Physicochemical Characterization of Galactomannan from Sugar Palm (Arenga saccharifera Labill.) Endosperm at Different Stages of Nut Maturity

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A water-soluble polysaccharide was extracted from the endosperm of nuts of Arenga saccharifera Labill. at different stages (young, 8–12 mo old; mid mature, 16–18 mo old; and mature, 22–24 mo old) of maturity. The polysaccharide was extracted with water, precipitated with 95% ethanol and further purified with Fehling solution and then freeze dried. The Arenga gum samples were white and powder-like after drying; insoluble in organic solvents, slightly soluble in inorganic solvents, and soluble in hot and cold water. Specific rotation values [α]D²⁷ of +32.97, +39.53 and +35.93 were obtained for the purified gum samples, young, mid mature and mature, respectively, before inversion; corresponding [α]D²⁷ values after inversion were -35.58, -41.70, and -41.03. The specific gravity of all gum isolates at different stages of nut maturity and those of commercial gums were not significantly different and was equal to the density of water at standard room temperature (25°C). The water-holding capacity of the three gum isolates — 42.55%, 47.00%, and 47.28%, respectively, were not significantly different from the value for gum ghatti. The gelatinization temperature of the gum isolates were the same (30–70°C). Viscosity of the gum isolates increased with concentration and maturity. Total sugar and soluble protein slightly increased with maturity while total reducing sugar remained the same upon maturity. The Arenga gums had high molecular weights of >2M daltons. Analysis by gas chromatography showed that the gum was composed of mannose and galactose and can, therefore, be correctly termed as galactomannan. The mannose:galactose (M/G) ratio of the Arenga galactomannan increased with maturity (2:1, 3:1 and 5:1) for the young, mid mature, and mature samples, respectively.

Key Words: Arenga saccharifera, galactomannan, gums, physicochemical characteristics

INTRODUCTION

Arenga saccharifera Labill. is a well known sugar palm in the humid tropics. Its generic name is derived from the Javanese word for sugar palm (Arenga). Its specific name, from Latin saccharum and Greek saccharon, also comes from sanskrit sarka, which mean sugar. The plant belongs to the subfamily Aracoidae, tribe Caryotae of the Palmae family. It is an uncultivated plant that grows in primary and secondary growth forests and in abandoned lands at low and medium altitudes in the Philippines. Kaong, as Arenga is known in the Philippines, is used as a source of sugar, wine, vinegar, and kulang-kaleng. The cooked endosperm of young sugar palm fruits, about 12–18 mo old, are used as ingredients in fruit mixes and desserts. However, there are no reported uses for the older nuts (>18 mo). High value products such as gums can be extracted from the Arenga endosperm since it has gelatinous texture. Gums obtained from plants are

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solids that consist of mixtures of polysaccharides, which are either water-soluble or absorb water and swells up to form a gel or jelly when added to water. Insoluble in oils or organic solvents, gums are often complex and on hydrolysis yield simple sugars such as arabinose, galactose, mannose, and glucuronic acid.

The immature unripe gelatinous endosperm of Arenga saccharifera has been shown to contain a gum composed mainly of water-soluble polysaccharide galactomannans that consists of repeating mannose (M) (linked β1→4) and galactose (G) (linked α1→6) unit with 2:1 M/G ratio (Kooiman 1971). No other work on Arenga galactomannan has been reported. Galactomannans are reserved polysaccharides of plants that form highly viscous substances commonly known as gums. Gums are either hydrophobic or hydrophilic high molecular weight molecules with colloidal properties. They produce gels in appropriate solvent or swelling agents and form highly viscous solution with low dry substance content (Whistler and BeMiller 1958). They also form stable solutions, and have the ability to form gel at very high temperature. They have some important properties such as strong water-binding capacity and stability in solution which is a characteristic of a textural modifying agent for different types of products. Due to its colloidal properties, the term “gum” is also referred to as hydrocolloid (Meer 1977). There is an interplay between viscosity and gelling characteristics of any specific gum, and these factors must be taken into consideration when gums are used. Commercial gums such as gum arabic, gum ghatti, gum karaya, gum tragacanth, locust bean gum, and guar gum are well known due to their wide applications in industries, especially in food industry, pharmaceuticals, cosmetics, paper products, paints and plasters, well drilling, mining and explosives, and fire fighting.

While the young Arenga saccharifera nut endosperm contains an edible galactomannan, the older (> 18 mo) nuts that do not have any reported uses might be a good industrial source of edible gum, which could be used as stabilizers, thickening agent, and gelling agent in the food industry. Its possible health uses could also be explored.

