in a dense silky hair when young. Flowers are pentamerous, pale yellow and fragrant. Fruit are rounded samara 4-10 mm × 6-10 mm, with two wings with a yellowish to reddish brown color, they contain one seed, enclosed horizontally in dense cone – like fructification (Andary, *et. al.*, 2005).

1.3- Botanical classification

Synonyms: *Anogeissus schimperi* Hochst. ex. Hutch. Of Dalze. (Andary

et. al., 2005), *conocarpus leiocarpus* Dc. (USDA, 2010) .

kingdom: *plantae*

Family : *combretaceae*

Order : *Myrtales*

Genus : *Anogeissus*

Species : *A. Leiocarpus*

Latin name : *Anogeissus leiocarpa* (Dc.)

Arabic name : Sahab

English name : African birch

1.4- Definition of family

Combretaceae is a family of 20 genera and 600 species tropical and subtropical trees and shrubs, generally *combretaceae* was known as a rich source of tannin. Genera include *terminalis*, *combretum*, *Quisqualis*, *Myrobolans* and *Anogeissus* (Hans, 1990). Some gums from *combretaceae* are being increasingly utilized commercially for example ghatti gum and *Leiocarpus* gum.

1.5- Uses of *Anogeissus Leiocarpus*

The wood is used mainly for transmission and building poles, fence posts, forked poles and as a beam of local building construction. it is also used for fire wood and charcoal.

The leaves and barks contain tannin materials recognized by Sudan tannin industry (Elamin, 1990). In Mali all parts of *Anogeissus Leiocarpus* (leaves, barks and roots) used as a medicine (antimicrobial anthelmintic activity) mixed with other plants in traditional system.

Derivative of ellagic acids (anogelline) extracted from the bark have been shown to delay the degradation of collagen and the tree is grown commercially since 2000 for the

production of cosmetics in the koro region of Burkina-faso (Jansen, *et. al.*, 2005). Also *Anogeissus Leiocarpus* gum was used as food additives mixed with gum arabic or as substitute for it.

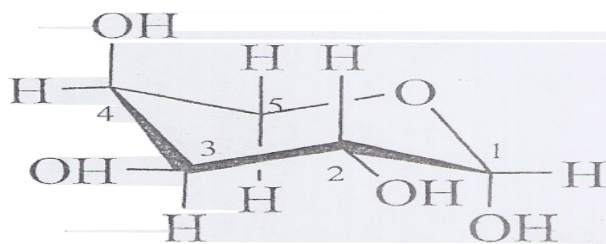
1.6- Chemical structure of gum arabic

Gum arabic is branched, neutral or slightly acidic, complex polysaccharide obtained as a mixed calcium, magnesium, and potassium salt. The backbone consists of 1,3- linked β - d -galactopyranosyl units. The side chains are composed of two to five 1,3 -linked β -d- galactopyranosyl units, joined to the main chain by 1,6-linkages. Both the main and the side chains contain units of α -1-arabinofuranosyl, α -1-rhamnopyranosyl, β -d-glucuronopyranosyl, and 4-O-methyl- β -d-glucuronopyranosyl, the latter two mostly as end-units (Anderson and Stoddart, 1966). It was noted that the gum was very heterogeneous and it has been described as "heteropolymolecular", i.e. having either a variation in monomer composition and or a variation in the mode of linking and branching in the monomer units (Anderson 1966b). This heterogeneity can be observed by using different methods by which different elution profile can

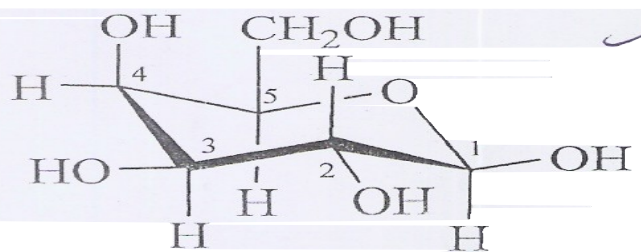
be obtained. (Anderson *et. al.* 1966b) using periodate subjected gum arabic to smith degradation in figure (1.2). They further analysed the product by methylation and gel permeation chromatography (GPC) and found that the uronic acid and the rhamnose residues eliminated first which proved that they are located at the periphery of the molecule and the core consisted of a β 1,3-galactopyranose chain with branches linked through 1,6 position. They also found that the protein component was associated with the high molecular weight fraction and lower molecular mass fraction were virtually exclusively polysaccharides (figure:1.1) show the polysaccharides in gum arabic. (street *et. al.* 1983) used computer modeling to analyze the previous data and proposed the structure illustrated in figure (1.3).

(churms *et al* 1983) subjected the gum to smith degradation leaving the reaction to reach completion after each stage of degradation procedure. They obtained different values for the composition and size of the molecule of each degradation product than those previously obtained by (Anderson, 1966b), and proposed a more regular structure than the previous one proposing that the galactan core consisted of 13 β -,3-D-galactopyranosyl residues having two branches which give single repeating subunits having molecular mass of 8×10^3 within the molecule.

As the whole gum was found to have molecular weight of 560,000 thus it was proposed that the molecule consists 64 of these subunits and that they were symmetrically arranged. (Defye and Wang 1986) in their structural studies of gum arabic using A25.182MHz ^{13}C -NMR



α - Arabinopyranose

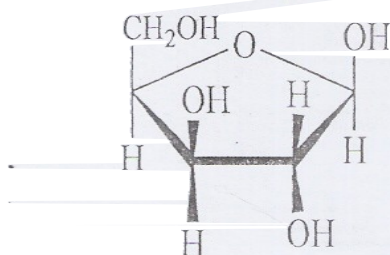


β - Galactopyranose

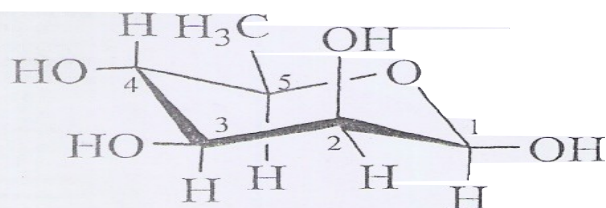
Figure

(1.1): Carbohydrates

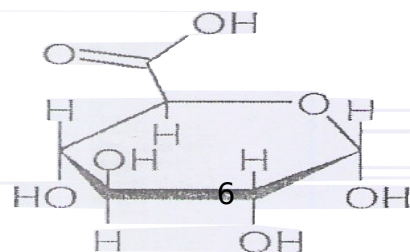
unites in gum molecule



Arabinofuranosyl



β - Rhamnopyranose



The α -D form of glucuronic acid

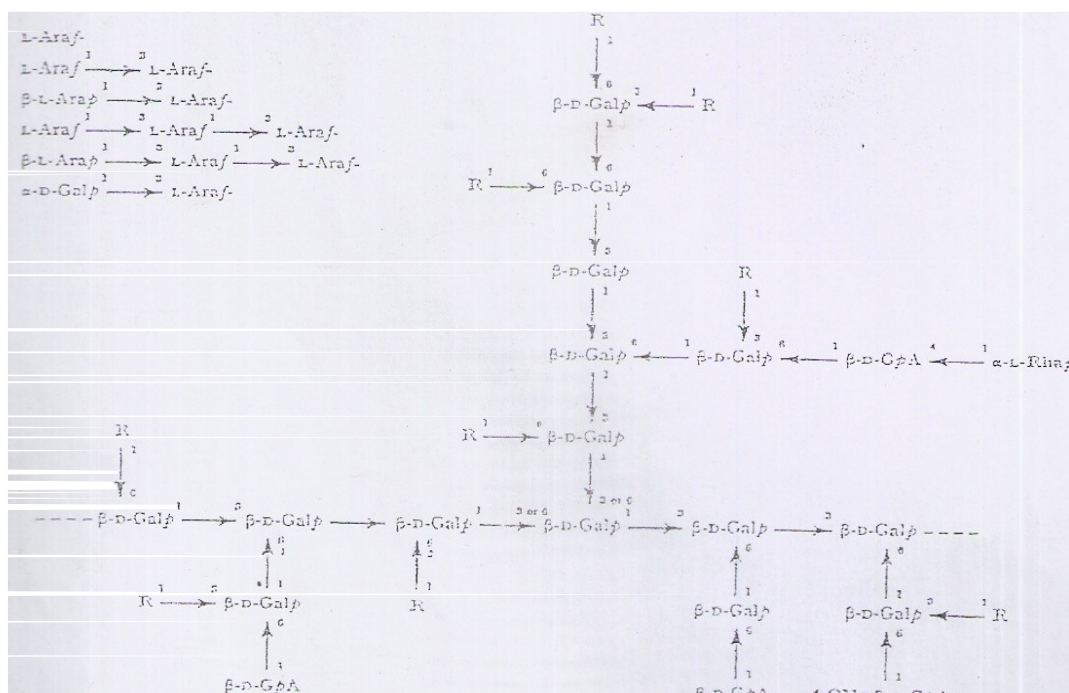


Figure (1.2): strutural model for *Acacia senegal* gum as proposed et.al.,(1966b)

