Chapter One

Introduction

1.1. Definition of gums

Gums are polysaccharides either hydrophobic or hydrophilic ,high molecular weight molecules, usually with colloidal properties, which in an appropriate solvent or swelling agent produce gel, highly viscous suspension, or solutions at low dry substance content (Anderson, Dea, and Hirst, 1968; Anderson, Dea, Karamalla, and Smith, 1968), thus, the term gum is applied to a wide variety of substances of "gummy" characteristics and cannot be, precisely, defined. Hydrophobic substances, often, called gums are high molecular weight hydrocarbons and other petroleum products, rubbers, certain synthetic polymers, chicly for chewing gum, and the resinous saps which often exude from evergreens which are sometimes, commercially, tapped yielding, gum balsam and gum resin.

Most commonly, however, the term gum as technically employed in industry refers to plant polysaccharides or their derivatives which are dispersible in either cold or hot water to produce viscous mixture or solutions. Thus, modern usage includes the water – soluble or water-swellable derivatives of cellulose and the derivatives and modifications of other polysaccharides which in the natural form are insoluble. Usage would classify as gums all polysaccharides or their derivatives which when dispersed in water at low dry substance content, swell to produce gels, highly

viscous dispersions, or solutions (Coppen, 1995). This definition does not require that gums have the property of tackiness, and consequently, such a definition includes as gums those polysaccharides and derivatives which are slimy or mucilaginous. Some authors have tried to classify, separately, these slimy substances from plants into a category called mucilage. Yet, it is more logical to consider tackiness and sliminess as the exhibition of two different physical properties of gums. Hence, there are tacky gums and slimy or mucilaginous gums. Tackiness and sliminess are manifestations of two, somewhat, controllable physical properties. It is possible to modify a gum so that tacky properties are withdrawn and mucilaginous properties introduced. Yet the gum remains hydrophilic and capable of giving high viscosity to its dispersions even at low concentrations consequently, the mucilaginous property is distinctive but a category of mucilage's has no chemical significance (Glicksman, 1962).

1.2. Colloidal systems

The word colloid is of Greek origin; the Greek word kola, meaning “glue”. Thomas Graham is usually regarded as the founder of colloids science (Sharma, 2009). A colloid is a solution in which a substance is dispersed evenly throughout a solvent. Because of this dispersal, some colloids have the appearance of solutions. Colloid is defined as a hydrocolloid system wherein the colloid particles are dispersed in water. Colloids are intermediate between true solutions on one hand

and suspensions on the other. It is, obviously impossible to draw a boundary between true solutions and colloidal solutions. Colloidal behavior can be connected with greatly increased area compared with the volume as the size is reduced. The essential properties of colloidal dispersions can be ascribed to the fact that the ratio of the surface area to the volume of particles is very large. In a true solution, the system consists of one phase only and there is no true surface of separation between the molecular particles of solute and solvent. The sizes of particles in colloidal state range from 1nm to 1 m (Levine, 2001). Ostwald regarded colloidal system as heterogeneous in character consisting of two phases: (1) Disperse phase and (2) Dispersion medium. Dispersed phase refers to the phase forming the particles. Dispersion medium is the medium in which dispersion of the particles takes place. Colloidal dispersions are, thermodynamically, unstable and tend to coagulate and precipitate on standing unless precautions are taken. Since both the disperse phase and dispersion medium may be solid, liquid or gaseous there can be several different types of colloidal system (Sharma, 2009). Colloidal solutions are known as sols. If the dispersion medium is water, they are called “hydrosols” or sometimes “aqua sols”. And if it is liquid, the colloidal solution is known as emulsion. Table 1.1 shows the classification of colloids (Sharma, 2009; Shaw, 1992).

Table1.1Classification of colloids

Dispersed phase	Dispersion medium	Name	Example
liquid	Gas	Liquid aerosol	Fog, liquid spray
Solid	Gas	Solid aerosol	Smoke, dust
Gas	liquid	Foam	Foam from soap
liquid	liquid	Emulsion	Milk, crude oil
Solid	liquid	Sol	AgI sol, pastes
Gas	Solid	Solid foam	Expanded polystyrene
liquid	Solid	Gel	Opal, pearl
Solid	Solid	Solid suspension	Pigmented plastics

Dispersion of solids in liquids can be roughly divided into two categories lyophilic and lyophobic sols. Lyophobic (solvent hating) sols have little attraction between the disperse phase and dispersion medium. These are relatively less stable as compared with lyophilic sols. On heating or cooling the lyophobic systems, solids are obtained which cannot be reconverted into sols either by adding solvent or by warming. Lyophilic (solvent loving) sols on the other hand are system in which the disperse phase shows some definite affinity for the medium. Lyophilic sols are generally reversible and behave like true solutions to some extent e.g. gums, starches and proteins. These substances are absorbed by the disperse phase and are stabilized by strong salvations. Hydrocolloids are more commonly called gums (Sharma, 2009).

1.3. Hydrocolloids

Hydrocolloids or gums are a diverse group of long chain polymers characterized by their property of forming viscous dispersions and/or gels when dispersed in water. These materials were first found in exudates from trees or shrubs, extracts from plants or seaweeds, flours from seeds or grains, gummy slimes from fermentation processes, and many other natural products. Occurrence of a large number of hydroxyl groups, noticeably, increases their affinity for binding water molecules rendering them into hydrophilic compounds. Further, they produce dispersions, which are intermediate between a true solution and a suspension, and exhibit the properties of a colloid. Considering these two properties, they are, appropriately, termed as 'hydrophilic colloids' or 'hydrocolloids' (Milani and Maleki, 2012). Food hydrocolloids are high molecular weight hydrophilic biopolymers used as functional ingredients in the food industry for the control of microstructure, texture, flavor and shelf-life. The term "hydrocolloid" embraces all polysaccharides that are exuded or extracted from plants, seaweeds and microbial sources, as well as gum derived from plant exudates, and modified biopolymers made by the chemical or enzymatic treatment of starch or cellulose. In addition, due to its polydispersity and highly hydrophilic character, the unique protein gelatin has become accepted as an exceptional member of this polysaccharide club. But other food proteins, like casein and gluten, are, traditionally, not classified as

hydrocolloids- even though they, certainly, do exhibit functional properties that overlap, considerably, with those of food polysaccharides (Dickinson, 2003; Mirhosseini, Tan, and Naghshineh, 2010).

1.4. Bioemulsifiers

Bioemulsifiers have been recently attracting the industrial community as natural and promising candidates for the replacement of synthetic commercial surfactants due to their intrinsic properties such as lower toxicity, higher biodegradability, higher foaming capacity and higher activity at extreme temperatures, pH levels and salinity. These compounds are biological molecules with surfactant properties similar to the well-known synthetic surfactants and include microbial compounds, natural polymers, such as Gum Arabic (GA) which has been extensively exploited and used in the food industry as a surfactant agent, and other amphiphilic polymer surfactants, usually, based on polysaccharides. Gum Arabic is among the most studied and widely used hydrocolloid due to its excellent emulsifying capacity, ample spectrum of applications and millenary use (Trindade et al., 2008).

1.5. Classification of gums

It has been customary, in the past, to classify most of the gums as polysaccharides and to group them according to plant origin. Thus, the seaweed group comprised the extracts known as agar, alginates, and carrageenan; tree exudates such as gum Arabic, gum karaya, gum tragacanth, and gum chatty; and the seed gums included

locust bean and guar gum. Other gum like materials such as pectin and starch were treated as separate groups, while gelatin, being a protein was not included at all. In addition, there was no room for the synthetic gums such as the cellulose derivatives which are carbohydrate gum, or for the synthetic vinyl polymers such as polyvinylpyroldinone (PVP) which require a completely new category. The use of botanical origin as a basis for the classification of important plant gums is valid and useful, since gums of similar origin and functionality frequently have similar properties and chemical structures, and can, occasionally, be employed for the same purpose. Thus, locust bean gum and guar gum, which are both derived from similar plant- seed sources, have the similar chemical structure of neutral Galacto-mannans, and differ only in the ratio of Galactose to mannose molecules. Their thickening properties are sufficiently similar and of the same magnitude to allow the interchange of the gums in certain specific applications, but not, indiscriminately, and not in all applications (Whistler and Miller, 1959). For a general classification to be useful, it should embrace all types of gums that are used in the food industry, and it should leave room for the new gums that are certain to be developed in the future. Following this line of thought it has been proposed that the following all-inclusive classification composed of three main categories. (1) natural gums – those found in nature; (2) modified natural , or semi synthetic, gums – those based on chemical modifications of natural gums or gum like

materials ; (3) synthetic gums – those prepared by total chemical synthesis. Specific gums comprising these categories are shown in Table 1.2. As a further aid to identification each category is broken down into subgroups based, where possible, on the common origins, functions, or properties of the particular gums.

1.6. Gum Arabic

Gum Arabic is defined as the dried exudation obtained from the stems and branches of natural strains of *Acacia senegal* (L), family Leguminosae (FAO, 1990). It consists mainly of high molecular mass polysaccharides and their calcium, magnesium and potassium salts, which on hydrolysis yields arabinose, galactose, rhamnose and glucuronic acid. Gum arabic, is the oldest and best known of all plants gum exudates and has been used as an article of commerce for over 5000 years (Glicksman and Sand, 1973). Gum arabic has a wide range of uses in foods and pharmaceutical industries, where it's stabilizing, thickening and gel forming properties are the main physical requirements. Gum arabic is also used in the mining industry and in the manufacture of textiles, ink and paper. It is also used in bakery, meat products, beverages, confectionery adhesives, cosmetics, printing, fertilizers and binder to explosives (Glicksman and Sand, 1973).Sudan is the world's largest producer of gum Arabic, with production reaching 40,000 tons in 2000. Chad is the second largest producer, followed by Nigeria, Mali and Senegal. In Sudan more than thirty distinct *Acacia* species are found (El Amin, 1990), but

the great majority of commercial gum comes from *Acacia senegal* var. *senegal*. Sudan is the world's largest producer of gum arabic with various grades gum, including handpicked selected, cleaned and sifted, cleaned, siftings, dust and red. Following export to Europe and the US, some grades of gum are processed providing greater quality and convenience to the users (Islam, Phillips, Sljivo, Snowden, and Williams, 1997). This may be by mechanical grinding (kibbling) which breaks up the gum nodules into various sizes for faster dissolution. Further processing may involve dissolution and filtration of the gum to remove impurities, followed by spray drying or roller drying (Phillips and Williams, 2009) . Gum arabic is a naturally occurring exudate collected from *Acacia senegal* trees and, to a lesser extent, from *Acacia seyal* trees (Islam et al., 1997). It is one of the oldest and most important industrial gums. The Ancient Egyptians used gum arabic as an adhesive when wrapping mummies and in mineral paints when making hieroglyphs (Verbeken, Dierckx, and Dewettinck, 2003). In modern times, the most important applications of gum arabic have been not as an adhesive but as an emulsifier in the food and pharmaceutical industries. Gum arabic is considered to be the best gum in use in dilute oil-in-water emulsion systems (Garti, 1999), one important example of which is the use of citrus oils as flavoring agents in soft drinks where the oils are converted into a water-dispersible emulsion (Verbeken et al., 2003).