This study aimed to isolate and purify the galactomannans from the endosperm of Arenga saccharifera nuts at different stages of maturity. The physicochemical properties and chemical composition of Arenga galactomannans or gums were also determined and compared with those of commercially available gums.

MATERIALS AND METHODS

Sample Collection. Samples of the nuts of Arenga saccharifera Labill. at 3 different stages of maturity were collected at Barangay Balagbag, Cuenca, Batangas. Maturity of the fruits was determined by tagging the nuts from pollination and by considering the hardness of the endosperm.

Sample Preparation. After collection, the endosperm was gathered by dividing the nut into halves and the endosperm was taken out with a small knife. The collected endosperms were kept in a refrigerator at 2–4°C for at most 24 h prior to isolation and purification.

Chemical Analysis. Moisture content, ash, crude fat, crude protein, crude fiber, and nitrogen free extract (total carbohydrate) were determined using standard procedures set by the Association of Official Analytical Chemists (AOAC 1995).

Extraction and Isolation of the gum. Extraction and isolation of the water-soluble polysaccharides from endosperm of sugar palm were done using the procedure of Kooiman (1971). The endosperm (~170 g) of sugar palm at different stages of maturity was suspended in 500 mL distilled water for 3 d at 0°C and was homogenized using a blender. The viscous mass was further stirred using a magnetic stirrer overnight at room temperature and centrifuged at x 9000 g at 0°C. The clear supernatant liquid was separated from the residue and an equal amount of 95% ethanol was added to the supernatant liquid with continuous stirring. The resulting white precipitate was allowed to settle and separated by decantation. The precipitate was washed with ethanol and freeze dried.

To purify the gum, the dried gum was redissolved in distilled water with continuous stirring until completely dissolved. Fehling’s solution was added to the gum solution resulting in the formation of light blue precipitate. The precipitate was separated by decantation, washed and suspended with distilled water and 2 M hydrochloric acid solution. The resulting mixture was stirred and an equal amount of 95% ethanol was added to regenerate the gum. The gum extract was washed again with ethanol and freeze dried.

Qualitative Analysis of the Gum

Solubility Test of Gum Extracts

Fifty (50) mL each of various organic solvents (petroleum ether, acetone, chloroform, benzene, methanol, ethanol, isopropanol, and butanol) and inorganic solvents (5% HCl, 5% H₂SO₄, 5% H₃PO₄, 5% NaOH, 5% NaHCO₃, 1 M and 0.1 M NaCl) were added to 0.50 g of the dried
purified gum extract. Solubility of the gum extract was also determined using hot (80–90°C) and cold water (10–15°C). Dissolution of the samples in test solvents was observed.

Benedict’s Test for Reducing Sugars (Davis 1963)

Each of the gum isolates (0.025 g) was dissolved in 10 mL distilled water. One (1) mL of Benedict’s reagent was mixed with 3 mL solution. The reaction mixture was heated in hot water bath until the color changed and a brick red precipitate formed.

Ninhydrin Test for Protein (Holmes 1968)

The purified gum (0.025 g) was dissolved in 10 mL distilled water. Ten (10) drops of 10% ninhydrin solution was added to 1–2 mL gum solution and was placed in a hot water bath. Formation of light lavender color indicates the presence of protein.

**Physicochemical Properties of the Gum**

**Determination of Specific Rotation of Gums (Dawber et al. 1966)**

Each gum sample (0.05 gram) was dissolved in 100 mL water. The gum solutions were filtered and equilibrated in 27°C constant temperature bath. Optical rotations were determined before addition of HCl. Twenty-five (25) mL of 4 N HCl was mixed with an equal volume of the gum solution and equilibrated in 27°C constant temperature bath. Optical rotations were observed every 15 min for the first hour of determination. Inversion of sugars present in the gum solutions was determined after standing in 27°C water bath for 2 d with optical readings made daily.

**Specific Gravity**

Specific gravity of the gum isolates was determined following the procedure of Skoog and West (1963) using standardized pycnometer.

A dried and clean pycnometer was filled with 1% gum solution that was previously equilibrated at 20°C to the indicated level, capped and placed in 25°C C constant temperature bath for 30 min. Afterwards, the pycnometer was dried and weighed. Specific gravity of the solution was obtained by dividing the weight of the gum solution by the weight of water at 25°C determined previously.

**Water-Holding Capacity (Jaurigue 1981)**

The gum (0.5 g) was dissolved in 30 mL water and stored overnight at 2–4°C. The solution was then centrifuged for 30 min at x 2000 g at 30°C. The supernatant was drained for 15 min. The volume of water decanted was measured and percent water retention was calculated.