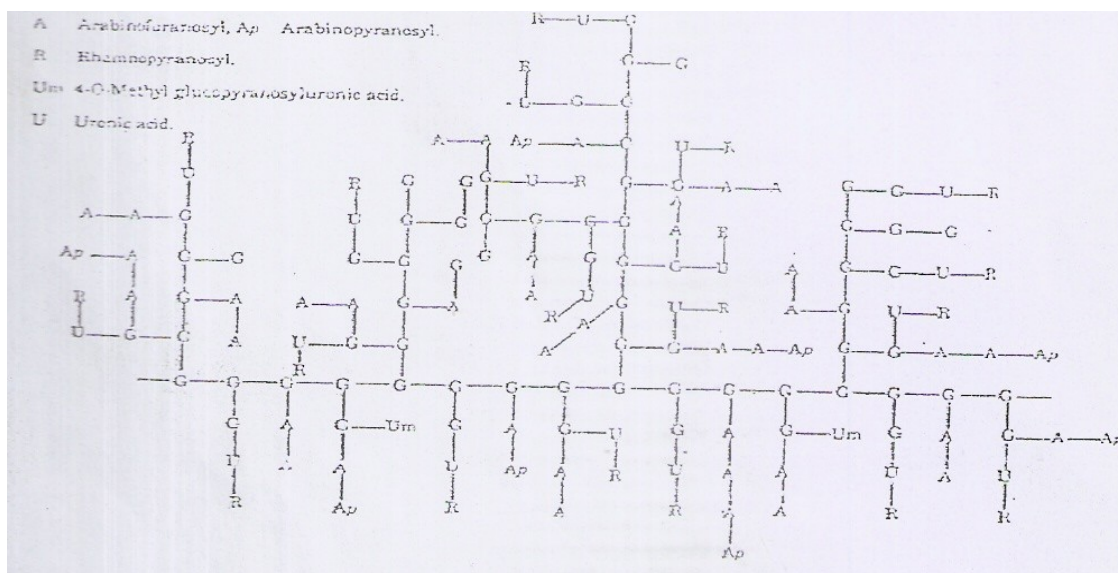
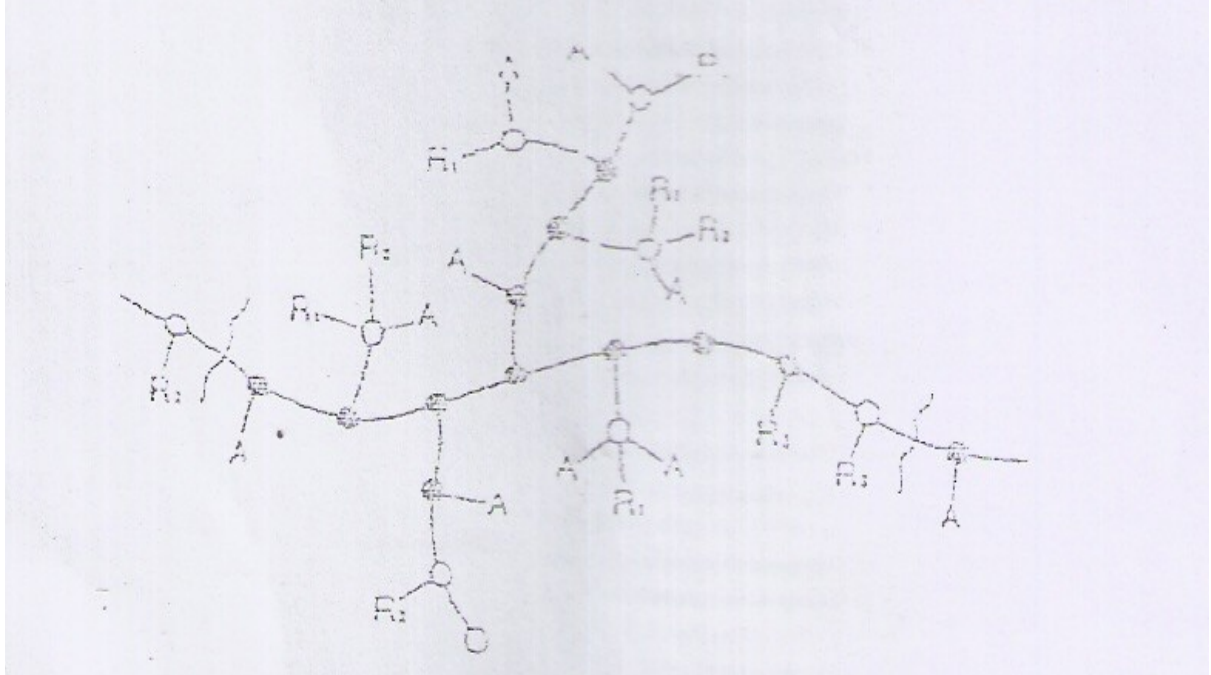


Figure (1.3): The strutural of *Acacia senegal* gum as proposed by street et.al.,(1983)

spectrum of gum arabic which allows unambiguous characterization of the C-1 resonance and so proposed the structural model in figure (1.4).

In studying the structure of gum arabic (Anderson and Mc Dougal 1987) subjected *senegal* gum to series of smith degradations and found that the molar ratio of polysaccharide/ protein in the whole gum (31:1) was decreased to 18:1 , 11:1 , 11:1 and 11:1 in the first second, third and fourth SD product respectively. Another series of SD was done by (Anderson *et al* 1987) in *seyal* gum and showed that the molar ratio of polysaccharide protein in the whole gum was decreased to 58:1, 27:1, 5.5:1 and 4:1 first, second, third and fourth SD products respectively this showed that the major of the relatively small amount of amino acids present in *seyal* gum are located at deep-seated location within the macromolecule and few are attached to the sugars in the peripheral positions.

A study was undertaken by (Connolly *rt. al.* 1988) in which they treated *senegal* gum by proteolytic enzyme pronase and reported that the intrinsic viscosity and molecular weight decrease while the specific rotation and equivalent weight have not change indicating that there was no major structural change had taken place.



(Anderson *et al.*) showed significant variation in nitrogen content, amino acid composition and molecular distribution of gums of *gummiferae* and *vulgaries* series which suggest significant variation in the structure of the gums exuded from the species are similar but there is variation in their proportion with hydroxy-proline, serine, and proline being the most abundant. Jurasek *et al* 1995, and AL- Assaf *et al* 2005 agreed with these findings.

Fractionation of *Acacia senegal* gum by hydrophobic affinity chromatography showed that it consists of at least of three components, fraction 3 GP(Glycoprotein) (Randal *et al*, 1989). (Osman *et al.* 1993) proposed that even those fraction contain a range of different molecular weight components revealing the polydispersity of the gum , fraction 1 representing the 88% of the total has only small amount of protein, fraction 2 contain 10 % of the total has a protein content of 12 %, fraction 3 represent 1.24% of the total but contain 50 % protein which is 25 % protein present in the whole gum.

Fractionation of *Acacia seyal* gum using the same condition showed that it has a similar but not identical composition, fraction 1 contain a higher proportion of total gum and higher protein content than the comparable fraction of *Acacia senegal*. The composition of the sugars doesn't differ significantly (Underwood 1994). The AGP consist of a poly peptide backbone to which one or more AGs with a molecular weight of $\approx 2 \times 10^5$ are attached, undertaking propanose treatment of the gum, it was shown that the

AGP is degraded to AG, while the weight average molecular weight (M_w) remained constant 190000 - 1800000 (Duvalled *et. al.* 1989). For AGP's generally the molecular weight of the blocks has been calculated to be of the order of 2×10^5 (connolly *et. al.* 1988). This result in a poly peptide gum with extremely high molecular weight containing components.

The complex structure of AG has order within the polysaccharide chain i.e there are regularly repeating blocks, each containing -13D galactopyranosyl residues. This repealing blocks with a molecular weight 2000 can also be found in a gums of Bentham series 2. There is strong evidence of the occurrence of uniform sub-units with a molecular weight of Ca (Stephan, 1987) these sub-units have also been postulated for some simpler polysaccharide with lower molecular weight. There also evidence that the side chains contain smaller units of (1-3) linked L-arabinofuranosyle residues , L- rhamanopyranosyl residues are terminal and frequently attached to 0-4 of D-glucopyranosyl- uronic acid . these results led to the suggestion that the gum had a " wattle common poly peptide chain figure (1.5) as proposed by (Fincher *et al* 1983). A new model based on the O-Galactosylhydroxyproline as a polysaccharide attachment site was proposed by (Qi *et al* 1991). They fractionated the gum on preparative soparose 6 column a high molecular weight gum arabic glycoprotein (GAGP) containing about 90% carbohydrate and a lower molecular weight hetrogenous gum Arabic polysaccharide fraction. Hydrogen fluoride-deglycosylation of GAGP gave a large (-400 residue) hydroxyproline- rich polypeptide backbone (dGAGP). Alkaline hydrolysis of GAGP showed that most of the carbohydrate was attached to the polypeptide

backbone as small (- 30 residue) hydroxylproline (Hyp)-polysaccharide substituent. after partial acid hydrolysis of the Hyp-polysaccharide fraction they identified O-galactosyl- hydroxylproline as the glycopeptidelinkage, identical with that of hydroxyproline-rich arabinogalactan - proteins (AGPs) . they concluded that the AGP molecules were rod like and resembled hairy tope (rather than the spheroidal molecule postulated by the "wattle blossom " model of both AGPs and the gum arabic protein complexe figure (1.6).