Table 1.2 Classification of gums (Ahmed, 2012)

Natural gums	Modified (semi-synthetic) gums	Synthetic gums
Plant exudates	**Cellulose derivatives**	**Vinyl polymers**
Arabic		
Tragacanth	Carboxymethyl cellulose	Poly vinyl pyrrolidone
Karaya		
Gatti	Methylcellulose	(PVP)
Plant extracts		
Pectins	Hydroxypropylmethyl- Cellulose	Polyvinyl alcohol (PVA)
Arabinogalactan		
(larch gum)	Methylethylcelulose	**Carboxyvinyl polymer**
Plant seed flours		
Locust Bean	Methylethylcelulose	(carbopol)
Quar		
Psyllium seed	Hydroxypropylcellulose (klucel)	**Ethyleneoxide polymers**
Quince seed		
Seaweed extracts	Low methoxy pectin	Polyox
Agar		
Alginates	**Microbial fermentation gums**	
Carrageenan		
Furcellaran	Dextran	
Cereal starches		
Seed starches	Xanthan gum	
Corn		
Wheat	Pregelatinized starches	
Rice		
Waxy maize	**Modified starches**	
Sorghum		
Waxy sorghum	Carboxymethyl starch	
Tuber starches		
Potato	Hydroxethyl starch	
Arrowroot		
Tapioca	Hydroxypropyl starch	
Animal		
Gelatin		
Albumen		
Casein		
Vegetable		
Soy protein		

1.7. *Acacia* species

Over 1350 species of *Acacia* exist around the world. About 185 are endemic to the Americas, 95 to Asia and the Pacific, nearly 1000 are native to Australia, and 150 are African native (Kull and Rangan, 2008). The genus *Acacia* is the second largest within the Leguminosae family and contains at least 900 species. With their extensive root system, *Acacia* trees can be found in semi-arid areas in Australia, India, and America, but mainly in the Sahelian region of Africa. They are multipurpose trees, not only producing gum, but also preventing desert encroachment, restoring soil fertility, and providing fuel and fodder. Almost all commercial gum comes from the so-called gum belt of Africa, a vast area which extends over Mauritania, Senegal, Mali, Burkina Faso, Benin, Niger, Nigeria, Chad, Sudan, Eritrea, Ethiopia, Somalia, Uganda, and Kenya (Coppen, 1995). Sudan is the world's largest producer of gum arabic, followed by Nigeria, Chad, Mali, and Senegal. Gum from the Sudanese Kordofan region is known as the best quality gum and is used as the standard to judge gums obtained from other areas. Commercial gum arabic is collected from a number of *Acacia* species, of which *Acacia senegal, Acacia seyal*, and *Acacia polyacantha* are the most widespread in the gum belt. *Acacia laeta*, *Acacia karoo*, and *Acacia gourmaensis* are some other gum yielding species with a more limited distribution (Islam et al., 1997). In Sudan, the gums from *Acacia senegal* var. *senegal* and *Acacia seyal* var. *seyal* are

referred to as hashab and talha respectively, the former considered of higher quality (Baldwin, Quah, and Menzies, 1999). Most of these species grow scattered in the wild and gum from these untended trees is collected by semi-nomadic people. Cultivation is only practiced for *Acacia senegal* var. *senegal*. Particularly in Sudan, wild stands of *Acacia* trees are replaced by monocultures of *Acacia senegal* var. *senegal* in order to facilitate collection and obtain a more consistent quality(Verbeken et al., 2003). Gum arabic from other African countries may be variable in quality, because it may contain gums obtained from different species which occur jointly in the collection area. *Acacia senegal* var. *senegal* is a thorny tree that reaches a height of 4.5–6.0 m. It is very drought-resistant and grows on sites with annual rainfall of 100–950 mm and dry periods of 5–11 months. It also tolerates high daily temperatures of up to 45C or more, dry winds, and sandstorms. After 5 years, trees reach maturity and are tapped. Although gum can be tapped from the trees after 3 years, the quality and yield are consistent only after 5 years, suggesting that gum biosynthesis and tree growth are in competition with each other (Joseleau and Ullmann, 1990).

1.8.*Acacia senegal* var. *senegal*

Acacia senegal var. *senegal* is a shrub or small tree 2 – 12 m tall, with a yellowish or grayish white, rather rough bark. The species has a wide distribution in Sudan

gum belt (Awouda, 1974) in sandy soils under annual rainfall of 280 – 450 mm and on dark clays under rainfall > 500 mm (Badi, Ahmed, and Bayoumi, 1989).

The trunk may vary in diameter up to about 30cm. The bark is grayish-white; although in old trees growing in the open it may be dark, scaly and thin, showing the bright green cambium layer just below the surface if scratched with a nail. The slash is mottled red. Powerful hooked thorns, 3-5 m long, with enlarged base appear at the nodes of the branches, usually in3s. They are sharp, with some pointing forwards and others backwards. Leaves bipinnate, 3-8 pinnae (glands between uppermost and lowermost pinnae); rachis up to 2.5 cm long; pinnacles are pairs of 8-15, green; 2 stipular spines strongly re-curved with a 3rd pseudo-stipular between them. Flowers yellowish-white and fragrant, in cylindrical, axillary pedunculate spikes, 5-10 cm long; calyx of each flower has 5 deep lobes, 5 petals and a mass of short stamens; pistil inconspicuous. The pods are straight, thin, flat, shortly stipulates and oblong (7.5 x2 cm), green and pubescent when young, maturing to shiny bronze, often with dark patches and bearing prominent veins; seeds 3-6, smooth, flat, rather small, shiny, dark brown. Varietal differences in *Acacia senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as the presence of or absence of hair on the axis of the flower spike, color of the axis, shape of pod tips, number of pinnae pairs, occurrence of a distinct trunk and shape of the crown. Four different varieties

of *Acacia senegal* are recognized: var. *senegal,* var. *kerensis Schweinf.,* var. *rostrata Brenan and* var. *leiorhachis Brenan*. The generic name '*Acacia*' comes from the Greek word 'akis', meaning a point or a barb.

Drought-tolerant, *Acacia senegal* var. *senegal* is the characteristic species in the drier parts of Sudan and the northern Sahara and is to be found throughout the vast area from Senegal to the Red Sea and to eastern India. It extends southwards to northern Nigeria, Uganda, Kenya, Tanzania and southern Africa. In India it is found chiefly in Sind and Ajmer. In Sudan, the tree exists both in the wild and is cultivated -mainly on sandy hills, but is also grows well in cotton soil.

Figure (1.1): ***Acacia senegal*** **var.** ***senegal*** **Tree.**

1.8.1. Botanical classification

Kingdom: Plantae

Division: *Magnoliophyta*

Class: *Magnoliopsida*

Order: *Fabales*

Family: *Fabaceae (Leguminosae)*

Subfamily: *Mimosoideae*

Tribe: *Acacieae*

Genus: *Acacia*

Species: *senegal*

English name: Gum Arabic tree, three thorned *Acacia.*

Arabic name: Hashab (El Amin, 1977; Vogt, 1995).

1.9.*Acacia mellifera*

Acacia mellifera is a low, branched tree with a more or less spherical crown. Black bark on stem becomes ash-grey to light brown on the branches, bearing small, short, sharply hooked spines in pairs. It has shallow but extensive rot system radiating from the crown, allowing the plant to exploit soil moisture and nutrients from a large volume of soil. The roots rarely penetrate more than 1m. Leaves characterized by2 pairs of pinnulae, each with a single pair of leaflets. Leaflets are elliptic 0.6-2 cm long and 0.6-1.2 cm wide, glabrous and highly coloured beneath. Flowers are sweetly scented, especially at night, in elongated spikes, cream to white in spiciform racemes, up to3.5 cm long; pedicels 0.5-1.5 m long; calyx up to 1m long; corolla 2.5-3.5 m long. The papery pods with 2-3seds are reticulate, flat, elongated, 2.5-.5 cm long, 6cm wide, hemmed, sometimes more or less narrowed between the seeds. The specific name *mellifera* means ‘honey-bearing’.

Acacia mellifera is a commonly occurring shrub on rangelands throughout the savannah in western, eastern and southern Africa. The train preference is rocky hillsides with rainfall along seasonal watercourse, mixed with other trees. If left unattended, especially if grazing is heavy and no fires check its spread, it may form dense, impenetrable thickets, 2-3 m high and sometimes hundreds of meters across, slowly taking over good grazing land. This species is drought-tolerant.

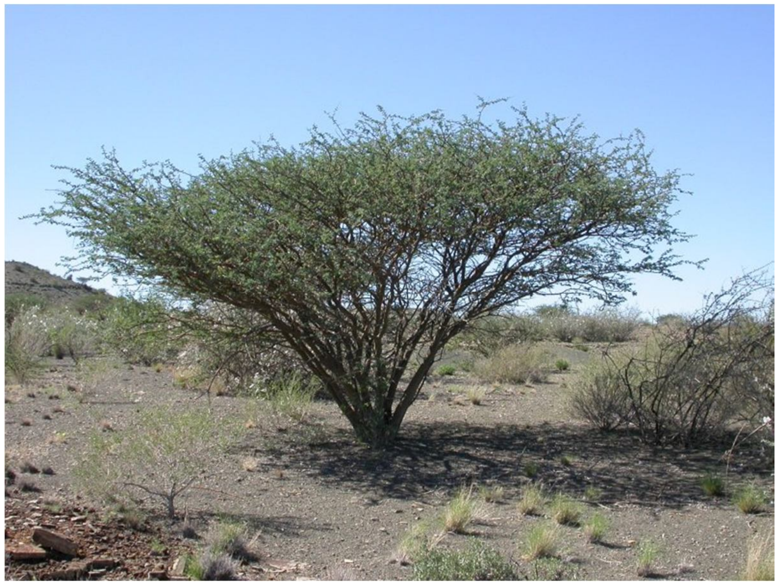

Figure (1.2): ***Acacia mellifera*** **Tree.**

1.9.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *mellifera*

English name: Black thorn

Arabic name: Kitir (El Amin, 1977; Vogt, 1995).

1.10. *Acacia seyal* var. *seyal*

Small, slender tree, reaching 6-15 m in height, with a stem diameter up to 60 cm, develops a characteristic umbrella-shaped canopy in adult individuals, usually thin and rather scarce foliage. Bark is usually smooth, pale green to greenish yellow when young or orange on exposure after the old bark has sloughed off. Bark smooth, peeling, rust-red or pale-green (both types may coexist in any population), covered with a pruinous, rusty, powdery coating. Bright red mottled slash, exuding a yellowish gum. Twigs with many small reddish glands and paired axillary thorns, are up to 7 cm long, narrow and straight, vulnerant-sharp-ended and grey in color. Leaves are dark green, with 4-12 pairs of pinnae having each 10-22 pairs of leaflets. Rachis is up to 8 cm long clustered by 2 or 3. Flowers clustered by 2-3 with bright yellow globose heads ca 1.5 cm in diameter on peduncles about 3 cm long starting from the leaves axils. Pods hanging, slightly curved, dehiscent, light brown when mature, 10-15 cm long by 1 cm wide at the bottom, containing 6-10 seeds each. *Acacia seyal* var. *seyal* grows on fine-textured soils.

Acacia seyal var. *seyal* occurs from Senegal to the Red Sea and in Arabia. It is common in many other parts of Africa, especially north of the equator, from 10 to 12 degrees. It also occurs in east and southern Africa. In the southern and western Sudan, it is one of the most common trees in the savannah and often occurs as a pure forest over quite large areas of the country side. Frequently, it grows in

groups or patches, sometimes of considerable size, in areas inhabited by *Acacia senegal*. This species is characteristic of the Nile region. It is tolerant to high pH (6-8), salts and periodic flooding.

Figure (1.3): ***Acacia seyal*** **var.** ***seyal*** **Tree.**

1.10.1. Botanical classification

Family: *Leguminosae*

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *seyal*

English name: Thirsty thorn

Arabic name: Talha (El Amin, 1977; Vogt, 1995).

1.11. *Acacia tortilis* var. *raddiana*

Acacia tortilis var. *raddiana* is a small to medium-sized evergreen tree or shrub that grows up to 21 m tall; well-developed multiple boles support a flat-topped or rounded, spreading crown; bark grey to black or dark brown, rough, fissured or smooth; young branch lets densely pubescent or glabrous to sub glabrous and red to brown; spines paired, 2 types-long, straight and white, or short, brownish and hooked; they range from 1.2 to 8 cm in length. Leaves glabrous to densely pubescent, glandular, short at 1.25-3.75 cm long; petiole 0.2-0.9 cm long, with a gland; rachis 0.3-2 cm long, glabrous to densely pubescent, with a small gland at the junction of the apical pair of pinnae; pinnae 2-10 pairs; leaflets 4-22 pairs per pinnae, 0.5-4 (6 max.)x 0.2-1 mm, glabrous to densely pubescent on the underside; margins with or without cilia, linear to linear oblong. Inflorescence globose heads; peduncle white, pubescent, 0.4-2.5 cm long, with involucel on the lower half; flowers white or pale yellowish-white, sessile or shortly pedicellate, scented, 0.5-1.1 cm in diameter, on axillary peduncles; calyx 1-2 mm long; corolla 1.5-2.5 mm long. Pods variable, indehiscent, spirally twisted or rarely almost straight, 7-10 cm long, 6-10(max. 13)mm broad, longitudinally veined, leathery, glabrous to tomentellous or villous, somewhat constricted between the seeds; seeds oblique or parallel to long axis of pod, 4-7 x 3-6 mm, compressed; areole 3-6 x 2-4 mm. The name *tortilis* means twisted and refers to the pod structure.

Acacia tortilis var. *raddiana* is drought resistant, can tolerate strong salinity and seasonal water logging and generally forms open, dry forests in pure stands or mixed with other species. The long taproot and numerous lateral roots enable it to utilize the limited soil moisture available in the arid areas. It tolerates a maximum temperature of 50 **C** and a minimum temperature close to 0**C**.

Figure (1.4): *Acacia tortilis* var. *raddiana* Tree.

1.11.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *tortilis* var. *raddiana*

English name: Umbrella thorn

Arabic name: Sayal (El Amin, 1977; Vogt, 1995).

1.12. Gum Arabic trade

France and United Kingdom, former colonial powers, maintain a significant stranglehold on the trading and processing of the gum. More generally, while raw gum arabic is only produced in African, Caribbean and Pacific Group of States (ACP) countries, both import and export trade are of major importance for European countries and the United States. It highlights how little gum is processed in Africa, with the best part of the added value being achieved in Western countries. This is estimated at between 100 and 180%. The gum is, frequently, exported raw; only manual cleaning, sifting and sorting operations are carried out to remove the many foreign bodies that are present. Crushing and grinding units also exist, the first stage in processing. However, some modern units can be found in Africa, with atomization towers and/or analysis laboratories and quality standards, such as Dansa Food Processing Co. Ltd, of the Dangote group in Nigeria, or Sanimex in Chad, in partnership with the French Alland et Robert, or Khartoum Gum Arabic Processing Co (GAPC) in Sudan. The international gum arabic market fluctuates and has seen considerable variations. Many factors contribute to this volatility, such as increasing demand, instability of supply and variability in quality and price (UNCTAD, 2013).