**Viscosity and Gelatinization Temperature (Stoloff 1958)**

Four (4) different concentrations (0.5, 0.75, 1.0, and 2%) of gum solutions were prepared by heating and continuous stirring using a magnetic stirrer until the solution gelatinized. The gelatinization temperature was recorded. The actual viscosity of the gel was measured at 30°C C at 2.5 rpm by a Well Brookfield Cone/Plate Microviscometer model RVT. The viscometer reading in centipoise was multiplied by a factor equivalent to the spindle number that has been used.

**Chemical Properties**

**Total Sugar**

Total sugar content was determined according to the procedure of Dubois et al. (1956). Each gum sample (0.005 g) was dissolved in 100 mL distilled water. One (1) mL of 5% phenol solution was added to 1 mL gum solution in acid-washed test tube. Five (5) mL concentrated H₂SO₄ (reagent grade 98.5% with specific gravity of 1.84) was directly and rapidly added to the test tubes. The solution was allowed to stand for 10 min and was shaken. Absorbance of the solution was read at 490 nm using a Biorad Model 3550 UV microplate reader.

Standard calibration solutions ranging from 0.01 to 0.60 mg/mL was prepared in triplicates from 10 mg/mL stock galactose solution.

**Total Reducing Sugar**

The reducing sugar of the gum samples was determined following the procedure of Miller (1959).

One (1) gram of each gum samples was dissolved in 100 mL distilled water. Three (3) mL DNS reagent (prepared as: 1 g dinitrosalicylic acid, 0.2 g phenol, 1 g NaOH and 20 g rochelle salt dissolved in distilled water up to 100 mL) was added to 1 mL gum solution. The solution was heated in hot bath for 15 min. The solution was cooled and diluted to 20 mL with distilled water. Absorbance was read at 550 nm in a microplate reader. Blanks were prepared by substituting distilled water for the gum solution.

Standard calibration solutions ranging from 0.1 to 1 mg/mL were prepared in triplicates from 1 mg/mL stock galactose solution.

**Total Soluble Protein (Lowry et al. 1951)**

One % (w/v) solution of each gum sample was prepared. Five (5) mL of freshly prepared reducing agent was
added to 0.5 mL of gum solution and immediately mixed using vortex mixer. Folin reagent (0.5 mL) was added to the solution after standing for 10 min. After mixing, the solution was allowed to stand for 30 min, and its absorbance was measured at 660 nm in a UV-Vis spectrophotometer.

Standard BSA solution ranging from 110 to 210 μg/mL was prepared in triplicate and treated in the same way as the sample. Blank was also prepared using distilled water.

Monosaccharide Composition
The monosaccharide composition of the gum isolates at different stages of maturity was determined by gas chromatography as alditol acetates using the method of Blakeney et al. (1983). Samples were digested in 72% H₂SO₄ and further hydrolyzed in 6M H₂SO₄. The hydrolysates were neutralized with NH₄ and reduced with NaBH₄. The reduced sugars were acetylated with acetic anhydride and the alditol acetate derivatives were analyzed by gas chromatography.

The monosaccharides were identified based on the retention times of the individual standards such as rhamnose, arabinose, xylose, mannose, glucose, and galactose, which were reduced and acetylated under the same conditions as the samples. Mixed standards (2 mg each) were also prepared to quantify the amount of sugars in the sample with myo-inositol as internal standard.

Physical Characterization
Molecular Weight Determination
Gel filtration using a Sephadex G-200 column was used for molecular weight determination. The polysaccharides used as standards were blue dextran (2000 KDa), gum tragacanth (840 KDa), gum arabic (580 KDa), and guar gum (220 KDa).

Two (2) mL of 1% solution of each sample (gum isolates and standards) were eluted in the column (30 cm x 2.5 cm) at a flow rate of 0.5 mL/min. The elution profile was followed by determining the total sugar in each fraction collected from gel chromatography.

Degree of Branching (Whistler 1973)
Gum isolates (200 mg) were dissolved in a 50-mL volumetric flask containing 25 mL CO₂-free distilled water. Ten (10) mL of 0.3M NaIO₄ and sufficient CO₂-free distilled water was added to the resulting solution to bring the volume to 50 mL. A blank was also prepared using distilled water instead of gum solution. The flask was capped and wrapped with used carbon paper and was kept in a dark place.

About 10 mL aliquots were removed from both blank and sample at 1, 4, 8, and 24 h after initiation of the reaction. To each aliquot was added 0.5 mL ethylene glycol. The samples were incubated for 10 min after which 2 drops of 1% phenolphthalein was added. The samples were then titrated with standardized CO₂-free 5 mM NaOH solution.