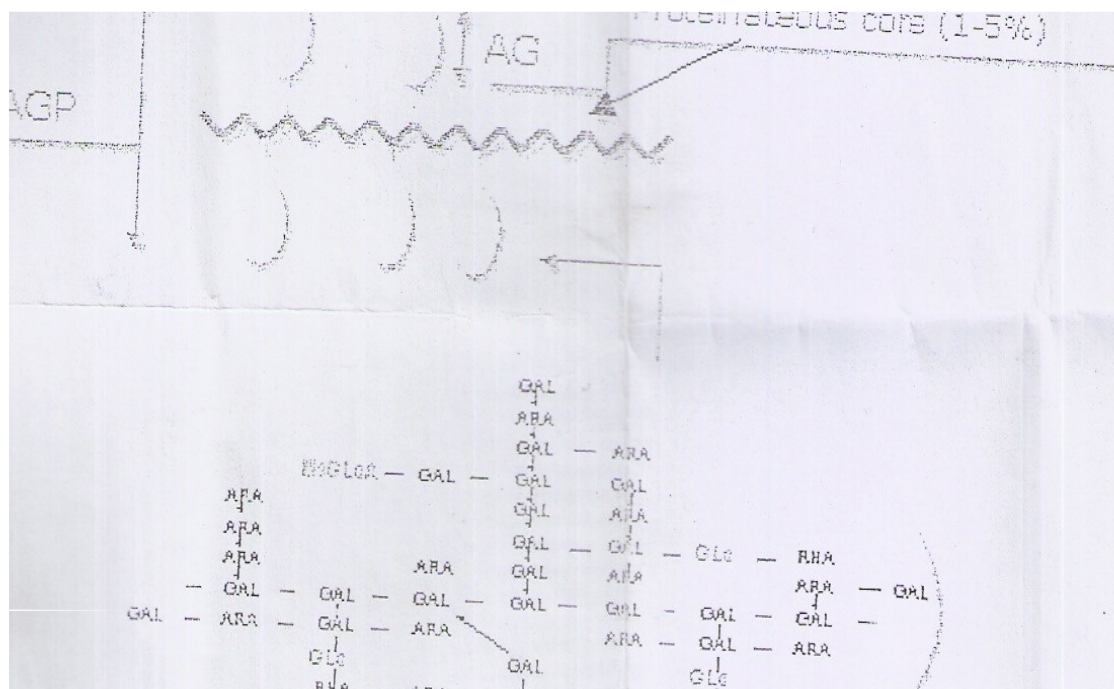


Figure (1.5):Wattle blossom type structure of *Acacia senegal* gum as proposed by Fincher *et.al.*,(1983)

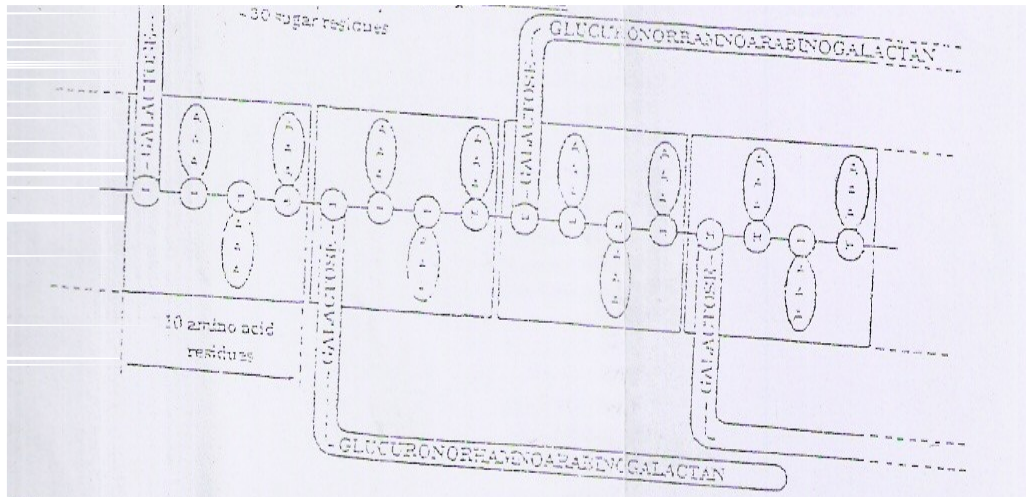


Figure (1.6):The twisted rope structure of *Acacia senegal* as proposed by Qi *et.al.*, (1990)

(Gooderm *et. al.*, 2000) tested the hypothesis of (Qi *et. al.* 1991) by sequence analysis of the AGP polypeptide after HF-deglycosylation figure (1.7). A family of closely related peptides confirmed the presence of a repetitive 19- residue consensus motif. However, the motif: ser-Hyp-Hyp-Thr-Leu-ser-Hyp-ser-Hyp-Thr-Hyp-Thr-Hyp-Hyp-Leu-Gly-Pro-His, was about twice the size anticipated. Thus, judging by Hyp-glycoside profiles of AGP, the consensus motif contained six Hyp-arabinosides rather than three and two Hyp-polysaccharides rather than one. We inferred the glycosylation sites based on the Hyp contiguity hypothesis which predicts arabinosides on contiguous Hyp residues and arabinogalactan polysaccharides on clustered non-contiguous Hyp residues, i.e. the AGP motif would consist of arabinosylated contiguous Hyp blocks flanking to

glycoprotein, enhances the overall symmetry of the glycopeptides motif, and may explain some of the remarkable properties of gum arabic.

(Anderson and Herlich 1963) proposed that *seyal* gum is similar to other *Acacia* gums that it contains glucuronic acid, galactose, arabinose and rabinose, but the presence of acid-labile residues and the mild decrease in viscosity detected in mild hydrolysis showed that *Acacia seyal* further resembles other *Acacia* gums in having a main chain , resistant to hydrolysis , to which is attached acid-labile side chain .

There is evidence that *Acacia seyal* gum is more compact in structure than the *Acacia senegal* gum (Anderson *et. al.*, 1968 , Siddig, 2003 , and AL-Assaf 2005)

(Siddig, 2004) showed that the three main component designated arabinogalactan protein (AGP), arabinogalactan (AG) and glycoprotein

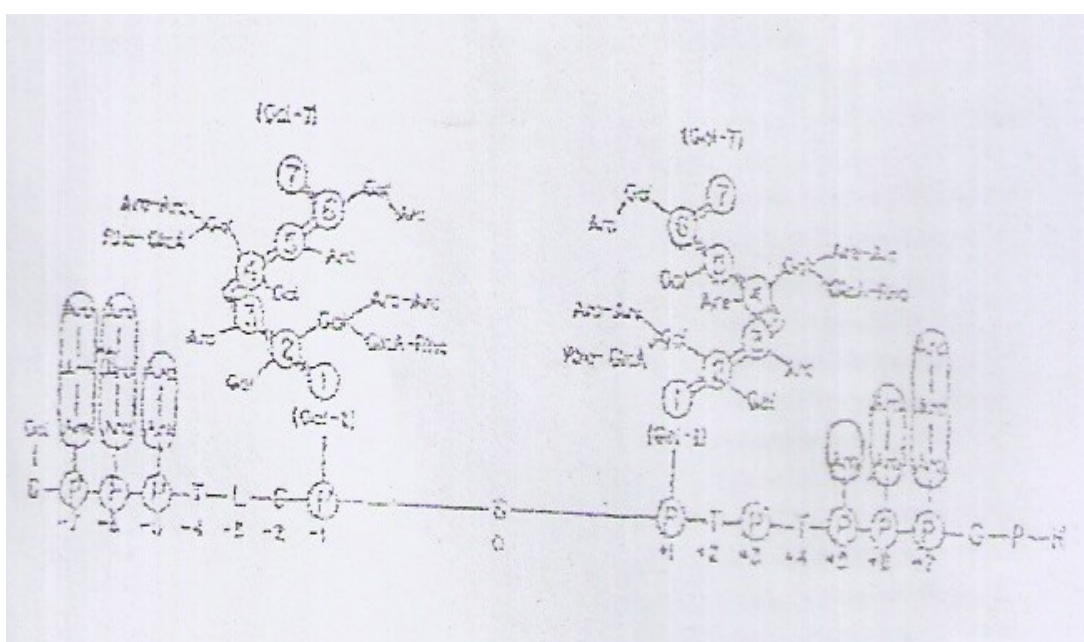


Figure (1.7): Model of (GAGP) as suggested by Goodrum *et.al.*, (2000)

(GP) known to be present in *Acacia senegal* could also be present in *A. seyal* gum. However, in *A. senegal* gum, the high molecular weight AGP component is more significant and is present in greater proportion than for *Acacia seyal* gum. The most important difference is that at least two components are present in the high molecular weight fraction in *Acacia seyal* gum, indicating that it would be erroneous to identify this completely with the AGP fraction in *Acacia senegal* gum.