1.13. Gum Arabic exports

Over the first decade of 2000, exports almost tripled from 52 000 tones in 2001 to 142 000 tones in 2010, accelerating from 2005, with the exception of 2008. Africa contributed to around 70% of exports in 2010. Whilst about fifteen countries export gum today, Sudan, Nigeria and Chad still dominate with at least 90% of African supply. Historically, Sudan was the principal supplier of gum Arabic, with a market share of about 80%. Exports halved in 40 years from 60 000 tons a year in the 1960s-70s to 30 000 tons a year in the 1980s-90s, rising again in the middle of the 2000s with a volume in excess of 35 000 tones. Today, it represents between 40 and 50% of global supply. With sharp fluctuations, Sudan exported an average of almost 30 000 tons a year 2001 and 2010. Whilst the United States have imposed economic sanctions on Sudan since 1997, gum Arabic has always been the exception with the United States being the second customer behind France. Chad and Nigeria emerged as important producers in the 1990s. In the last two years Nigeria and Sudan have been competing for first place in worldwide exportation. Chad, which primarily exports *talha* gum, became increasingly important from the end of the 1990s with exports of between 10 000 and 17 000 tons depending on the year, averaging 12 500 tons a year between 2001 and 2010. A characteristic of Nigeria is that India is its second customer, with a sharp increase in exports (from 300 tons in 2006 to 5 784 tones in 2010).

European countries and the United States occupy the top spots among exporting countries, mainly with processed gum. France, leader in this sector, confirms its first position with flows of exports increasing by 66% between 2001 and 2010 (almost 28 000 tones in 2010). However its share in terms of value in worldwide exports reduced regularly, from 40% in 2001 to 20% in 2010. It is followed by the United Kingdom and the United States (Neilson, Pritchard, and Yeung, 2014).

1.14. African gum belt

The gum belt refers to a broad band, situated at a latitude of between 12° and 16° North, stretching across sub-Saharan Africa, from Mauritania in the West, through Senegal and Mali, Burkina Faso, Niger , Northern Nigeria to Sudan, Eritrea, Ethiopia, Kenya, Somalia and Northern Uganda in the East. Most of these countries appear in the statistics as sources of gum arabic, although they greatly differ in terms of the quantities involved. We can assume that they all have a comparative advantage in the production of gum arabic on account of the natural conditions that prevail and the presence of *Acacia senegal* or *Acacia seyal* on their soil (Macrae and Merlin, 2002).

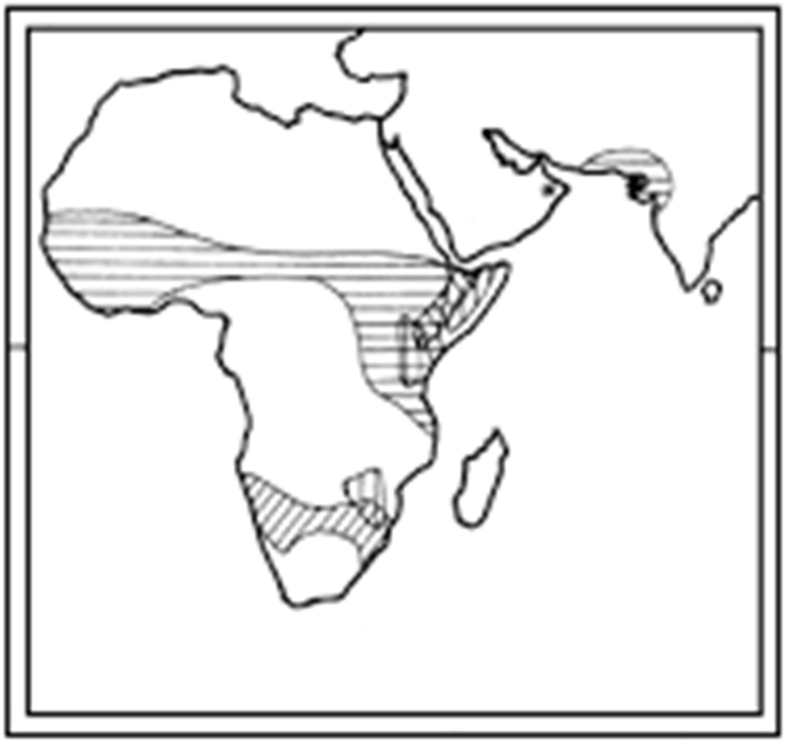

Figure (1.5): African gum belt.
Figure 1. 1

1.15. Grades and qualities of gum arabic sold on the world market

The Sudan has established a very detailed classification for its hard variety of gum arabic and this has become the reference on the world market. This classification known as Kordofan, takes its name from the main producing area in the country. Kordofan is a hard variety of gum that comes from the *Acacia senegal* var. *senegal* (Macrae and Merlin, 2002). Some typical grades of Sudanese gum available are listed in Table 1.3.

Table 1.3 Grades of gum arabic (Macrae and Merlin, 2002; Williams and Phillips, 2000).

Grade	Description
Hand-picked selected	The most expensive grade. Cleanest, lightest colour and in the form of large whole nodule, Ø >20 mm.
Cleaned and sifted	The material that remains after hand-picked selected and siftings are removed. Comprises whole or broken lumps varying in colour from pale to dark amber.
Cleaned	The standard grade varying from light to dark amber. Contains siftings but dust removed. Whole nodules plus fragments , 10 < Ø <20 mm.
Siftings	Fine particles remaining following sorting of the choicer grades. Contains some sand, bark and dirt. Fragments and siftings, 2.5<Ø < 10 mm.
Dust	Very fine particles collected after the cleaning process. Contains sand and dirt. Ø< 2.5 mm.
Red	Dark red particles - Rejects – local use only.

1.16. Weighting agents

Cloudiness or opacity (cloudy appearance) is an important property in citrus beverages, since it enhances their juice-like appearance and gives it a natural fruit juice appeal. This property is achievable through the addition of oil-in-water emulsions known as clouding agents. These emulsions are thermodynamically unstable and tend to break down during storage. Moreover, product and legal constraints put severe limits on materials that can be used to insure emulsion stability, particularly the introduction of weighting agents into the oil phase.

Weighing agents (density-adjusting agents) are lipophilic compounds with specific gravity higher than that of water and have a restricted use because of the perceived health risk disadvantage, undesirable taste, and oxidative instability. The stability of beverage emulsions is a problem of serious concern faced by the flavor and beverage industry. This research carried out by the authors on basic factors affecting the physical stability of emulsions having a bearing on droplet size, rheological properties of emulsion and phases components, and the stability of emulsion in concentrated form without addition of weighting agents.

1.17. Rheology

Rheology concerns the flow and deformation of substances and, in particular, to their behavior in the transient area between solids and fluids. Moreover, rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place. The science of rheology has many applications in the fields of food acceptability, food processing, and food handling. Foods, however, are complex materials structurally and rheologically and, in many cases, they consist of mixtures of solids as well as fluid structural components. Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished foods. There are several approaches to conduct these rheological characterizations, and the selected

technique pretty much depends on the specific product and the functional characteristics in need to be analyzed. Several different types of equipments are available to scientists as a tool in food rheological studies leading to acceptable results in most design situations(Tabilo-Munizaga and Barbosa-Cánovas, 2005). Rheology is concerned with how all materials respond to applied forces and deformations. Basic concepts of stress (force per area) and strain (deformation per length) are key to all rheological evaluations. Stress(r) is always a measurement of force per unit of surface area and is expressed in units of Pascal (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface. On the other hand, strain represents a dimensionless quantity of relative deformation of a material. The direction of the applied stress with respect to the material surface will determine the type of strain. Normal strain (e) occurs when the stress is normal to a sample surface. Foods show normal strain when compressed (compressive stress) or pulled apart (tensile stress) (Nielsen, 1998).

The objectives of this work are:

- To characterize the *Acacia* gum samples from different species (*Acacia senegal* var. *senegal, Acacia mellifera, Acacia seyal* var. *seyal*, & *Acacia tortilis* var. *raddiana*.)
- To study emulsions prepared using *Acacia* gums under the study.
- To explore viability of blending *Acacia* gums in preparing emulsions.
- To study the rheological properties of gums and emulsions prepared from gums and their blends.

Chapter One

Introduction

1.1.Definition of gums

Gums are polysaccharides either hydrophobic or hydrophilic ,high molecular weight molecules, usually with colloidal properties, which in an appropriate solvent or swelling agent produce gel, highly viscous suspension, or solutions at low dry substance content (Anderson, Dea, and Hirst, 1968; Anderson, Dea, Karamalla, and Smith, 1968), thus, the term gum is applied to a wide variety of substances of "gummy" characteristics and cannot be, precisely, defined. Hydrophobic substances, often, called gums are high molecular weight hydrocarbons and other petroleum products, rubbers, certain synthetic polymers, chicly for chewing gum, and the resinous saps which often exude from evergreens which are sometimes, commercially, tapped yielding, gum balsam and gum resin.

Most commonly, however, the term gum as technically employed in industry refers to plant polysaccharides or their derivatives which are dispersible in either cold or hot water to produce viscous mixture or solutions. Thus, modern usage includes the water – soluble or water-swellable derivatives of cellulose and the derivatives and modifications of other polysaccharides which in the natural form are insoluble. Usage would classify as gums all polysaccharides or their derivatives which when dispersed in water at low dry substance content, swell to produce gels, highly

viscous dispersions, or solutions (Coppen, 1995). This definition does not require that gums have the property of tackiness, and consequently, such a definition includes as gums those polysaccharides and derivatives which are slimy or mucilaginous. Some authors have tried to classify, separately, these slimy substances from plants into a category called mucilage. Yet, it is more logical to consider tackiness and sliminess as the exhibition of two different physical properties of gums. Hence, there are tacky gums and slimy or mucilaginous gums. Tackiness and sliminess are manifestations of two, somewhat, controllable physical properties. It is possible to modify a gum so that tacky properties are withdrawn and mucilaginous properties introduced. Yet the gum remains hydrophilic and capable of giving high viscosity to its dispersions even at low concentrations consequently, the mucilaginous property is distinctive but a category of mucilage's has no chemical significance (Glicksman, 1962).

1.2. Colloidal systems

The word colloid is of Greek origin; the Greek word kola, meaning “glue”. Thomas Graham is usually regarded as the founder of colloids science (Sharma, 2009). A colloid is a solution in which a substance is dispersed evenly throughout a solvent. Because of this dispersal, some colloids have the appearance of solutions. Colloid is defined as a hydrocolloid system wherein the colloid particles are dispersed in water. Colloids are intermediate between true solutions on one hand

and suspensions on the other. It is, obviously impossible to draw a boundary between true solutions and colloidal solutions. Colloidal behavior can be connected with greatly increased area compared with the volume as the size is reduced. The essential properties of colloidal dispersions can be ascribed to the fact that the ratio of the surface area to the volume of particles is very large. In a true solution, the system consists of one phase only and there is no true surface of separation between the molecular particles of solute and solvent. The sizes of particles in colloidal state range from 1nm to 1 m (Levine, 2001). Ostwald regarded colloidal system as heterogeneous in character consisting of two phases: (1) Disperse phase and (2) Dispersion medium. Dispersed phase refers to the phase forming the particles. Dispersion medium is the medium in which dispersion of the particles takes place. Colloidal dispersions are, thermodynamically, unstable and tend to coagulate and precipitate on standing unless precautions are taken. Since both the disperse phase and dispersion medium may be solid, liquid or gaseous there can be several different types of colloidal system (Sharma, 2009). Colloidal solutions are known as sols. If the dispersion medium is water, they are called “hydrosols” or sometimes “aqua sols”. And if it is liquid, the colloidal solution is known as emulsion. Table 1.1 shows the classification of colloids (Sharma, 2009; Shaw, 1992).

Table1.1Classification of colloids

Dispersed phase	**Dispersion medium**	**Name**	**Example**
liquid	Gas	Liquid aerosol	Fog, liquid spray
Solid	Gas	Solid aerosol	Smoke, dust
Gas	liquid	Foam	Foam from soap
liquid	liquid	Emulsion	Milk, crude oil
Solid	liquid	Sol	AgI sol, pastes
Gas	Solid	Solid foam	Expanded polystyrene
liquid	Solid	Gel	Opal, pearl
Solid	Solid	Solid suspension	Pigmented plastics

Dispersion of solids in liquids can be roughly divided into two categories lyophilic and lyophobic sols. Lyophobic (solvent hating) sols have little attraction between the disperse phase and dispersion medium. These are relatively less stable as compared with lyophilic sols. On heating or cooling the lyophobic systems, solids are obtained which cannot be reconverted into sols either by adding solvent or by warming. Lyophilic (solvent loving) sols on the other hand are system in which the disperse phase shows some definite affinity for the medium. Lyophilic sols are generally reversible and behave like true solutions to some extent e.g. gums, starches and proteins. These substances are absorbed by the disperse phase and are stabilized by strong salvations. Hydrocolloids are more commonly called gums (Sharma, 2009).