Statistical Analysis
Analysis of variance (ANOVA) was done by Randomized Complete Block Design (RCBD) and Duncan’s Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Proximate composition of Arenga endosperms
Proximate analyses show that the endosperm of sugar palm nuts at 8–12, 16–18, and 22–24 mo old, respectively, contained 90.23–92.28% water, 1.57–3.11% protein, 3.42–4.09% carbohydrates, 1.59–2.50 crude fiber, and 0.27–0.67 crude fat (Table 1).

<table>
<thead>
<tr>
<th>Samples (month old)</th>
<th>% moisture content</th>
<th>% ash</th>
<th>% crude fat</th>
<th>% crude protein</th>
<th>% crude fiber</th>
<th>% NFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-12 (young)</td>
<td>92.28⁵</td>
<td>0.12 ⁴</td>
<td>0.27 ⁴</td>
<td>1.42 ⁴</td>
<td>2.50 ⁵</td>
<td>3.42 ⁵</td>
</tr>
<tr>
<td>16-18 (mid-mature)</td>
<td>92.09 ⁶</td>
<td>0.29 ⁵</td>
<td>0.42 ⁵</td>
<td>1.57 ⁵</td>
<td>2.06 ⁶</td>
<td>3.57 ⁶</td>
</tr>
<tr>
<td>22-24 (mature)</td>
<td>90.23 ⁶</td>
<td>0.30 ⁵</td>
<td>0.67 ⁵</td>
<td>3.11 ⁶</td>
<td>1.59 ⁶</td>
<td>4.09 ⁶</td>
</tr>
</tbody>
</table>

Means followed by a common letter in a column are not significantly different at 5% level DMRT

The samples at 8–12 and 16–18 mo old were not significantly different in terms of moisture, crude protein, crude fiber, and carbohydrates while samples at 16–18 and 22–24 mo old were not significantly different in terms of ash and crude fiber. Crude fat content significantly increased during maturation of the nut. Significant increases in crude protein and carbohydrate contents of the endosperm of the maturing nut were observed, while moisture and crude fiber contents significantly decreased.
Isolation of gums from sugar palm endosperm

The endosperms of sugar palm (*A. saccharifera*) nuts differed in texture and weight as they matured (Table 2). The young sugar palm nut endosperm (8–12 mo old) was transparent, very soft and, lightest with an average weight of 0.82 g/nut (Figure 1). The 16–18 mo old nut has white endosperm, hard center, and was heavier with an average weight of 1.35 g/nut. The 22–24 mo old mature nut has white hard endosperm and was heaviest at 2.50 g/nut. The different samples can thus be described as young for the 8–12 mo old, mid mature for the 16–18 mo old, and mature for the 22–24 mo old nuts.

The purified gum at different stages of nut maturity is characterized by white, thread-like precipitate, which upon drying produced a powder-like substance (Figure 2). The most mature sample (22–24 mo old) has the highest gum content with 3.72%, followed by the mid-mature sample (16–18 mo old) with 2.71%, and the youngest sample (8–12 mo old) with 1.27%.

The sugar palm endosperm gum isolates were insoluble in organic solvents; mostly soluble in inorganic solvents such as salts, acids and bases, and; slightly soluble in cold and hot water similar to the characteristics of commercially available gums, except for gum arabic (Table 3).

The degree of branching or galactose content of the gums could explain the solubility of gums since the extension of mannan chains by galactose side chains prevents the formation of hydrogen-bonded intermolecular association.
For the gum isolates, since they contain galactose side chains in their structure or are highly branched [as shown later in the paper and also by Kooiman (1971)], they behave as partially soluble in hot and cold water. The same behavior was observed with the other commercial gums such as guar gum, gum tragacanth, and gum ghatti. Guar gum forms a viscous solution in hot and cold water due to its high degree of branching or high galactose content along the mannann chain. For gum tragacanth, its solubility behavior is due to its soluble fraction, tragacanthin, and insoluble fraction, bassorin (60–70% of its structure) (Rowson 1937). For gum ghatti, it also forms a viscous solution because it has a soluble fraction (almost 90%) and insoluble fraction in its structure (Stoloff 1958). Gum arabic is exceptional since it is totally soluble in water due to the presence of neutral or slightly acidic salt of a complex saccharide containing calcium, magnesium, and potassium ions that are highly water-soluble.

The gum isolates and the commercial gums gave positive results using the Benedict’s test. This confirms the presence of reducing sugar in their structure that is useful in verification of the gum’s structure.