1.7- Physiochemical properties of gum arabic

1.7.1- Solubility

Gum arabic is highly soluble in water. the solubility of some species of *Anogeissus leiocarpus* is more than 60%. It is insoluble in most organic solvent.

1.7.2- Moisture content %:

Moisture content involves the measuring of the weight lost due to the evaporation of water (D. Person, 1970). It helps to determine the dry weight of the gum. (FAO, 1988).

1.7.3- Ash content %:

Ash content is measure of inorganic residue remaining after removal of organic matter by burning. the inorganic residue exists as elements explaining that, the type of the soil (clay or sand) affect the ash content significantly (FAO, 1988).

1.7.4- Nitrogen and protein content %:

Protein content in gum arabic had effects on emulsifying behavior of gum arabic and the best emulsion capacity and stability is found in gums with highest nitrogen content (Randall *et. al.*, 1988, Dickinson, 1992).

1.7.5- Optical rotation :

Specific rotation [α] is a property of a chiral chemical compound. It is defined as the change in orientation of monochromatic plane-polarized light, as the light passes through a sample of a compound in solution. Compounds which rotate light clockwise are said to be dextrorotary, and correspond with positive specific rotation values, while compounds which rotate light anticlockwise are said to be levorotary, and correspond with negative values. If a

compound is able to rotate plane-polarized light, it is said to be “optically active”.

Specific rotation is an intensive property, distinguishing it from the more General phenomenon of optical rotation. The observed rotation (α) of a sample of a compound can be used to quantify the enantiomeric excess of that compound, provided that the specific rotation $[\alpha]$ for the enantiopure compound is known. The variance of specific rotation with wavelength (a phenomenon known as optical rotatory dispersion) can be used to find the absolute configuration of a molecule.

1.7.6- Intrinsic viscosity:

The viscosity of the solvent increases when the polymer is dissolving in it. Intrinsic viscosity is quantity which is independent of concentration of a sample, and is a simple and accurate measure which can be used to obtain the viscosity average molecular weight.

To determine the viscosity of polymer solution the time of flow was measured by the solution between two marked point in a glass capillary viscometer.

To determine the viscosity of the liquid or solution, the time between two fixed marks in a capillary tube was measured. the viscosity co-efficient (η) of a liquid or solution is then calculated from following equation :

$$\eta = \left[\frac{\pi \Delta p r^4}{8 l V} \right] \cdot t \dots\dots\dots (1.7.6.1)$$

Where:

Δp differences of pressure at the capillary ends.

t is the time of efflux.

V is volume of sphere containing the liquid .

r and l are radius and length of the capillary tube respectively .

$$\Delta p = g h d \dots\dots\dots (1.7.6.2)$$

g is acceleration of gravity

h is a different of liquid levels in arms of instrument

d is a relative density of liquid

substituting the value of Δp into equation (1.7.6.1)

$$\eta = \left[\frac{\pi g d r^4}{8 l V} \right] \cdot t \dots\dots\dots (1.7.6.3)$$

The liquid level in the capillaries is variable, to kept it as the constant using specially designed viscometers .

If the measurement are always carried out in the same viscometer, the values of V , l and r remain constant, then the liquid column height should also be constant , and hence

$$\eta = k \cdot d \cdot t \dots\dots\dots (1.7.6.4)$$

where

$$k = \frac{\pi g h r^4}{8 l V} \dots\dots\dots (1.7.6.5)$$

Where: k is viscometer constant, and is calculated from the time of efflux of liquid of known viscometer in a following equation :

$$k = \frac{\eta_o}{d_o t_o} \dots\dots\dots (1.7.6.6)$$

where:

η_o is viscosity co-efficient, d_o density

t_o is a time of efflux of the calibration liquid.

1.7.6.1- Relative viscosity (η_r)

Is the ratio of solution viscosity $\eta_{sol.}$ to pure solvent viscosity $\eta_{solv.}$

$$\eta_r = \frac{\eta_{sol.}}{\eta_{solv.}} \dots\dots\dots (1.7.6.1.1)$$

To determine the relative viscosity, the time of efflux of solution and solvent was measured in the same viscometer, taking the density of both solution and solvent as equal ($d = d_o$)

$$\eta_r = \frac{t}{t_o} \dots\dots\dots (1.7.6.1.2)$$

t : the efflux time of solution

t_o : the efflux time of the solvent

1.7.6.2- Specific viscosity (η_{sp})

Specific viscosity is viscosity of solution upon addition of the polymer, the additional of the polymer to solvent increasing the viscosity of the solution.

$$\eta_{sp} = \left[\frac{(\eta_{sol} - \eta_{solv})}{\eta_{solv}} \right] \dots\dots\dots (1.7.6.2.1)$$

$$\eta_{sp} = \eta_r - 1 \dots\dots\dots(1.7.6.2.2)$$

1.7.6.3- Reduced viscosity (η_{red})

Reduced viscosity is the ratio of the specific viscosity to concentration

$$\eta_{red} = \frac{\eta_{sp}}{C} \quad (\text{ml g}^{-1}) \dots\dots\dots(1.7.6.3.1)$$

Intrinsic viscosity is the limit of reduced viscosity as the polymer solute concentration (C) approaches zero .

The variation of specific viscosity with concentration in dilute solution is a given by straight line as :

$$\frac{\eta_{sp}}{C} = a_1 + a_2 C \dots\dots\dots(1.7.6.3.2)$$

Where: a_1 = intercept a_2 = slope of the line

$$a_1 = \left[\lim_{C \rightarrow 0} \frac{\eta_{sp}}{C} \right]$$

Also

$$\left[\right]$$

$$[\eta] = \lim_{C \rightarrow 0} \frac{\eta_{sp}}{C} \dots\dots\dots(1.7.6.3.3)$$

Where $[\eta]$ is known as the limiting viscosity number (intrinsic viscosity).

Intrinsic viscosity is the quantity which is independent of concentration of a solution.

$$[\eta] = a_1 \dots\dots\dots(1.7.6.3.4)$$

Substituted with equation (1.7.6.3.2)

$$\frac{\eta_{sp}}{C} = [\eta] + a_2 C \dots\dots\dots(1.7.6.3.5)$$

1.7.7- Refractive index:

In [optics](#) the refractive index n of an [optical medium](#) is [dimensionless](#) number that describes how [light](#), or any other [radiation](#), propagates through that medium. It is defined as

$$n = \frac{c}{v} \dots\dots\dots(1.7.7.1)$$

where c is the [speed of light](#) in [vacuum](#) and v is the speed of light in the substance. For example, the refractive index of water is 1.33, meaning that light travels 1.33 times faster in a vacuum than it does in water.

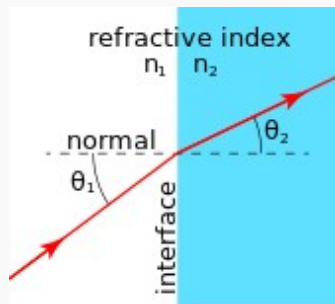


Figure (1.8): Refraction of a light ray

The refractive index determines how much light is bent, or [refracted](#), when entering a material. This is the historically first use of refractive indices and is described by [Snell's law](#) of refraction,

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \dots\dots\dots(1.7.7.2)$$

where θ_1 and θ_2 are the [angles of incidence](#) and refraction, respectively, of a ray crossing the interface between two media with refractive indices n_1 and n_2 . The refractive indices also determine the amount of light that is [reflected](#) when reaching the interface, as well as the critical angle for [total internal reflection](#) and [Brewster's angle](#).

The refractive index can be seen as the factor by which the speed and the [wavelength](#) of the radiation are reduced with respect to their vacuum values: the speed of light in a medium is

$$v = c/n \dots\dots\dots(1.7.7.3)$$

and similarly the wavelength in that medium is

$$\lambda = \lambda_0/n \dots\dots\dots(1.7.7.4)$$

where λ_0 is the wavelength of that light in vacuum.

This implies that vacuum has a refractive index of 1, and that the [frequency](#) ($f = v/\lambda$) of the wave is not affected by the refractive index.

The refractive index varies with the wavelength of light. This is called [dispersion](#) and causes the splitting of white light into its constituent colors in [prisms](#) and [rainbows](#), and [chromatic aberration](#) in lenses. Light propagation in [absorbing](#) materials can be described using a [complex](#)-valued refractive index. The [imaginary](#) part then handles the [attenuation](#), while the [real](#) part accounts for refraction.