1.3. Hydrocolloids

Hydrocolloids or gums are a diverse group of long chain polymers characterized by their property of forming viscous dispersions and/or gels when dispersed in water. These materials were first found in exudates from trees or shrubs, extracts from plants or seaweeds, flours from seeds or grains, gummy slimes from fermentation processes, and many other natural products. Occurrence of a large number of hydroxyl groups, noticeably, increases their affinity for binding water molecules rendering them into hydrophilic compounds. Further, they produce dispersions, which are intermediate between a true solution and a suspension, and exhibit the properties of a colloid. Considering these two properties, they are, appropriately, termed as 'hydrophilic colloids' or 'hydrocolloids' (Milani and Maleki, 2012). Food hydrocolloids are high molecular weight hydrophilic biopolymers used as functional ingredients in the food industry for the control of microstructure, texture, flavor and shelf-life. The term "hydrocolloid" embraces all polysaccharides that are exuded or extracted from plants, seaweeds and microbial sources, as well as gum derived from plant exudates, and modified biopolymers made by the chemical or enzymatic treatment of starch or cellulose. In addition, due to its polydispersity and highly hydrophilic character, the unique protein gelatin has become accepted as an exceptional member of this polysaccharide club. But other food proteins, like casein and gluten, are, traditionally, not classified as

hydrocolloids- even though they, certainly, do exhibit functional properties that overlap, considerably, with those of food polysaccharides (Dickinson, 2003; Mirhosseini, Tan, and Naghshineh, 2010).

1.4. Bioemulsifiers

Bioemulsifiers have been recently attracting the industrial community as natural and promising candidates for the replacement of synthetic commercial surfactants due to their intrinsic properties such as lower toxicity, higher biodegradability, higher foaming capacity and higher activity at extreme temperatures, pH levels and salinity. These compounds are biological molecules with surfactant properties similar to the well-known synthetic surfactants and include microbial compounds, natural polymers, such as Gum Arabic (GA) which has been extensively exploited and used in the food industry as a surfactant agent, and other amphiphilic polymer surfactants, usually, based on polysaccharides. Gum Arabic is among the most studied and widely used hydrocolloid due to its excellent emulsifying capacity, ample spectrum of applications and millenary use (Trindade et al., 2008).

1.5. Classification of gums

It has been customary, in the past, to classify most of the gums as polysaccharides and to group them according to plant origin. Thus, the seaweed group comprised the extracts known as agar, alginates, and carrageenan; tree exudates such as gum Arabic, gum karaya, gum tragacanth, and gum chatty; and the seed gums included

locust bean and guar gum. Other gum like materials such as pectin and starch were treated as separate groups, while gelatin, being a protein was not included at all. In addition, there was no room for the synthetic gums such as the cellulose derivatives which are carbohydrate gum, or for the synthetic vinyl polymers such as polyvinylpyroldinone (PVP) which require a completely new category. The use of botanical origin as a basis for the classification of important plant gums is valid and useful, since gums of similar origin and functionality frequently have similar properties and chemical structures, and can, occasionally, be employed for the same purpose. Thus, locust bean gum and guar gum, which are both derived from similar plant- seed sources, have the similar chemical structure of neutral Galacto-mannans, and differ only in the ratio of Galactose to mannose molecules. Their thickening properties are sufficiently similar and of the same magnitude to allow the interchange of the gums in certain specific applications, but not, indiscriminately, and not in all applications (Whistler and Miller, 1959). For a general classification to be useful, it should embrace all types of gums that are used in the food industry, and it should leave room for the new gums that are certain to be developed in the future. Following this line of thought it has been proposed that the following all-inclusive classification composed of three main categories. (1) natural gums – those found in nature; (2) modified natural , or semi synthetic, gums – those based on chemical modifications of natural gums or gum like

materials ; (3) synthetic gums – those prepared by total chemical synthesis. Specific gums comprising these categories are shown in Table 1.2. As a further aid to identification each category is broken down into subgroups based, where possible, on the common origins, functions, or properties of the particular gums.

1.6. Gum Arabic

Gum Arabic is defined as the dried exudation obtained from the stems and branches of natural strains of *Acacia senegal* (L), family Leguminosae (FAO, 1990). It consists mainly of high molecular mass polysaccharides and their calcium, magnesium and potassium salts, which on hydrolysis yields arabinose, galactose, rhamnose and glucuronic acid. Gum arabic, is the oldest and best known of all plants gum exudates and has been used as an article of commerce for over 5000 years (Glicksman and Sand, 1973). Gum arabic has a wide range of uses in foods and pharmaceutical industries, where it's stabilizing, thickening and gel forming properties are the main physical requirements. Gum arabic is also used in the mining industry and in the manufacture of textiles, ink and paper. It is also used in bakery, meat products, beverages, confectionery adhesives, cosmetics, printing, fertilizers and binder to explosives (Glicksman and Sand, 1973).Sudan is the world's largest producer of gum Arabic, with production reaching 40,000 tons in 2000. Chad is the second largest producer, followed by Nigeria, Mali and Senegal. In Sudan more than thirty distinct *Acacia* species are found (El Amin, 1990), but

the great majority of commercial gum comes from *Acacia senegal* var. *senegal*. Sudan is the world's largest producer of gum arabic with various grades gum, including handpicked selected, cleaned and sifted, cleaned, siftings, dust and red. Following export to Europe and the US, some grades of gum are processed providing greater quality and convenience to the users (Islam, Phillips, Sljivo, Snowden, and Williams, 1997). This may be by mechanical grinding (kibbling) which breaks up the gum nodules into various sizes for faster dissolution. Further processing may involve dissolution and filtration of the gum to remove impurities, followed by spray drying or roller drying (Phillips and Williams, 2009) . Gum arabic is a naturally occurring exudate collected from *Acacia senegal* trees and, to a lesser extent, from *Acacia seyal* trees (Islam et al., 1997). It is one of the oldest and most important industrial gums. The Ancient Egyptians used gum arabic as an adhesive when wrapping mummies and in mineral paints when making hieroglyphs (Verbeken, Dierckx, and Dewettinck, 2003). In modern times, the most important applications of gum arabic have been not as an adhesive but as an emulsifier in the food and pharmaceutical industries. Gum arabic is considered to be the best gum in use in dilute oil-in-water emulsion systems (Garti, 1999), one important example of which is the use of citrus oils as flavoring agents in soft drinks where the oils are converted into a water-dispersible emulsion (Verbeken et al., 2003).

Table 1.2 Classification of gums (Ahmed, 2012)

Natural gums	Modified (semi-synthetic) gums	Synthetic gums
Plant exudates	**Cellulose derivatives**	**Vinyl polymers**
Arabic		
Tragacanth	Carboxymethyl cellulose	Poly vinyl pyrrolidone
Karaya		
Gatti	Methylcellulose	(PVP)
Plant extracts		
Pectins	Hydroxypropylmethyl- Cellulose	Polyvinyl alcohol (PVA)
Arabinogalactan		
(larch gum)	Methylethylcelulose	**Carboxyvinyl polymer**
Plant seed flours		
Locust Bean	Methylethylcelulose	(carbopol)
Quar		
Psyllium seed	Hydroxypropylcellulose (klucel)	**Ethyleneoxide polymers**
Quince seed		
Seaweed extracts	Low methoxy pectin	Polyox
Agar		
Alginates	**Microbial fermentation gums**	
Carrageenan		
Furcellaran	Dextran	
Cereal starches		
Seed starches	Xanthan gum	
Corn		
Wheat	Pregelatinized starches	
Rice		
Waxy maize	**Modified starches**	
Sorghum		
Waxy sorghum	Carboxymethyl starch	
Tuber starches		
Potato	Hydroxethyl starch	
Arrowroot		
Tapioca	Hydroxypropyl starch	
Animal		
Gelatin		
Albumen		
Casein		
Vegetable		
Soy protein		

1.7. *Acacia* species

Over 1350 species of *Acacia* exist around the world. About 185 are endemic to the Americas, 95 to Asia and the Pacific, nearly 1000 are native to Australia, and 150 are African native (Kull and Rangan, 2008). The genus *Acacia* is the second largest within the Leguminosae family and contains at least 900 species. With their extensive root system, *Acacia* trees can be found in semi-arid areas in Australia, India, and America, but mainly in the Sahelian region of Africa. They are multipurpose trees, not only producing gum, but also preventing desert encroachment, restoring soil fertility, and providing fuel and fodder. Almost all commercial gum comes from the so-called gum belt of Africa, a vast area which extends over Mauritania, Senegal, Mali, Burkina Faso, Benin, Niger, Nigeria, Chad, Sudan, Eritrea, Ethiopia, Somalia, Uganda, and Kenya (Coppen, 1995). Sudan is the world's largest producer of gum arabic, followed by Nigeria, Chad, Mali, and Senegal. Gum from the Sudanese Kordofan region is known as the best quality gum and is used as the standard to judge gums obtained from other areas. Commercial gum arabic is collected from a number of *Acacia* species, of which *Acacia senegal, Acacia seyal*, and *Acacia polyacantha* are the most widespread in the gum belt. *Acacia laeta*, *Acacia karoo*, and *Acacia gourmaensis* are some other gum yielding species with a more limited distribution (Islam et al., 1997). In Sudan, the gums from *Acacia senegal* var. *senegal* and *Acacia seyal* var. *seyal* are

referred to as hashab and talha respectively, the former considered of higher quality (Baldwin, Quah, and Menzies, 1999). Most of these species grow scattered in the wild and gum from these untended trees is collected by semi-nomadic people. Cultivation is only practiced for *Acacia senegal* var. *senegal*. Particularly in Sudan, wild stands of *Acacia* trees are replaced by monocultures of *Acacia senegal* var. *senegal* in order to facilitate collection and obtain a more consistent quality(Verbeken et al., 2003). Gum arabic from other African countries may be variable in quality, because it may contain gums obtained from different species which occur jointly in the collection area. *Acacia senegal* var. *senegal* is a thorny tree that reaches a height of 4.5–6.0 m. It is very drought-resistant and grows on sites with annual rainfall of 100–950 mm and dry periods of 5–11 months. It also tolerates high daily temperatures of up to 45C or more, dry winds, and sandstorms. After 5 years, trees reach maturity and are tapped. Although gum can be tapped from the trees after 3 years, the quality and yield are consistent only after 5 years, suggesting that gum biosynthesis and tree growth are in competition with each other (Joseleau and Ullmann, 1990).

1.8.*Acacia senegal* var. *senegal*

Acacia senegal var. *senegal* is a shrub or small tree 2 – 12 m tall, with a yellowish or grayish white, rather rough bark. The species has a wide distribution in Sudan

gum belt (Awouda, 1974) in sandy soils under annual rainfall of 280 – 450 mm and on dark clays under rainfall > 500 mm (Badi, Ahmed, and Bayoumi, 1989).

The trunk may vary in diameter up to about 30cm. The bark is grayish-white; although in old trees growing in the open it may be dark, scaly and thin, showing the bright green cambium layer just below the surface if scratched with a nail. The slash is mottled red. Powerful hooked thorns, 3-5 m long, with enlarged base appear at the nodes of the branches, usually in3s. They are sharp, with some pointing forwards and others backwards. Leaves bipinnate, 3-8 pinnae (glands between uppermost and lowermost pinnae); rachis up to 2.5 cm long; pinnacles are pairs of 8-15, green; 2 stipular spines strongly re-curved with a 3rd pseudo-stipular between them. Flowers yellowish-white and fragrant, in cylindrical, axillary pedunculate spikes, 5-10 cm long; calyx of each flower has 5 deep lobes, 5 petals and a mass of short stamens; pistil inconspicuous. The pods are straight, thin, flat, shortly stipulates and oblong (7.5 x2 cm), green and pubescent when young, maturing to shiny bronze, often with dark patches and bearing prominent veins; seeds 3-6, smooth, flat, rather small, shiny, dark brown. Varietal differences in *Acacia senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as the presence of or absence of hair on the axis of the flower spike, color of the axis, shape of pod tips, number of pinnae pairs, occurrence of a distinct trunk and shape of the crown. Four different varieties

of *Acacia senegal* are recognized: var. *senegal,* var. *kerensis Schweinf.,* var. *rostrata Brenan and* var. *leiorhachis Brenan*. The generic name '*Acacia*' comes from the Greek word 'akis', meaning a point or a barb.

Drought-tolerant, *Acacia senegal* var. *senegal* is the characteristic species in the drier parts of Sudan and the northern Sahara and is to be found throughout the vast area from Senegal to the Red Sea and to eastern India. It extends southwards to northern Nigeria, Uganda, Kenya, Tanzania and southern Africa. In India it is found chiefly in Sind and Ajmer. In Sudan, the tree exists both in the wild and is cultivated -mainly on sandy hills, but is also grows well in cotton soil.

Figure (1.1): ***Acacia senegal*** **var.** ***senegal*** **Tree.**

1.8.1. Botanical classification

Kingdom: Plantae

Division: *Magnoliophyta*

Class: *Magnoliopsida*

Order: *Fabales*

Family: *Fabaceae (Leguminosae)*

Subfamily: *Mimosoideae*

Tribe: *Acacieae*

Genus: *Acacia*

Species: *senegal*

English name: Gum Arabic tree, three thorned *Acacia.*

Arabic name: Hashab (El Amin, 1977; Vogt, 1995).

1.9.*Acacia mellifera*

Acacia mellifera is a low, branched tree with a more or less spherical crown. Black bark on stem becomes ash-grey to light brown on the branches, bearing small, short, sharply hooked spines in pairs. It has shallow but extensive rot system radiating from the crown, allowing the plant to exploit soil moisture and nutrients from a large volume of soil. The roots rarely penetrate more than 1m. Leaves characterized by2 pairs of pinnulae, each with a single pair of leaflets. Leaflets are elliptic 0.6-2 cm long and 0.6-1.2 cm wide, glabrous and highly coloured beneath.

Flowers are sweetly scented, especially at night, in elongated spikes, cream to white in spiciform racemes, up to3.5 cm long; pedicels 0.5-1.5 m long; calyx up to 1m long; corolla 2.5-3.5 m long. The papery pods with 2-3seds are reticulate, flat, elongated, 2.5-.5 cm long, 6cm wide, hemmed, sometimes more or less narrowed between the seeds. The specific name *mellifera* means 'honey-bearing'.

Acacia mellifera is a commonly occurring shrub on rangelands throughout the savannah in western, eastern and southern Africa. The train preference is rocky hillsides with rainfall along seasonal watercourse, mixed with other trees. If left unattended, especially if grazing is heavy and no fires check its spread, it may form dense, impenetrable thickets, 2-3 m high and sometimes hundreds of meters across, slowly taking over good grazing land. This species is drought-tolerant.

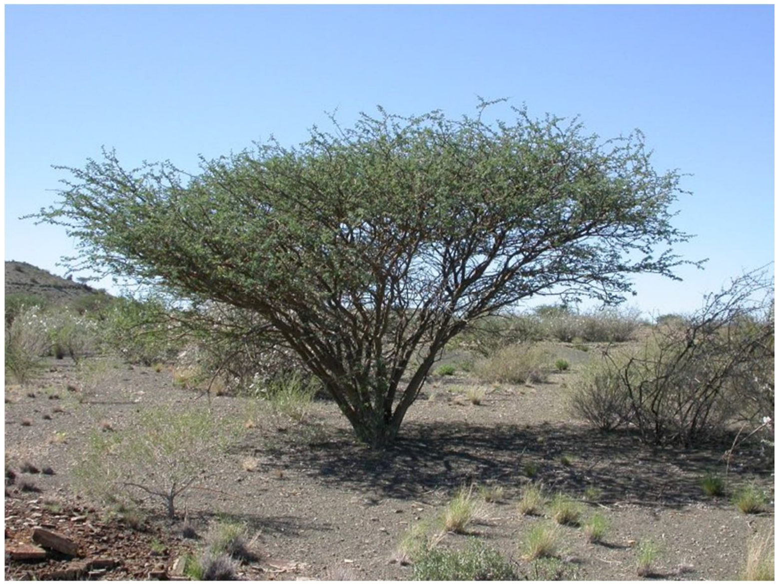

Figure (1.2): ***Acacia mellifera*** **Tree.**

1.9.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *mellifera*

English name: Black thorn

Arabic name: Kitir (El Amin, 1977; Vogt, 1995).

1.10. *Acacia seyal* var. *seyal*

Small, slender tree, reaching 6-15 m in height, with a stem diameter up to 60 cm, develops a characteristic umbrella-shaped canopy in adult individuals, usually thin and rather scarce foliage. Bark is usually smooth, pale green to greenish yellow when young or orange on exposure after the old bark has sloughed off. Bark smooth, peeling, rust-red or pale-green (both types may coexist in any population), covered with a pruinous, rusty, powdery coating. Bright red mottled slash, exuding a yellowish gum. Twigs with many small reddish glands and paired axillary thorns, are up to 7 cm long, narrow and straight, vulnerant-sharp-ended and grey in color. Leaves are dark green, with 4-12 pairs of pinnae having each 10-22 pairs of leaflets. Rachis is up to 8 cm long clustered by 2 or 3. Flowers clustered by 2-3 with bright yellow globose heads ca 1.5 cm in diameter on peduncles about 3 cm long starting from the leaves axils. Pods hanging, slightly curved, dehiscent, light brown when mature, 10-15 cm long by 1 cm wide at the bottom, containing 6-10 seeds each. *Acacia seyal* var. *seyal* grows on fine-textured soils.

Acacia seyal var. *seyal* occurs from Senegal to the Red Sea and in Arabia. It is common in many other parts of Africa, especially north of the equator, from 10 to 12 degrees. It also occurs in east and southern Africa. In the southern and western Sudan, it is one of the most common trees in the savannah and often occurs as a pure forest over quite large areas of the country side. Frequently, it grows in

groups or patches, sometimes of considerable size, in areas inhabited by *Acacia senegal*. This species is characteristic of the Nile region. It is tolerant to high pH (6-8), salts and periodic flooding.

Figure (1.3): *Acacia seyal* var. *seyal* Tree.

1.10.1. Botanical classification

Family: *Leguminosae*

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *seyal*

English name: Thirsty thorn

Arabic name: Talha (El Amin, 1977; Vogt, 1995).

1.11. *Acacia tortilis* var. *raddiana*

Acacia tortilis var. *raddiana* is a small to medium-sized evergreen tree or shrub that grows up to 21 m tall; well-developed multiple boles support a flat-topped or rounded, spreading crown; bark grey to black or dark brown, rough, fissured or smooth; young branch lets densely pubescent or glabrous to sub glabrous and red to brown; spines paired, 2 types-long, straight and white, or short, brownish and hooked; they range from 1.2 to 8 cm in length. Leaves glabrous to densely pubescent, glandular, short at 1.25-3.75 cm long; petiole 0.2-0.9 cm long, with a gland; rachis 0.3-2 cm long, glabrous to densely pubescent, with a small gland at the junction of the apical pair of pinnae; pinnae 2-10 pairs; leaflets 4-22 pairs per pinnae, 0.5-4 (6 max.)x 0.2-1 mm, glabrous to densely pubescent on the underside; margins with or without cilia, linear to linear oblong. Inflorescence globose heads; peduncle white, pubescent, 0.4-2.5 cm long, with involucel on the lower half; flowers white or pale yellowish-white, sessile or shortly pedicellate, scented, 0.5-1.1 cm in diameter, on axillary peduncles; calyx 1-2 mm long; corolla 1.5-2.5 mm long. Pods variable, indehiscent, spirally twisted or rarely almost straight, 7-10 cm long, 6-10(max. 13)mm broad, longitudinally veined, leathery, glabrous to tomentellous or villous, somewhat constricted between the seeds; seeds oblique or parallel to long axis of pod, 4-7 x 3-6 mm, compressed; areole 3-6 x 2-4 mm. The name *tortilis* means twisted and refers to the pod structure.

Acacia tortilis var. *raddiana* is drought resistant, can tolerate strong salinity and seasonal water logging and generally forms open, dry forests in pure stands or mixed with other species. The long taproot and numerous lateral roots enable it to utilize the limited soil moisture available in the arid areas. It tolerates a maximum temperature of 50 **C** and a minimum temperature close to 0**C**.

Figure (1.4): ***Acacia tortilis*** **var.** ***raddiana*** **Tree.**

1.11.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *tortilis* var. *raddiana*

English name: Umbrella thorn

Arabic name: Sayal (El Amin, 1977; Vogt, 1995).

1.12. Gum Arabic trade

France and United Kingdom, former colonial powers, maintain a significant stranglehold on the trading and processing of the gum. More generally, while raw gum arabic is only produced in African, Caribbean and Pacific Group of States (ACP) countries, both import and export trade are of major importance for European countries and the United States. It highlights how little gum is processed in Africa, with the best part of the added value being achieved in Western countries. This is estimated at between 100 and 180%. The gum is, frequently, exported raw; only manual cleaning, sifting and sorting operations are carried out to remove the many foreign bodies that are present. Crushing and grinding units also exist, the first stage in processing. However, some modern units can be found in Africa, with atomization towers and/or analysis laboratories and quality standards, such as Dansa Food Processing Co. Ltd, of the Dangote group in Nigeria, or Sanimex in Chad, in partnership with the French Alland et Robert, or Khartoum Gum Arabic Processing Co (GAPC) in Sudan. The international gum arabic market fluctuates and has seen considerable variations. Many factors contribute to this volatility, such as increasing demand, instability of supply and variability in quality and price (UNCTAD, 2013).

1.13. Gum Arabic exports

Over the first decade of 2000, exports almost tripled from 52 000 tones in 2001 to 142 000 tones in 2010, accelerating from 2005, with the exception of 2008. Africa contributed to around 70% of exports in 2010. Whilst about fifteen countries export gum today, Sudan, Nigeria and Chad still dominate with at least 90% of African supply. Historically, Sudan was the principal supplier of gum Arabic, with a market share of about 80%. Exports halved in 40 years from 60 000 tons a year in the 1960s-70s to 30 000 tons a year in the 1980s-90s, rising again in the middle of the 2000s with a volume in excess of 35 000 tones. Today, it represents between 40 and 50% of global supply. With sharp fluctuations, Sudan exported an average of almost 30 000 tons a year 2001 and 2010. Whilst the United States have imposed economic sanctions on Sudan since 1997, gum Arabic has always been the exception with the United States being the second customer behind France. Chad and Nigeria emerged as important producers in the 1990s. In the last two years Nigeria and Sudan have been competing for first place in worldwide exportation. Chad, which primarily exports *talha* gum, became increasingly important from the end of the 1990s with exports of between 10 000 and 17 000 tons depending on the year, averaging 12 500 tons a year between 2001 and 2010. A characteristic of Nigeria is that India is its second customer, with a sharp increase in exports (from 300 tons in 2006 to 5 784 tones in 2010).

European countries and the United States occupy the top spots among exporting countries, mainly with processed gum. France, leader in this sector, confirms its first position with flows of exports increasing by 66% between 2001 and 2010 (almost 28 000 tones in 2010). However its share in terms of value in worldwide exports reduced regularly, from 40% in 2001 to 20% in 2010. It is followed by the United Kingdom and the United States (Neilson, Pritchard, and Yeung, 2014).

1.14. African gum belt

The gum belt refers to a broad band, situated at a latitude of between 12° and 16° North, stretching across sub-Saharan Africa, from Mauritania in the West, through Senegal and Mali, Burkina Faso, Niger , Northern Nigeria to Sudan, Eritrea, Ethiopia, Kenya, Somalia and Northern Uganda in the East. Most of these countries appear in the statistics as sources of gum arabic, although they greatly differ in terms of the quantities involved. We can assume that they all have a comparative advantage in the production of gum arabic on account of the natural conditions that prevail and the presence of *Acacia senegal* or *Acacia seyal* on their soil (Macrae and Merlin, 2002).

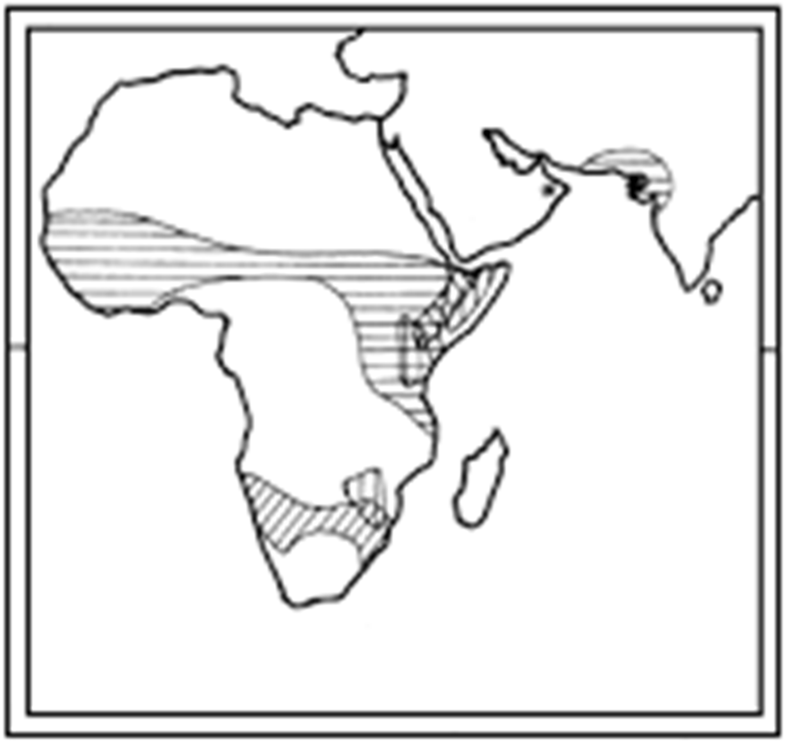

Figure (1.5): African gum belt.
Figure 1. 1

1.15. Grades and qualities of gum arabic sold on the world market

The Sudan has established a very detailed classification for its hard variety of gum arabic and this has become the reference on the world market. This classification known as Kordofan, takes its name from the main producing area in the country. Kordofan is a hard variety of gum that comes from the *Acacia senegal* var. *senegal* (Macrae and Merlin, 2002). Some typical grades of Sudanese gum available are listed in Table 1.3.