The concept of refractive index is widely used within the full [electromagnetic spectrum](#), from [x-rays](#) to [radio waves](#). It can also be used with [wave](#) phenomena such as [sound](#). In this case the speed of sound is used instead of that of light and a reference medium other than vacuum must be chosen.

The refractive index n of an optical medium is defined as the ratio of the speed of light in vacuum, $c = 299792458$ m/s, and the [phase velocity](#) v_{phase} of light in the medium

$$n = \frac{c}{v_{\text{phase}}} \dots\dots\dots(1.7.7.5)$$

The phase velocity is the speed at which the crests and the [phase](#) of the [wave](#) moves, which may be different from the [group velocity](#), the speed at which the pulse of light, or the [envelope](#) of the wave, moves.

The definition above is sometimes referred to as the absolute index of refraction to distinguish it from definitions where the speed of light in other reference media than vacuum is used. Historically [air](#) at a standardized [pressure](#) and [temperature](#) have been common as a reference medium.

1.8- Thermodynamic Parameters

1.8.1- Weight fraction(ω)

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

$$\omega_1 = \frac{g_1}{g_1 + g_2} \dots\dots\dots (1.8.1.1)$$

$$\omega_2 = \frac{g_2}{g_1 + g_2} \dots\dots\dots (1.8.1.2)$$

g_1 and g_2 are the weight of component 1 and 2 respectively.

1.8.2- mole fraction(X)

The mole fraction is very important to theoretical understanding of solution like size of molecules. It can be determined for component(i) of a binary solution from the following equation:

$$X_1 = \frac{n_1}{n_1 + n_2} \dots\dots\dots (1.8.2.1)$$

$$X_2 = \frac{n_2}{n_1 + n_2} \dots\dots\dots (1.8.2.2)$$

Where: n_1 and n_2 are number of moles of components.

1.8.3- volume fraction(Φ)

The volume fraction of a component (Φ_i) is the ratio of its partial molar volume to the total volume of the solution. (Tager, 1978)

$$\Phi_1 = n_1 v_1 / n_1 v_1 + n_2 v_2 \dots\dots\dots (1.8.3.1)$$

$$\Phi_2 = n_2 v_2 / n_1 v_1 + n_2 v_2 \dots\dots\dots (1.8.3.1)$$

Where: v_1 and v_2 are partial molar (specific) volume of solvent and solute respectively.

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

The partial molar volume of substance in a mixture is the change in volume per mole added to a large volume of a mixture.

When the molecular mass is not known the molar fraction cannot be calculated, then using partial molar function.

To determine the partial molar function of a liquid of a binary solution V_m , the molar volume of each component must be known.

$$\bar{V}_m = N_1 \bar{V}_1 + N_2 \bar{V}_2 \dots\dots\dots (1.8.4.1)$$

Where: N_1 , N_2 is mole fraction

The molar fraction of a binary solution can be determined from by two graphical method, tangent method or intercept method.

1.8.4.2- Tangent method

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

The derivative $\frac{dv}{dn}$ or $\frac{dv}{dg}$ determined at any point of the curve, equal partial specific volume of component.

1.8.4.3- Intercept method

When plotting the value of volume (V) or its change (ΔV) referred to one mole of solution $V_{tot.} / (n_1 + n_2)$ or one gram of solution ($V / g_1 + g_2$) is plotting along the ordinate is against composition in weight fraction (ω), the tangent intercepts on the ordinate will be numerically equal to partial specific volume (Tager, 1978).

1.8.5- Chemical potential

The chemical potential equals the change in internal energy of a solution on addition of an infinitely small number of moles of its component, referred to amount of substance at constant volume, entropy, and quantity of each of the other component

$$\mu_1 = \frac{d\mu}{dni} \dots\dots\dots (1.8.5.1)$$

$$\Delta G = \Sigma \Delta \mu_i$$

Since

$$\Delta G = \Delta H - T\Delta S \quad , \quad \Delta \mu = \Delta H - T\Delta S$$

$$\bar{V} = \left[\frac{d\mu}{dp} \right] \dots\dots\dots (1.8.5.2)$$

$$d\bar{\mu} = \bar{V} dp$$

hence

$$\int d\bar{\mu}_1 = \int \bar{V} dp$$

Assuming $\bar{V}$ to be constant

$$\mu_{1_0} - \bar{\mu}_1 = \bar{V} (p - p_0) = \bar{V} \pi$$

$$\text{since } \mu_1 - \mu_{1_0} = \Delta \mu_1$$

$$\text{then } \Delta \bar{\mu}_1 = \bar{V} \pi \dots\dots\dots (1.8.5.3)$$

1.8.6- Osmotic pressure

1.8.6.1- Osmometry:

Based on the phenomenon of osmosis, the membrane osmometry is widely used technique for number average molecular weight M_n determination.

Osmotic pressure is the only one of the four colligative properties that provides a convenient practical method for measuring M_w . It can be used to determine molecular weight for a macromolecules.

In osmosis, the semi permeable membrane allows the solvent molecules to pass freely but the polymer molecules are unable to pass through it. Thus, when a pure solvent is separated from the polymer solution by semi-permeable membrane then there is a net flow of solvent towards the cell containing the polymer solution. This causes an increase in liquid in the polymer solution cell which then subsequently produces a rise in liquid level in the corresponding measuring capillary tube. The rise in the liquid levels opposed and balanced by a hydrostatic pressure which results due to the difference in the liquid levels of the two measuring capillary tubes. This difference in the liquid levels is directly related to the osmotic pressure of the containing polymer solution. Thus, static equilibrium is reached when no further flow of solvent towards solution side occurs.

The difference in height (h) of the liquids in the tubes may be converted to osmotic pressure π .

$$\pi = h.d.g \dots\dots\dots(1.8.6.1.1)$$

where g is the gravity, d is the density of solution.

The osmotic pressure of the polymer solution is related to M_n by Vant Hoff's equation.

$$\pi = C R T \dots\dots\dots(1.8.6.1.2)$$

$$\pi = \left(\frac{RT}{M_n} \right) C$$

$$\frac{\pi}{C} = \frac{RT}{M_n} \dots\dots\dots(1.8.6.1.3)$$

A plot of $\frac{\pi}{C}$ Vs C gives straight line.

the intercept of which is RT/M_n , when the curve is extrapolated to zero concentration, M_n can be calculated from the value of the intercept.

The vant hoff's equation does not apply to polymer solution, even though they are very dilute .

The concentration related by osmotic pressure is expressed by complex equation.

$$\pi = RT(A_1 C + A_2 C^2 + A_3 C^3 + \dots)$$

Or

$$\frac{\pi}{C} = RT (A_1 + A_2 C + A_3 C^2 + \dots)$$

Where:

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

C is concentration of polymer in solution.

The first virial co-efficient is related directly to molecular mass by relation $A_1 = \frac{1}{M_n}$ (Tager, 1978). then the equation becomes

$$\frac{\pi}{C} = RT \left(\frac{1}{M_n} + A_2 C + A_3 C^2 + \dots \right)$$

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

Where: $\Gamma = \frac{A_2}{A_1}$ and g is varying function of the polymer solvent interaction (equal zero for poor solvent . 0.25 for good solvent)

C^2 may be neglected then the equation becomes

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

Or

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

When plot $\left(\frac{\pi}{C}\right)^{1/2}$ Vs. C that gives a straight line , the molecular mass can obtain from intercept , and the second virial co efficient from slope

$$\text{Intercept} = \left(\frac{RT}{M_n}\right)^{1/2} \dots\dots\dots(1.8.6.1.4)$$

$$\text{Slope} = \left(\frac{RT}{M_n}\right)^{1/2} A_2 \frac{M_n}{2} \dots\dots\dots(1.8.6.1.5)$$

1.8.6.2- Number average molecular weight :

Physical properties of a substance depends on the intermolecular forces which originate in the internal structure or the constitution of molecules.

Thus their determination can give valuable information about the structure of molecules. Oswald classified the physical properties into four categories; additive properties,

constitutive properties, additive and constitutive properties and colligative properties (Singh *et. al.*, 2007).

1.8.6.3- Colligative properties :

The properties of solutions that depend on the number of molecules present, and not on the kind of molecules. Historically they have been one means for determining the molecular weight. (Moriss and Coll, 1989).

1.8.6.4- Osmotic pressure:

Osmotic pressure appears to be a suitable method for measuring number average molecular weights(M_n) in polymers.

We expect polymer solutions to deviate from ideal behavior and thus osmotic pressure expression will need to be corrected. At infinite dilution, the solution will eventually become ideal.

1.8.6.5- Membrane Osmometry:

It is an absolute technique which determines M_w . The solvent is separated from the polymer solution by a semi-permeable membrane which held between the two chambers. The solvent chamber is filled with solvent and closed to atmosphere except for the solvent passage through the membrane, while the solute chamber is left open to the atmosphere. The solute cannot flow in this case but the solvent can flow through the membrane.