Table 1.3 Grades of gum arabic (Macrae and Merlin, 2002; Williams and Phillips, 2000).

Grade	Description
Hand-picked selected	The most expensive grade. Cleanest, lightest colour and in the form of large whole nodule, Ø >20 mm.
Cleaned and sifted	The material that remains after hand-picked selected and siftings are removed. Comprises whole or broken lumps varying in colour from pale to dark amber.
Cleaned	The standard grade varying from light to dark amber. Contains siftings but dust removed. Whole nodules plus fragments , 10 < Ø <20 mm.
Siftings	Fine particles remaining following sorting of the choicer grades. Contains some sand, bark and dirt. Fragments and siftings, 2.5<Ø < 10 mm.
Dust	Very fine particles collected after the cleaning process. Contains sand and dirt. Ø< 2.5 mm.
Red	Dark red particles - Rejects – local use only.

1.16. Weighting agents

Cloudiness or opacity (cloudy appearance) is an important property in citrus beverages, since it enhances their juice-like appearance and gives it a natural fruit juice appeal. This property is achievable through the addition of oil-in-water emulsions known as clouding agents. These emulsions are thermodynamically unstable and tend to break down during storage. Moreover, product and legal constraints put severe limits on materials that can be used to insure emulsion stability, particularly the introduction of weighting agents into the oil phase.

Weighing agents (density-adjusting agents) are lipophilic compounds with specific gravity higher than that of water and have a restricted use because of the perceived health risk disadvantage, undesirable taste, and oxidative instability. The stability of beverage emulsions is a problem of serious concern faced by the flavor and beverage industry. This research carried out by the authors on basic factors affecting the physical stability of emulsions having a bearing on droplet size, rheological properties of emulsion and phases components, and the stability of emulsion in concentrated form without addition of weighting agents.

1.17. Rheology

Rheology concerns the flow and deformation of substances and, in particular, to their behavior in the transient area between solids and fluids. Moreover, rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place. The science of rheology has many applications in the fields of food acceptability, food processing, and food handling. Foods, however, are complex materials structurally and rheologically and, in many cases, they consist of mixtures of solids as well as fluid structural components. Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished foods. There are several approaches to conduct these rheological characterizations, and the selected

technique pretty much depends on the specific product and the functional characteristics in need to be analyzed. Several different types of equipments are available to scientists as a tool in food rheological studies leading to acceptable results in most design situations(Tabilo-Munizaga and Barbosa-Cánovas, 2005). Rheology is concerned with how all materials respond to applied forces and deformations. Basic concepts of stress (force per area) and strain (deformation per length) are key to all rheological evaluations. Stress(r) is always a measurement of force per unit of surface area and is expressed in units of Pascal (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface. On the other hand, strain represents a dimensionless quantity of relative deformation of a material. The direction of the applied stress with respect to the material surface will determine the type of strain. Normal strain (e) occurs when the stress is normal to a sample surface. Foods show normal strain when compressed (compressive stress) or pulled apart (tensile stress) (Nielsen, 1998).

The objectives of this work are:

- To characterize the *Acacia* gum samples from different species (*Acacia senegal* var. *senegal, Acacia mellifera, Acacia seyal* var. *seyal*, & *Acacia tortilis* var. *raddiana*.)
- To study emulsions prepared using *Acacia* gums under the study.
- To explore viability of blending *Acacia* gums in preparing emulsions.
- To study the rheological properties of gums and emulsions prepared from gums and their blends.

Chapter One

Introduction

1.1.Definition of gums

Gums are polysaccharides either hydrophobic or hydrophilic ,high molecular weight molecules, usually with colloidal properties, which in an appropriate solvent or swelling agent produce gel, highly viscous suspension, or solutions at low dry substance content (Anderson, Dea, and Hirst, 1968; Anderson, Dea, Karamalla, and Smith, 1968), thus, the term gum is applied to a wide variety of substances of "gummy" characteristics and cannot be, precisely, defined. Hydrophobic substances, often, called gums are high molecular weight hydrocarbons and other petroleum products, rubbers, certain synthetic polymers, chicly for chewing gum, and the resinous saps which often exude from evergreens which are sometimes, commercially, tapped yielding, gum balsam and gum resin.

Most commonly, however, the term gum as technically employed in industry refers to plant polysaccharides or their derivatives which are dispersible in either cold or hot water to produce viscous mixture or solutions. Thus, modern usage includes the water – soluble or water-swellable derivatives of cellulose and the derivatives and modifications of other polysaccharides which in the natural form are insoluble. Usage would classify as gums all polysaccharides or their derivatives which when dispersed in water at low dry substance content, swell to produce gels, highly

viscous dispersions, or solutions (Coppen, 1995). This definition does not require that gums have the property of tackiness, and consequently, such a definition includes as gums those polysaccharides and derivatives which are slimy or mucilaginous. Some authors have tried to classify, separately, these slimy substances from plants into a category called mucilage. Yet, it is more logical to consider tackiness and sliminess as the exhibition of two different physical properties of gums. Hence, there are tacky gums and slimy or mucilaginous gums. Tackiness and sliminess are manifestations of two, somewhat, controllable physical properties. It is possible to modify a gum so that tacky properties are withdrawn and mucilaginous properties introduced. Yet the gum remains hydrophilic and capable of giving high viscosity to its dispersions even at low concentrations consequently, the mucilaginous property is distinctive but a category of mucilage's has no chemical significance (Glicksman, 1962).

1.2. Colloidal systems

The word colloid is of Greek origin; the Greek word kola, meaning “glue”. Thomas Graham is usually regarded as the founder of colloids science (Sharma, 2009). A colloid is a solution in which a substance is dispersed evenly throughout a solvent. Because of this dispersal, some colloids have the appearance of solutions. Colloid is defined as a hydrocolloid system wherein the colloid particles are dispersed in water. Colloids are intermediate between true solutions on one hand

and suspensions on the other. It is, obviously impossible to draw a boundary between true solutions and colloidal solutions. Colloidal behavior can be connected with greatly increased area compared with the volume as the size is reduced. The essential properties of colloidal dispersions can be ascribed to the fact that the ratio of the surface area to the volume of particles is very large. In a true solution, the system consists of one phase only and there is no true surface of separation between the molecular particles of solute and solvent. The sizes of particles in colloidal state range from 1nm to 1 m (Levine, 2001). Ostwald regarded colloidal system as heterogeneous in character consisting of two phases: (1) Disperse phase and (2) Dispersion medium. Dispersed phase refers to the phase forming the particles. Dispersion medium is the medium in which dispersion of the particles takes place. Colloidal dispersions are, thermodynamically, unstable and tend to coagulate and precipitate on standing unless precautions are taken. Since both the disperse phase and dispersion medium may be solid, liquid or gaseous there can be several different types of colloidal system (Sharma, 2009). Colloidal solutions are known as sols. If the dispersion medium is water, they are called "hydrosols" or sometimes "aqua sols". And if it is liquid, the colloidal solution is known as emulsion. Table 1.1 shows the classification of colloids (Sharma, 2009; Shaw, 1992).

Table1.1Classification of colloids

Dispersed phase	**Dispersion medium**	**Name**	**Example**
liquid	Gas	Liquid aerosol	Fog, liquid spray
Solid	Gas	Solid aerosol	Smoke, dust
Gas	liquid	Foam	Foam from soap
liquid	liquid	Emulsion	Milk, crude oil
Solid	liquid	Sol	AgI sol, pastes
Gas	Solid	Solid foam	Expanded polystyrene
liquid	Solid	Gel	Opal, pearl
Solid	Solid	Solid suspension	Pigmented plastics

Dispersion of solids in liquids can be roughly divided into two categories lyophilic and lyophobic sols. Lyophobic (solvent hating) sols have little attraction between the disperse phase and dispersion medium. These are relatively less stable as compared with lyophilic sols. On heating or cooling the lyophobic systems, solids are obtained which cannot be reconverted into sols either by adding solvent or by warming. Lyophilic (solvent loving) sols on the other hand are system in which the disperse phase shows some definite affinity for the medium. Lyophilic sols are generally reversible and behave like true solutions to some extent e.g. gums, starches and proteins. These substances are absorbed by the disperse phase and are stabilized by strong salvations. Hydrocolloids are more commonly called gums (Sharma, 2009).

1.3. Hydrocolloids

Hydrocolloids or gums are a diverse group of long chain polymers characterized by their property of forming viscous dispersions and/or gels when dispersed in water. These materials were first found in exudates from trees or shrubs, extracts from plants or seaweeds, flours from seeds or grains, gummy slimes from fermentation processes, and many other natural products. Occurrence of a large number of hydroxyl groups, noticeably, increases their affinity for binding water molecules rendering them into hydrophilic compounds. Further, they produce dispersions, which are intermediate between a true solution and a suspension, and exhibit the properties of a colloid. Considering these two properties, they are, appropriately, termed as 'hydrophilic colloids' or 'hydrocolloids' (Milani and Maleki, 2012). Food hydrocolloids are high molecular weight hydrophilic biopolymers used as functional ingredients in the food industry for the control of microstructure, texture, flavor and shelf-life. The term "hydrocolloid" embraces all polysaccharides that are exuded or extracted from plants, seaweeds and microbial sources, as well as gum derived from plant exudates, and modified biopolymers made by the chemical or enzymatic treatment of starch or cellulose. In addition, due to its polydispersity and highly hydrophilic character, the unique protein gelatin has become accepted as an exceptional member of this polysaccharide club. But other food proteins, like casein and gluten, are, traditionally, not classified as

hydrocolloids- even though they, certainly, do exhibit functional properties that overlap, considerably, with those of food polysaccharides (Dickinson, 2003; Mirhosseini, Tan, and Naghshineh, 2010).

1.4. Bioemulsifiers

Bioemulsifiers have been recently attracting the industrial community as natural and promising candidates for the replacement of synthetic commercial surfactants due to their intrinsic properties such as lower toxicity, higher biodegradability, higher foaming capacity and higher activity at extreme temperatures, pH levels and salinity. These compounds are biological molecules with surfactant properties similar to the well-known synthetic surfactants and include microbial compounds, natural polymers, such as Gum Arabic (GA) which has been extensively exploited and used in the food industry as a surfactant agent, and other amphiphilic polymer surfactants, usually, based on polysaccharides. Gum Arabic is among the most studied and widely used hydrocolloid due to its excellent emulsifying capacity, ample spectrum of applications and millenary use (Trindade et al., 2008).

1.5. Classification of gums

It has been customary, in the past, to classify most of the gums as polysaccharides and to group them according to plant origin. Thus, the seaweed group comprised the extracts known as agar, alginates, and carrageenan; tree exudates such as gum Arabic, gum karaya, gum tragacanth, and gum chatty; and the seed gums included

locust bean and guar gum. Other gum like materials such as pectin and starch were treated as separate groups, while gelatin, being a protein was not included at all. In addition, there was no room for the synthetic gums such as the cellulose derivatives which are carbohydrate gum, or for the synthetic vinyl polymers such as polyvinylpyroldinone (PVP) which require a completely new category. The use of botanical origin as a basis for the classification of important plant gums is valid and useful, since gums of similar origin and functionality frequently have similar properties and chemical structures, and can, occasionally, be employed for the same purpose. Thus, locust bean gum and guar gum, which are both derived from similar plant- seed sources, have the similar chemical structure of neutral Galacto-mannans, and differ only in the ratio of Galactose to mannose molecules. Their thickening properties are sufficiently similar and of the same magnitude to allow the interchange of the gums in certain specific applications, but not, indiscriminately, and not in all applications (Whistler and Miller, 1959). For a general classification to be useful, it should embrace all types of gums that are used in the food industry, and it should leave room for the new gums that are certain to be developed in the future. Following this line of thought it has been proposed that the following all-inclusive classification composed of three main categories. (1) natural gums – those found in nature; (2) modified natural , or semi synthetic, gums – those based on chemical modifications of natural gums or gum like

materials ; (3) synthetic gums – those prepared by total chemical synthesis. Specific gums comprising these categories are shown in Table 1.2. As a further aid to identification each category is broken down into subgroups based, where possible, on the common origins, functions, or properties of the particular gums.