The chemical potential of the solvent is much higher than that of the solution. The solvent flows through the membrane to the polymer solution. The solvent diffuse to the solute side, its pressure decreases until the pressure difference across the membrane counteracts the chemical

potential difference caused by the potential on both sides of the membrane is regarded as the osmotic pressure.

The osmotic pressure is related to the change in chemical potential by the equation:

$$(1.8.6.5.1) \quad (\mu_1 - \mu_{1o}) = -V_1 \pi \dots\dots\dots$$

Where:

μ_{1o} : chemical potential of pure solvent

μ : chemical potential of solvent in solution

V_1 : molar volume of solvent

π : osmotic pressure

1.8.7- Density of solid

the density of specific volume of gum sample can be determine by using solvent which the gum was insoluble in it, pyknometer or density bottle method can be use to determine density of polymer (Tager, 1978).

1.8.8- Gibbs free energy of *Anogeissus leiocarpus*

To calculate the free energy of gum sample ΔG , it is necessary to know chemical potential of polymer, the quantity $\Delta\mu_2$, it is value is calculate by using the Gibbs -Duhaem equation

$$\omega_2 d\Delta\mu_2 = \omega_1 d\Delta\mu_1 \dots\dots\dots(1.8.8.1)$$

where ω_1 and ω_2 weight fraction of two component

Hence:

$$\Delta\mu_2 = - \int \frac{\omega_1}{\omega_2} d(\Delta\mu_1) + C$$

To solve these equation it is necessary to plotting $\frac{\omega_1}{\omega_2}$ versus $\Delta\mu_1$

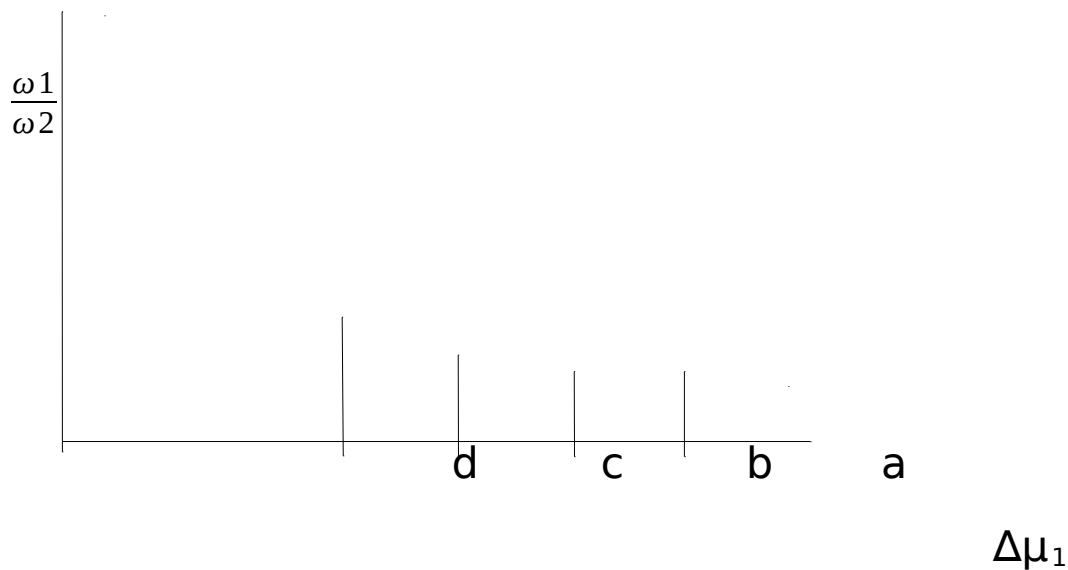


Figure (1.9): Variation of $\frac{\omega_1}{\omega_2}$ with $\Delta\mu_1$

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

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

Hence , the curve goes with both ends into infinity, and the integral may be determined within the limit ranging from $-\infty$ to a certian value of $\Delta\mu_1$.

The finite value $\Delta\mu_1$ which conform to concentration ω_2 less than one is a taken as the lower limit. The calculated areas

under the curve $\Delta\mu_2$ are less than the true value obtained of $\Delta\mu_2$, the graph $\Delta\mu_2$ versus ω_1 we obtain segment A.

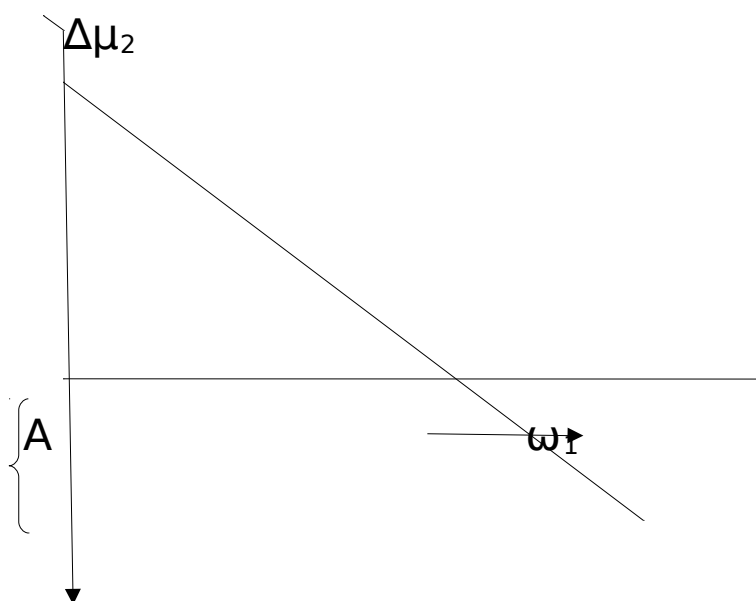


Figure (1.10): Correction of $\Delta\mu_2$

Knowing $\Delta\mu_1$ and $\Delta\mu_2$ the average free energy per gram of solution can be calculated .

$$\Delta G = \omega_1 \Delta\mu_1 + \omega_2 \Delta\mu_2 \dots\dots\dots(1.8.8.1.2)$$

1.10- application of *Anogeissus leiocarpus*

Anogeissus leiocarpus, family *Combretaceae*, (Common name: Axlewood tree) has many applications. Leaves, roots and trunk bark of *A. leiocarpus* are used by traditional

practitioners for the treatment of helminthiasis, trypanosomiasis, malaria and dysenteric syndrome. It is also used in traditional medicine as a remedy for many ailments of livestock and man, which include *schistosomiasis*, leprosy, diarrhoea and psoriasis ([Burkill, 1985](#)). Some members of the *Combretaceae* have high concentrations of flavonoids, terpenoids, tannins or polyphenolic compounds ([Eloff et. al., 2008](#)).

In general, the influence of herbal medicine and natural products upon drug discovery is impressive and a number of clinically active drugs are either natural products or have a natural product pharmacophore ([Koehn and Carter, 2005](#)). The need to study medicinal plants in detail from various points of view, to discover new therapeutically active compounds, or to understand which component of plant is responsible for the activity and validate their toxic effect therefore becomes imperative.

1.11-The Aim of this work

1. To investigate the physicochemical properties of *Anogeissus leiocarpus* gum .
2. To study the thermodynamices behavior of *Anogeissus leiocarpus* gum .

2- Materials and Methods

2.2- purification of gum sample

The gum sample (*Anogeissus leiocarpus*) was cleaned by hand to be sure it was free from sand, dust and bark impurities, then grounded using pestle and mortar, then backed in labeled containers (polyethylene).

The sample becomes ready for use.

2.3- Chemicals

- Distill water
- Sulphuric Acid (conc.)
- Copper sulphate
- Sodium hydroxide (30%)
- Hydrochloric Acid (0.1N)
- Boric Acid (2%)
- Sodium Chloride (1 M)
- Hydrochloric Acid (3N)

2.4- Physiochemical methods of gum

Physiochemical characterization methods was used to determine physical and chemical properties of *Anogeissus leiocarpus* such as moisture content, ash content, Total nitrogen and protein content, specific optical rotation, pH value, refractive index, intrinsic viscosity, cationic composition.

2.4.1- Method of determination of moisture content

2.0 g of the sample were weighed in evaporation dishes and placed in oven at 105°C to constant weight (about four hours) then cooled in a desiccators and weighed. (in duplicate)

The percentage weight loss was calculated according to the following equation :

$$\text{Moisture \%} = \frac{(W_1 - W_2)}{W_1} \times 100 \dots\dots\dots(2.4.1.1)$$

Where:

W_1 = weight of the sample before loss of moisture

W_2 = weight of the sample after loss of moisture

2.4.2- Method of determination of Ash content

2.0 g of the samples were weighed in dry crucible (in duplicate), then heated in a furnace at 550°C, after three hours cooled in desiccators and weighed (crucible was weighed before using) total ash was calculated as follows :

$$\text{Total ash \%} = \frac{(W_3 - W_2)}{W_1} \times 100 \dots\dots\dots(1.4.2.1)$$

Where:

W_3 = weight of the sample and crucible after heating

W_2 = weight of empty crucible , W_1 = weight of the sample before heating

2.4.3- Method of determination of Specific optical rotation

1 g/100cm⁻³ aqueous solution of the gum was prepared, the solution was filtered to be highly pure . optical rotation was measured using a 2 dm tube filled with the test solution, at room temperature specific optical rotation was calculated by following equation :

$$[\alpha] = \frac{\alpha}{l(dm)} \times C \dots\dots\dots(2.4.3.1)$$

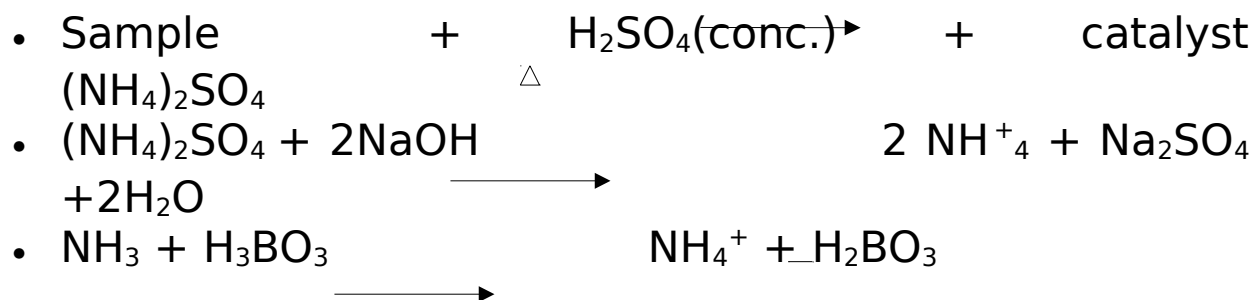
Where : α = observed rotation of the solution in circular degree

C = grams of substance per cm³

l = length of the tube (decimeters)

2.4.4- Determination of total nitrogen and protein content

Kjeldal method was used to determine the total nitrogen in *Anogeissus leiocarpus* sample. These process as kjeldal in which the sample is digested in a hot concentration sulphuric acid with copper sulphate as a catalyst, using sodium hydroxide to neutralized the ammonia which released, boric acid using also to neutralize as following equation :



Then back titration of result solution with hydrochloric acid is carried out as a following equation :



Method :

0.5 g of the sample (in duplicate) was weighed and transferred to kjeldal digestion flask and kjeldal tablet was added (copper sulphate catalyst) to each, then 10 ml concentrated sulphuric acid was added. the solution was heated until a pale green color was observed, which indicates the completion of the digestion.

The tube then transferred to kjeldal distillation apparatus, added 30% (w/v) sodium hydroxide, then started with steam distillation and released ammonia was a in 25 ml of 2 % boric acid.

Back titration with 0.1 N of hydrochloric acid was used, nitrogen content was calculated according to following equation :

$$\text{Nitrogen \%} = \frac{0.014 \times N \times (\text{volume of titrant} - \text{volume of blank}) \times 100}{\text{weight of sample (grams)}}$$

N is the normality of hydrochloric acid

Protein content was calculated using nitrogen conversion factor (NCF) of 6.6 (Anderson,1986) as follows :

$$\text{Protein \%} = N \times 6.6$$

2.4.5- Method of determination of intrinsic viscosity

1M of sodium chloride solution was prepared as a solvent, about 1.0 g of gum sample was dissolved as starting concentration to prepare a different concentration from gum solution, then transferred the gum solution to clean and dry viscometer and then using a syringe to create a vacuum to bring the solution to the top demarcation line .

The time which taken by the gum solution between top and low marked line was detected in (minutes, seconds and milliseconds), the readings of each concentration were taken in triplicate .

In the same way taken the flow time of the pure solvent was calculated.

2.4.6- Method of determination of refractive index

1 g/100ml of gum solution was used to measure the refractive index by instrument [Type: Abbe 60 refractometer] at room temperature 25°C

2.4.7- Determination of cationic composition

Dry ash-ing method was used in sample preparation , 1 g of the gum sample was placed in cold furnace and heated to 550°C , maintain the temperature for four hours , and cool the sample. Then added 10 ml of hydrochloric acid 3N to the sample, watch glass was used to covered the sample and heated gently for 10 min . then cooled and filtered into 100 ml volumetric flask and dilute with a distill water to mark.

Atomic absorption spectrometer [type: Buck Scientific-210 VGP] was used to determine eight element : potassium (K), Calcium (Ca), Magnesium (mg), Copper (Cu), Sodium (Na), Zinc (Zn), Iron (Fe) and Lead (pb)

2.5- Thermodynamic methods

2.5.1- Method of determination of molecular weight of the gum using Osmotic pressure

Different concentration of gum solution were prepared by dissolving in distill water to the mark of the flask. Each of them was filtered through filter paper. Osmotic pressure were measured using Osmomat^R 050 (collide- osmometer) at 25 °C.

2.5.2- Determination of Partial specific volume of water

Tangent method was used to determine partial specific volume of the solvent, by dissolved a constant weight of gum sample in a different weight of water, then the density was calculate by using density bottle , and determine the total volume of solution . plotted the total volume against the weight of water then calculated the partial specific volume of water (dv/dg) from slope.

2.5.3- Determination of Partial specific volume of sample

Tangent method was used to determine partial specific volume of gum sample, by dissolved a different weight of gum sample in a constant weight of water, then the density was calculate by using density bottle, and determine the total volume of solution . plotted the total volume against the weight of sample then calculated the partial specific volume of sample (dv/dg) from slope.

2.5.4- Determination of Density of solid

0.5 g of gum sample was weighed in a density bottle with acetone. The density of acetone was determined before, and the volume occupied by sample was calculated. From volume and weight of gum was measuring the density.

3- Results and Discussions

3.1- Physiochemical properties of *Anogeissus leiocarpus*

Table (3.1) shows physiochemical properties of *Anogeissus leiocarpus* gum which reported by (Karamalla, 2009) and this study. The results expressed as the mean value of this properties: solubility, moisture content, Ash content, protein percentage, nitrogen percentage, refractive index, pH value, optical rotation, intrinsic viscosity and molecular weight.

The solubility of *Anogeissus leiocarpus* in this study is similar to that obtained by (Karamalla, 2009) for samples which collected from the three location.

The moisture content of these sample is highest value, but it is nearly to the moisture content for sample collected from Abojebiha then El-Rosares.

Ash content of this sample is so nearly from the value of sample collected from Elfula by (Karamalla, 2009), and is significantly higher than the mean values reported from three location.

The nitrogen and protein percentage of these sample is so close to the value of Abojebiha sample.

The pH value of these sample is significantly higher than the mean value reported for three locations.

Refractive index is similar to the mean value of three type of gum.

Anogeissus leiocarpus gum is optically active, it has a negative value (laevorotatory). This result is so close to Elfula and Elrosares samples.

Table (3.1): physiochemical properties of *Anogeissus leiocarpus* gum samples

Property	Karamalla(2009) Abojebiha	Karamalla(2009) Elfula	Karamalla (2009) El-Rosaries	This study
Solubility	65.5	65.5	65.5	65.5
Moisture%	10.1	9.8	9.9	10.72 %
Ash%	4.5	2.3	3.6	2.6 %
Nitrogen%	0.69	0.84	0.61	0.679
Protein%	4.5	5.5	4.0	4.48
pH value	4.0	4.1	4.5	4.99
Refractive index	1.334	1.334	1.334	1.333
Specific rotation	-38.3 ^o	-45.1 ^o	-41.3 ^o	- 43.75 ^o

Figure (1.3) illustrated intrinsic viscosity which obtained from intercept of the plotting reduced viscosity with concentration, it was found to be 0.43 ml g^{-1}

Table (3.2): The reduced viscosity value of the composite sample

Conc. g/100ml	Reduced viscosity ml g^{-1}
0.05	0.540
0.10	0.660
0.15	0.760
0.20	0.875
0.25	0.988
1.0	0.595

Figure (3.1): show variation of reduced viscosity with concentration

Figure (3.1): variation of reduced viscosity with concentration

Cationic composition of the sample was determined (using atomic absorption spectrophotometer) and the average values were shown in table (3.3).

Table (3.3): shows average values of element composition of the sample

The elements	<i>Anogeissus leiocarpus</i>	
	w/w%	µg/g
Sodium	50.50	0.005050
Potassium	494.4	0.04944
Calcium	356.7	0.03567
Magnesium	285.7	0.02857
Copper	95.5	0.00955
Iron	0.00049	4.9
Zinc	0.00085	8.5
Lead	0.00003	0.3

3.2- Thermodynamic properties of *Anogeissus leiocarpus*

Osmotic pressure of aqueous solution was found as following table .