1.6.Gum Arabic

Gum Arabic is defined as the dried exudation obtained from the stems and branches of natural strains of *Acacia senegal* (L), family Leguminosae (FAO, 1990). It consists mainly of high molecular mass polysaccharides and their calcium, magnesium and potassium salts, which on hydrolysis yields arabinose, galactose, rhamnose and glucuronic acid. Gum arabic, is the oldest and best known of all plants gum exudates and has been used as an article of commerce for over 5000 years (Glicksman and Sand, 1973). Gum arabic has a wide range of uses in foods and pharmaceutical industries, where it's stabilizing, thickening and gel forming properties are the main physical requirements. Gum arabic is also used in the mining industry and in the manufacture of textiles, ink and paper. It is also used in bakery, meat products, beverages, confectionery adhesives, cosmetics, printing, fertilizers and binder to explosives (Glicksman and Sand, 1973).Sudan is the world's largest producer of gum Arabic, with production reaching 40,000 tons in 2000. Chad is the second largest producer, followed by Nigeria, Mali and Senegal. In Sudan more than thirty distinct *Acacia* species are found (El Amin, 1990), but

the great majority of commercial gum comes from *Acacia senegal* var. *senegal*. Sudan is the world's largest producer of gum arabic with various grades gum, including handpicked selected, cleaned and sifted, cleaned, siftings, dust and red. Following export to Europe and the US, some grades of gum are processed providing greater quality and convenience to the users (Islam, Phillips, Sljivo, Snowden, and Williams, 1997). This may be by mechanical grinding (kibbling) which breaks up the gum nodules into various sizes for faster dissolution. Further processing may involve dissolution and filtration of the gum to remove impurities, followed by spray drying or roller drying (Phillips and Williams, 2009) . Gum arabic is a naturally occurring exudate collected from *Acacia senegal* trees and, to a lesser extent, from *Acacia seyal* trees (Islam et al., 1997). It is one of the oldest and most important industrial gums. The Ancient Egyptians used gum arabic as an adhesive when wrapping mummies and in mineral paints when making hieroglyphs (Verbeken, Dierckx, and Dewettinck, 2003). In modern times, the most important applications of gum arabic have been not as an adhesive but as an emulsifier in the food and pharmaceutical industries. Gum arabic is considered to be the best gum in use in dilute oil-in-water emulsion systems (Garti, 1999), one important example of which is the use of citrus oils as flavoring agents in soft drinks where the oils are converted into a water-dispersible emulsion (Verbeken et al., 2003).

Table 1.2 Classification of gums (Ahmed, 2012)

Natural gums	Modified (semi-synthetic) gums	Synthetic gums
Plant exudates	**Cellulose derivatives**	**Vinyl polymers**
Arabic		
Tragacanth	Carboxymethyl cellulose	Poly vinyl pyrrolidone
Karaya		
Gatti	Methylcellulose	(PVP)
Plant extracts		
Pectins	Hydroxypropylmethyl- Cellulose	Polyvinyl alcohol (PVA)
Arabinogalactan		
(larch gum)	Methylethylcelulose	**Carboxyvinyl polymer**
Plant seed flours		
Locust Bean	Methylethylcelulose	(carbopol)
Quar		
Psyllium seed	Hydroxypropylcellulose (klucel)	**Ethyleneoxide polymers**
Quince seed		
Seaweed extracts	Low methoxy pectin	Polyox
Agar		
Alginates	**Microbial fermentation gums**	
Carrageenan		
Furcellaran	Dextran	
Cereal starches		
Seed starches	Xanthan gum	
Corn		
Wheat	Pregelatinized starches	
Rice		
Waxy maize	**Modified starches**	
Sorghum		
Waxy sorghum	Carboxymethyl starch	
Tuber starches		
Potato	Hydroxethyl starch	
Arrowroot		
Tapioca	Hydroxypropyl starch	
Animal		
Gelatin		
Albumen		
Casein		
Vegetable		
Soy protein		

1.7. *Acacia* species

Over 1350 species of *Acacia* exist around the world. About 185 are endemic to the Americas, 95 to Asia and the Pacific, nearly 1000 are native to Australia, and 150 are African native (Kull and Rangan, 2008). The genus *Acacia* is the second largest within the Leguminosae family and contains at least 900 species. With their extensive root system, *Acacia* trees can be found in semi-arid areas in Australia, India, and America, but mainly in the Sahelian region of Africa. They are multipurpose trees, not only producing gum, but also preventing desert encroachment, restoring soil fertility, and providing fuel and fodder. Almost all commercial gum comes from the so-called gum belt of Africa, a vast area which extends over Mauritania, Senegal, Mali, Burkina Faso, Benin, Niger, Nigeria, Chad, Sudan, Eritrea, Ethiopia, Somalia, Uganda, and Kenya (Coppen, 1995). Sudan is the world's largest producer of gum arabic, followed by Nigeria, Chad, Mali, and Senegal. Gum from the Sudanese Kordofan region is known as the best quality gum and is used as the standard to judge gums obtained from other areas. Commercial gum arabic is collected from a number of *Acacia* species, of which *Acacia senegal, Acacia seyal*, and *Acacia polyacantha* are the most widespread in the gum belt. *Acacia laeta*, *Acacia karoo*, and *Acacia gourmaensis* are some other gum yielding species with a more limited distribution (Islam et al., 1997). In Sudan, the gums from *Acacia senegal* var. *senegal* and *Acacia seyal* var. *seyal* are

referred to as hashab and talha respectively, the former considered of higher quality (Baldwin, Quah, and Menzies, 1999). Most of these species grow scattered in the wild and gum from these untended trees is collected by semi-nomadic people. Cultivation is only practiced for *Acacia senegal* var. *senegal*. Particularly in Sudan, wild stands of *Acacia* trees are replaced by monocultures of *Acacia senegal* var. *senegal* in order to facilitate collection and obtain a more consistent quality(Verbeken et al., 2003). Gum arabic from other African countries may be variable in quality, because it may contain gums obtained from different species which occur jointly in the collection area. *Acacia senegal* var. *senegal* is a thorny tree that reaches a height of 4.5–6.0 m. It is very drought-resistant and grows on sites with annual rainfall of 100–950 mm and dry periods of 5–11 months. It also tolerates high daily temperatures of up to 45C or more, dry winds, and sandstorms. After 5 years, trees reach maturity and are tapped. Although gum can be tapped from the trees after 3 years, the quality and yield are consistent only after 5 years, suggesting that gum biosynthesis and tree growth are in competition with each other (Joseleau and Ullmann, 1990).

1.8.*Acacia senegal* var. *senegal*

Acacia senegal var. *senegal* is a shrub or small tree 2 – 12 m tall, with a yellowish or grayish white, rather rough bark. The species has a wide distribution in Sudan

gum belt (Awouda, 1974) in sandy soils under annual rainfall of 280 – 450 mm and on dark clays under rainfall > 500 mm (Badi, Ahmed, and Bayoumi, 1989).

The trunk may vary in diameter up to about 30cm. The bark is grayish-white; although in old trees growing in the open it may be dark, scaly and thin, showing the bright green cambium layer just below the surface if scratched with a nail. The slash is mottled red. Powerful hooked thorns, 3-5 m long, with enlarged base appear at the nodes of the branches, usually in3s. They are sharp, with some pointing forwards and others backwards. Leaves bipinnate, 3-8 pinnae (glands between uppermost and lowermost pinnae); rachis up to 2.5 cm long; pinnacles are pairs of 8-15, green; 2 stipular spines strongly re-curved with a 3rd pseudo-stipular between them. Flowers yellowish-white and fragrant, in cylindrical, axillary pedunculate spikes, 5-10 cm long; calyx of each flower has 5 deep lobes, 5 petals and a mass of short stamens; pistil inconspicuous. The pods are straight, thin, flat, shortly stipulates and oblong (7.5 x2 cm), green and pubescent when young, maturing to shiny bronze, often with dark patches and bearing prominent veins; seeds 3-6, smooth, flat, rather small, shiny, dark brown. Varietal differences in *Acacia senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as the presence of or absence of hair on the axis of the flower spike, color of the axis, shape of pod tips, number of pinnae pairs, occurrence of a distinct trunk and shape of the crown. Four different varieties

of *Acacia senegal* are recognized: var. *senegal,* var. *kerensis Schweinf.,* var. *rostrata Brenan and* var. *leiorhachis Brenan*. The generic name '*Acacia*' comes from the Greek word 'akis', meaning a point or a barb.

Drought-tolerant, *Acacia senegal* var. *senegal* is the characteristic species in the drier parts of Sudan and the northern Sahara and is to be found throughout the vast area from Senegal to the Red Sea and to eastern India. It extends southwards to northern Nigeria, Uganda, Kenya, Tanzania and southern Africa. In India it is found chiefly in Sind and Ajmer. In Sudan, the tree exists both in the wild and is cultivated -mainly on sandy hills, but is also grows well in cotton soil.

Figure (1.1): ***Acacia senegal*** **var.** ***senegal*** **Tree.**

1.8.1. Botanical classification

Kingdom: Plantae

Division: *Magnoliophyta*

Class: *Magnoliopsida*

Order: *Fabales*

Family: *Fabaceae (Leguminosae)*

Subfamily: *Mimosoideae*

Tribe: *Acacieae*

Genus: *Acacia*

Species: *senegal*

English name: Gum Arabic tree, three thorned *Acacia.*

Arabic name: Hashab (El Amin, 1977; Vogt, 1995).

1.9. *Acacia mellifera*

Acacia mellifera is a low, branched tree with a more or less spherical crown. Black bark on stem becomes ash-grey to light brown on the branches, bearing small, short, sharply hooked spines in pairs. It has shallow but extensive rot system radiating from the crown, allowing the plant to exploit soil moisture and nutrients from a large volume of soil. The roots rarely penetrate more than 1m. Leaves characterized by2 pairs of pinnulae, each with a single pair of leaflets. Leaflets are elliptic 0.6-2 cm long and 0.6-1.2 cm wide, glabrous and highly coloured beneath.

Flowers are sweetly scented, especially at night, in elongated spikes, cream to white in spiciform racemes, up to3.5 cm long; pedicels 0.5-1.5 m long; calyx up to 1m long; corolla 2.5-3.5 m long. The papery pods with 2-3seds are reticulate, flat, elongated, 2.5-.5 cm long, 6cm wide, hemmed, sometimes more or less narrowed between the seeds. The specific name *mellifera* means 'honey-bearing'.

Acacia mellifera is a commonly occurring shrub on rangelands throughout the savannah in western, eastern and southern Africa. The train preference is rocky hillsides with rainfall along seasonal watercourse, mixed with other trees. If left unattended, especially if grazing is heavy and no fires check its spread, it may form dense, impenetrable thickets, 2-3 m high and sometimes hundreds of meters across, slowly taking over good grazing land. This species is drought-tolerant.

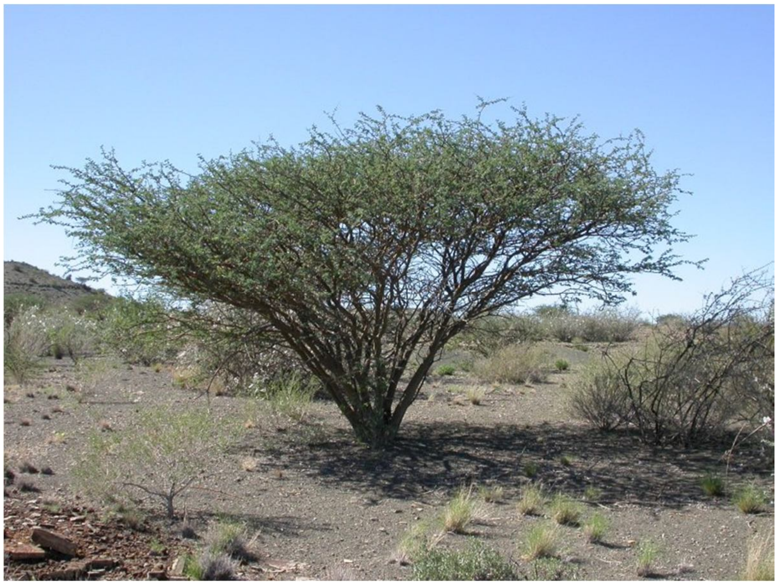

Figure (1.2): ***Acacia mellifera*** **Tree.**

1.9.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *mellifera*

English name: Black thorn

Arabic name: Kitir (El Amin, 1977; Vogt, 1995).