Table (3.4): Osmotic pressure of different concentration of gum solution

Conc. cm ⁻³	g	π mmHg	$\sqrt{\pi/C}$
0.05		6.3	11.2249
0.06		10.7	13.354
0.07		15.6	14.928
0.08		21.5	16.3935
0.09		28.5	17.7951
0.10		35.6	18.8679
0.11		45.9	20.427
0.12		56.0	21.6

Figure (3.2):variation of osmotic pressure with concentration of *Anogeissus leiocarpus* gum solution

The molecular weight of *Anogeissus leiocarpus* gum sample was found to be 6.81919×10^5 , while the first and second virial coefficient were calculated from equation(1.8.6.1.4) and (1.8.6.1.5), it found to be 0.14664×10^{-5} , 7.65372×10^{-5} respectively.

The density of solid was determined by density bottle when added 1g to 50 ml of acetone is equal 0.881 gcm^{-3} .

Tangent method was used to calculate the partial specific volume of the solute and solvent from the slope in figure

(3.5, 3.6) and the values were found to be $1.001\text{cm}^3\text{g}^{-1}$ and $0.699\text{cm}^3\text{g}^{-1}$ for water and gum respectively.

Figure (3.3) shows the partial specific volume of water $\delta v/\delta g$ which obtain from slope of the curve, the curve was plotted as the values in table (3.5). Figure (3.4) shows the partial specific volume of sample $\delta v/\delta g$ which obtain from slope of the curve, the curve was plotting as the values in table (3.6) .

Table (3.5): partial specific volume of water as a solvent in gum solution

Concentration of gum w/w%	Weight of gum W_2 (g)	Weight of water W_1 (g)	Volume of solution V (cm^3)
1 %	1.0	90.2823	91.1001
1.1 %	1.0	82.5789	83.2459

1.5 %	1.0	61.6527	62.3409
2.1 %	1.0	44.7460	45.1589
2.6 %	1.0	36.9306	37.4808
3.7 %	1.0	25.4281	26.4016

Figure (3.3):partial specific volume of water in *Anogeissus leiocarpus* solution

Table(3.6): partial specific volume of the sample in gum solution

Concentration of gum w/w%	Weight of gum W_2 (g)	Weight of water W_1 (g)	Volume of solution V (cm ³)
1.4 %	0.4244	30.00	30.30318
2.4 %	0.7346	30.00	30.52095
3.9 %	1.2368	30.00	30.9275
5.5 %	1.7565	30.00	31.2871
6.5 %	2.1028	30.00	31.6283
8.8 %	2.8536	30.00	32.08359

Figure (3.4): partial specific volume of *Anogeissus leiocarpus* gum solution

Using equation(1.8.1.1) and (1.8.1.2) volume fraction of water Φ_1 and gum sample Φ_2 were calculated

Table (3.7): shows the values of volume fraction of water Φ_1 and gum Φ_2 in gum solution

Water volume fraction	Gum volume fraction
0.59	0.41

Chemical potential of a water as a solvent in *Anogeissus leiocarpus* gum solution was obtained using equation (1.8.5.3) in table (3.8)

Table(3.8): Chemical potential values of water in different concentration of gum solution at a different units

Conc. g cm^{-3}	$\Delta\mu_1$ (erg g^{-1})	$\Delta\mu_1$ (Joule g^{-1})
0.05	- 8407.7	- 0.8408×10^{-3}
0.06	-14279.7	- 1.4279×10^{-3}
0.07	-20819.0	- 2.0819×10^{-3}
0.08	-28692.9	- 2.8692×10^{-3}
0.09	-38034.8	- 3.8034×10^{-3}
0.10	-47510.2	- 4.7510×10^{-3}
0.11	-61256.1	- 6.1256×10^{-3}
0.12	-74735.1	- 7.4735×10^{-3}

Table (3.9) show that the osmotic pressure and chemical potential of water as a solvent in a different concentration gum solution and weight fraction

Conc . g cm^{-3}	$\bar{V}$ cm^3g^{-1}	π $mmHg$ g	$\Delta\mu_1$ $Joule\ g^{-1}$	ω_1	ω_2	ω_1/ω_2
0.05	1.00 1	6.3	- 0.8408 $\times 10^{-3}$	0.952	0.048	19.8
0.06	1.00 1	10.7	-1.4279 $\times 10^{-3}$	0.943	0.057	16.5
0.07	1.00 1	15.6	- 2.0819 $\times 10^{-3}$	0.934	0.065	14.4
0.08	1.00 1	21.5	- 2.8692 $\times 10^{-3}$	0.925	0.074	12.5
0.09	1.00 1	28.5	- 3.8034 $\times 10^{-3}$	0.917	0.083	11.0
0.10	1.00 1	35.6	-4.7510 $\times 10^{-3}$	0.909	0.09	10.1
0.11	1.00 1	45.9	- 6.1256 $\times 10^{-3}$	0.9	0.099	9
0.12	1.00 1	56.0	- 7.4735 $\times 10^{-3}$	0.892	0.1	8.9

*where ω_1 and ω_2 are weight fraction of water and gum respectively.

Figure(3.5): show the chemical potential of gum solution before correction using result in table (3.10) .

The free energy of gum solution was calculated using $\Delta\mu_1$ and $\Delta\mu_2$.

Table (3.10): data for plotting $\Delta\mu_1$ versus ω_1/ω_2 of *Anogeissus leiocarpus* gum solution

Conc. $g\ cm^{-3}$	ω_1/ω_2	$\Delta\mu_1$ $erg\ g^{-1}$
0.05	19.8	- 8407.7
0.06	16.5	-14279.7
0.07	14.4	-20819.0
0.08	12.5	-28692.9
0.09	11.0	-38034.8
0.10	10.1	-47510.2
0.11	9	-61256.1
0.12	8.9	-74735.1

Figure (3.5) Chemical potential of *Anogeissus leiocarpus* gum ($\Delta\mu_2$)

The area under the curve , that are bounded by ordination corresponding to $\Delta\mu_2$ which less than the true areas values obtained for $\Delta\mu_2$ to correct this areas a graph of dependence $\Delta\mu_2$ versus ω_1 was plotted to obtain segment A as figure (3.6) .

Table (3.11): Data of plotting $\Delta\mu_2$ versus ω_1

$\Delta\mu_2$	ω_1
175000	0.892
350000	0.9
531000	0.909
714500	0.917
913000	0.925
1121000	0.934
1341500	0.943
1576000	0.952

Figure (3.6): Correct the chemical potential of *Anogeissus leiocarpus* using A segment value:

Figure (3.6): correct the chemical potential of gum using A segment

Table (3.12) Chemical potential of gum sample ($\Delta\mu_2$) after correction

$\Delta\mu_2$ erg g ⁻¹	A	$\Delta\mu_2$ erg g ⁻¹
175000	- 320000	- 495000
350000	- 320000	- 670000
531000	- 320000	- 851000
714500	- 320000	- 1034500
913000	- 320000	- 1233000
1121000	- 320000	- 4321000
1341500	- 320000	- 1661500
1576000	- 320000	- 1896000

The changes in Free energy of mixing of *Anogeissus leiocarpus* for different concentration were calculated using equation (1.8.8.1.2), as showed in table (3.13).

Table (3.13): calculating the free energy of gum solution

$\Delta\mu_1$ <i>erg g⁻¹</i>	ω_1	$\Delta\mu_1 \times \omega_1$	ω_2	$\Delta\mu_2$ <i>erg g⁻¹</i>	$\Delta\mu_2 \times \omega_2$	ΔG^m <i>erg g⁻¹</i> ($\Delta\mu_1 \times \omega_1 + \Delta\mu_2 \times \omega_2$)
-8407.7	0.892	-78859.7	0.048	-495000	-23760	-102619
-14279.7	0.9	-12851.7	0.057	-670000	-38.190	-12889
-20819.0	0.909	-18924.5	0.065	-851000	-55315	-74240
-28692.9	0.917	-26311.4	0.074	-1034500	-76553	-102864
-38034.8	0.925	-35182.2	0.083	-1233000	-102339	-137521
-47510.2	0.934	-44374.5	0.09	-4321000	-388890	-433265
-61256.1	0.943	-57764.5	0.099	-1661500	-164488.5	-222253
-74735.1	0.952	-71147.8	0.1	-1896000	-189600	-260748

Table (3.14): the free energy of *Anogeissus leiocarpus* gum solution in different units

Conc. <i>g cm⁻³</i>	ΔG^m <i>erg g⁻¹</i>	ΔG^m <i>J g⁻¹</i>
0.05	-102619	-1.02619×10^{-2}
0.06	-12889	-0.12889×10^{-2}
0.07	-74240	-0.74240×10^{-2}
0.08	-102864	-1.02864×10^{-2}
0.09	-137521	-1.37521×10^{-2}
0.1	-433265	-4.33265×10^{-2}

0.11	-222253	-2.22253×10^{-2}
0.12	-260748	-2.60748×10^{-2}

Conclusion

Physiochemical characterization show that the composite sample is *Anogeissus leiocarpus* gum.

The gum sample under studies have positive value of second virial coefficient, negative changes in chemical potential and negative changes in free energy of mixing of the gum solution, this indicates that water is a good solvent for these gum.

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