1.10. *Acacia seyal* var. *seyal*

Small, slender tree, reaching 6-15 m in height, with a stem diameter up to 60 cm, develops a characteristic umbrella-shaped canopy in adult individuals, usually thin and rather scarce foliage. Bark is usually smooth, pale green to greenish yellow when young or orange on exposure after the old bark has sloughed off. Bark smooth, peeling, rust-red or pale-green (both types may coexist in any population), covered with a pruinous, rusty, powdery coating. Bright red mottled slash, exuding a yellowish gum. Twigs with many small reddish glands and paired axillary thorns, are up to 7 cm long, narrow and straight, vulnerant-sharp-ended and grey in color. Leaves are dark green, with 4-12 pairs of pinnae having each 10-22 pairs of leaflets. Rachis is up to 8 cm long clustered by 2 or 3. Flowers clustered by 2-3 with bright yellow globose heads ca 1.5 cm in diameter on peduncles about 3 cm long starting from the leaves axils. Pods hanging, slightly curved, dehiscent, light brown when mature, 10-15 cm long by 1 cm wide at the bottom, containing 6-10 seeds each. *Acacia seyal* var. *seyal* grows on fine-textured soils.

Acacia seyal var. *seyal* occurs from Senegal to the Red Sea and in Arabia. It is common in many other parts of Africa, especially north of the equator, from 10 to 12 degrees. It also occurs in east and southern Africa. In the southern and western Sudan, it is one of the most common trees in the savannah and often occurs as a pure forest over quite large areas of the country side. Frequently, it grows in

groups or patches, sometimes of considerable size, in areas inhabited by *Acacia senegal*. This species is characteristic of the Nile region. It is tolerant to high pH (6-8), salts and periodic flooding.

Figure (1.3): *Acacia seyal* var. *seyal* Tree.

1.10.1. Botanical classification

Family: *Leguminosae*

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *seyal*

English name: Thirsty thorn

Arabic name: Talha (El Amin, 1977; Vogt, 1995).

1.11. *Acacia tortilis* var. *raddiana*

Acacia tortilis var. *raddiana* is a small to medium-sized evergreen tree or shrub that grows up to 21 m tall; well-developed multiple boles support a flat-topped or rounded, spreading crown; bark grey to black or dark brown, rough, fissured or smooth; young branch lets densely pubescent or glabrous to sub glabrous and red to brown; spines paired, 2 types-long, straight and white, or short, brownish and hooked; they range from 1.2 to 8 cm in length. Leaves glabrous to densely pubescent, glandular, short at 1.25-3.75 cm long; petiole 0.2-0.9 cm long, with a gland; rachis 0.3-2 cm long, glabrous to densely pubescent, with a small gland at the junction of the apical pair of pinnae; pinnae 2-10 pairs; leaflets 4-22 pairs per pinnae, 0.5-4 (6 max.)x 0.2-1 mm, glabrous to densely pubescent on the underside; margins with or without cilia, linear to linear oblong. Inflorescence globose heads; peduncle white, pubescent, 0.4-2.5 cm long, with involucel on the lower half; flowers white or pale yellowish-white, sessile or shortly pedicellate, scented, 0.5-1.1 cm in diameter, on axillary peduncles; calyx 1-2 mm long; corolla 1.5-2.5 mm long. Pods variable, indehiscent, spirally twisted or rarely almost straight, 7-10 cm long, 6-10(max. 13)mm broad, longitudinally veined, leathery, glabrous to tomentellous or villous, somewhat constricted between the seeds; seeds oblique or parallel to long axis of pod, 4-7 x 3-6 mm, compressed; areole 3-6 x 2-4 mm. The name *tortilis* means twisted and refers to the pod structure.

Acacia tortilis var. *raddiana* is drought resistant, can tolerate strong salinity and seasonal water logging and generally forms open, dry forests in pure stands or mixed with other species. The long taproot and numerous lateral roots enable it to utilize the limited soil moisture available in the arid areas. It tolerates a maximum temperature of 50 **C** and a minimum temperature close to 0**C**.

Figure (1.4): *Acacia tortilis* var. *raddiana* Tree.

1.11.1. Botanical classification

Family: Leguminosae

Subfamily: *Mimosoideae*

Genus: *Acacia*

Species: *tortilis* var. *raddiana*

English name: Umbrella thorn

Arabic name: Sayal (El Amin, 1977; Vogt, 1995).

1.12. Gum Arabic trade

France and United Kingdom, former colonial powers, maintain a significant stranglehold on the trading and processing of the gum. More generally, while raw gum arabic is only produced in African, Caribbean and Pacific Group of States (ACP) countries, both import and export trade are of major importance for European countries and the United States. It highlights how little gum is processed in Africa, with the best part of the added value being achieved in Western countries. This is estimated at between 100 and 180%. The gum is, frequently, exported raw; only manual cleaning, sifting and sorting operations are carried out to remove the many foreign bodies that are present. Crushing and grinding units also exist, the first stage in processing. However, some modern units can be found in Africa, with atomization towers and/or analysis laboratories and quality standards, such as Dansa Food Processing Co. Ltd, of the Dangote group in Nigeria, or Sanimex in Chad, in partnership with the French Alland et Robert, or Khartoum Gum Arabic Processing Co (GAPC) in Sudan. The international gum arabic market fluctuates and has seen considerable variations. Many factors contribute to this volatility, such as increasing demand, instability of supply and variability in quality and price (UNCTAD, 2013).

1.13. Gum Arabic exports

Over the first decade of 2000, exports almost tripled from 52 000 tones in 2001 to 142 000 tones in 2010, accelerating from 2005, with the exception of 2008. Africa contributed to around 70% of exports in 2010. Whilst about fifteen countries export gum today, Sudan, Nigeria and Chad still dominate with at least 90% of African supply. Historically, Sudan was the principal supplier of gum Arabic, with a market share of about 80%. Exports halved in 40 years from 60 000 tons a year in the 1960s-70s to 30 000 tons a year in the 1980s-90s, rising again in the middle of the 2000s with a volume in excess of 35 000 tones. Today, it represents between 40 and 50% of global supply. With sharp fluctuations, Sudan exported an average of almost 30 000 tons a year 2001 and 2010. Whilst the United States have imposed economic sanctions on Sudan since 1997, gum Arabic has always been the exception with the United States being the second customer behind France. Chad and Nigeria emerged as important producers in the 1990s. In the last two years Nigeria and Sudan have been competing for first place in worldwide exportation. Chad, which primarily exports *talha* gum, became increasingly important from the end of the 1990s with exports of between 10 000 and 17 000 tons depending on the year, averaging 12 500 tons a year between 2001 and 2010. A characteristic of Nigeria is that India is its second customer, with a sharp increase in exports (from 300 tons in 2006 to 5 784 tones in 2010).

European countries and the United States occupy the top spots among exporting countries, mainly with processed gum. France, leader in this sector, confirms its first position with flows of exports increasing by 66% between 2001 and 2010 (almost 28 000 tones in 2010). However its share in terms of value in worldwide exports reduced regularly, from 40% in 2001 to 20% in 2010. It is followed by the United Kingdom and the United States (Neilson, Pritchard, and Yeung, 2014).

1.14. African gum belt

The gum belt refers to a broad band, situated at a latitude of between 12° and 16° North, stretching across sub-Saharan Africa, from Mauritania in the West, through Senegal and Mali, Burkina Faso, Niger , Northern Nigeria to Sudan, Eritrea, Ethiopia, Kenya, Somalia and Northern Uganda in the East. Most of these countries appear in the statistics as sources of gum arabic, although they greatly differ in terms of the quantities involved. We can assume that they all have a comparative advantage in the production of gum arabic on account of the natural conditions that prevail and the presence of *Acacia senegal* or *Acacia seyal* on their soil (Macrae and Merlin, 2002).

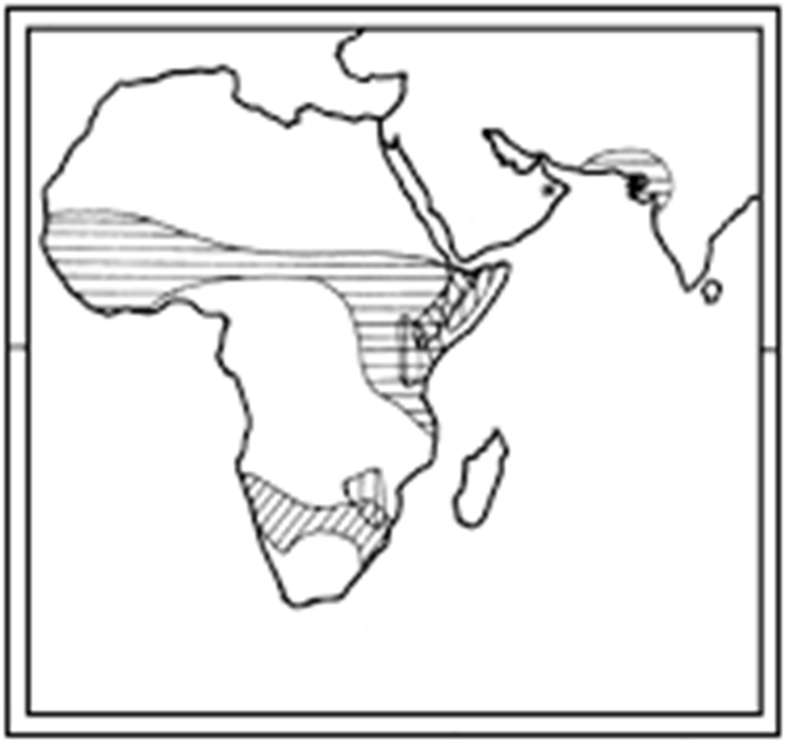

Figure (1.5): African gum belt.
Figure 1. 1

1.15. Grades and qualities of gum arabic sold on the world market

The Sudan has established a very detailed classification for its hard variety of gum arabic and this has become the reference on the world market. This classification known as Kordofan, takes its name from the main producing area in the country. Kordofan is a hard variety of gum that comes from the *Acacia senegal* var. *senegal* (Macrae and Merlin, 2002). Some typical grades of Sudanese gum available are listed in Table 1.3.

Table 1.3 Grades of gum arabic (Macrae and Merlin, 2002; Williams and Phillips, 2000).

Grade	Description
Hand-picked selected	The most expensive grade. Cleanest, lightest colour and in the form of large whole nodule, Ø >20 mm**.**
Cleaned and sifted	The material that remains after hand-picked selected and siftings are removed. Comprises whole or broken lumps varying in colour from pale to dark amber.
Cleaned	The standard grade varying from light to dark amber. Contains siftings but dust removed. Whole nodules plus fragments , 10 < Ø <20 mm**.**
Siftings	Fine particles remaining following sorting of the choicer grades. Contains some sand, bark and dirt. Fragments and siftings, 2.5<Ø < 10 mm.
Dust	Very fine particles collected after the cleaning process. Contains sand and dirt. Ø< 2.5 mm**.**
Red	Dark red particles **-** Rejects – local use only**.**

1.16. Weighting agents

Cloudiness or opacity (cloudy appearance) is an important property in citrus beverages, since it enhances their juice-like appearance and gives it a natural fruit juice appeal. This property is achievable through the addition of oil-in-water emulsions known as clouding agents. These emulsions are thermodynamically unstable and tend to break down during storage. Moreover, product and legal constraints put severe limits on materials that can be used to insure emulsion stability, particularly the introduction of weighting agents into the oil phase.

Weighing agents (density-adjusting agents) are lipophilic compounds with specific gravity higher than that of water and have a restricted use because of the perceived health risk disadvantage, undesirable taste, and oxidative instability. The stability of beverage emulsions is a problem of serious concern faced by the flavor and beverage industry. This research carried out by the authors on basic factors affecting the physical stability of emulsions having a bearing on droplet size, rheological properties of emulsion and phases components, and the stability of emulsion in concentrated form without addition of weighting agents.

1.17. Rheology

Rheology concerns the flow and deformation of substances and, in particular, to their behavior in the transient area between solids and fluids. Moreover, rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place. The science of rheology has many applications in the fields of food acceptability, food processing, and food handling. Foods, however, are complex materials structurally and rheologically and, in many cases, they consist of mixtures of solids as well as fluid structural components. Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished foods. There are several approaches to conduct these rheological characterizations, and the selected

technique pretty much depends on the specific product and the functional characteristics in need to be analyzed. Several different types of equipments are available to scientists as a tool in food rheological studies leading to acceptable results in most design situations(Tabilo-Munizaga and Barbosa-Cánovas, 2005). Rheology is concerned with how all materials respond to applied forces and deformations. Basic concepts of stress (force per area) and strain (deformation per length) are key to all rheological evaluations. Stress(r) is always a measurement of force per unit of surface area and is expressed in units of Pascal (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface. On the other hand, strain represents a dimensionless quantity of relative deformation of a material. The direction of the applied stress with respect to the material surface will determine the type of strain. Normal strain (e) occurs when the stress is normal to a sample surface. Foods show normal strain when compressed (compressive stress) or pulled apart (tensile stress) (Nielsen, 1998).

The objectives of this work are:

- To characterize the *Acacia* gum samples from different species (*Acacia senegal* var. *senegal, Acacia mellifera, Acacia seyal* var. *seyal*, & *Acacia tortilis* var. *raddiana*.)
- To study emulsions prepared using *Acacia* gums under the study.
- To explore viability of blending *Acacia* gums in preparing emulsions.
- To study the rheological properties of gums and emulsions prepared from gums and their blends.