The different gum isolates and commercial gums were also positive to the ninhydrin test indicating that the samples also contained proteins. These proteins likely are from cytoplasmic proteins, which co-precipitated during isolation and purification of the gum in addition to intrinsic wall protein. The protein can also be linked to galactomannan chain indicating that the gum may also be a glycoprotein (Tizard et al. 1989; Valentine and Salyers 1992).

Qualitative analysis proves that the gum isolates contain not only carbohydrates but also proteins. The presence of proteins also contributes to the physicochemical properties of the gum. Also, the study on the attractive interactions between proteins and carbohydrates is important in many biological systems and in pharmaceutical products and processed food (e.g. purification of macromolecules, microencapsulation of ingredients or cosmetics, fat substitutes, meat analogues, films, coating, packaging and others) (Dickinson 1998; Doublier et al. 2000; de Kruif and Tuinier 2001; Sanchez and Paquin 1997; Tolstoguzov 1996).

Physicochemical characteristics
The Arenga gum isolates as well as the other gums tested were found to be optically active (Table 4). Optical rotation of guar gum before inversion was lowest, while that of the mid-mature (sample B) Arenga was the highest. After inversion, gum tragacanth has the lowest whereas guar gum has the highest. Before inversion, the gums were dextrorotatory. After addition of HCl, they became levorotatory. The change in optical rotation of the gum solutions suggests that the sugars under went mutarotation and indicates that they can be digested or acted upon by enzymes in the human body if they could form the D-enantiomers, thus they are safe as food additives. Addition of HCl or partial acid hydrolysis could have cleaved the galactose side chains that is α-linked along the mannann chain. The alpha (α) linkage was easily cleaved because the β-linkage has relatively greater stability (Morrison and Boyd 1987).

### Table 4. Physicochemical characteristics of the gum isolates at different stages of nut maturity and some commercially available gums

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>A (young)</th>
<th>B (mid-mature)</th>
<th>C (mature)</th>
<th>Guar gum</th>
<th>Gum tragacanth</th>
<th>Gum arabic</th>
<th>Gum ghatti</th>
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<tbody>
<tr>
<td>Specific Rotation</td>
<td></td>
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<tr>
<td>Before</td>
<td>+32.97</td>
<td>+39.53</td>
<td>+35.93</td>
<td>+24.93</td>
<td>+26.05</td>
<td>+31.98</td>
<td>+33.72</td>
</tr>
<tr>
<td>After</td>
<td>-35.68</td>
<td>-41.70</td>
<td>-41.03</td>
<td>-44.18</td>
<td>-31.95</td>
<td>-38.47</td>
<td>-37.43</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.0035³</td>
<td>1.0055⁴</td>
<td>1.0055⁵</td>
<td>1.0065⁴</td>
<td>1.0065⁵</td>
<td>1.0045⁴</td>
<td>1.0045⁴</td>
</tr>
<tr>
<td>Gravity water holding capacity</td>
<td>42.55⁴</td>
<td>47.00⁵</td>
<td>47.28⁵</td>
<td>100.0⁴</td>
<td>53.68⁶</td>
<td>7.49⁷</td>
<td>44.90⁸</td>
</tr>
<tr>
<td>Gelatinization</td>
<td>30-70</td>
<td>30-70</td>
<td>30-70</td>
<td>30-60</td>
<td>30-62</td>
<td>45-90</td>
<td>30-65</td>
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<tr>
<td>Temperature (°C)</td>
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<td>Actual Viscosity (CPS)</td>
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<tr>
<td>0.5%</td>
<td>100⁸</td>
<td>115⁹</td>
<td>120⁹</td>
<td>140⁹</td>
<td>320⁹</td>
<td>95⁹</td>
<td>310⁹</td>
</tr>
<tr>
<td>0.75%</td>
<td>130⁹</td>
<td>150⁹</td>
<td>160⁹</td>
<td>200⁹</td>
<td>360⁹</td>
<td>110⁹</td>
<td>340⁹</td>
</tr>
<tr>
<td>1.00%</td>
<td>370¹⁰</td>
<td>440¹¹</td>
<td>630¹²</td>
<td>340¹³</td>
<td>820¹⁴</td>
<td>200¹⁵</td>
<td>800¹⁵</td>
</tr>
<tr>
<td>2.00%</td>
<td>980¹⁰</td>
<td>1160¹¹</td>
<td>1550¹²</td>
<td>1870¹³</td>
<td>3400¹⁴</td>
<td>250¹⁵</td>
<td>2000¹⁶</td>
</tr>
</tbody>
</table>

³Means followed by a common letter are not significantly different at 5% level DMRT.
The specific gravity of guar gum, gum tragacanth, gum arabic, and gum ghatti from literature were 0.9, 1.384, 1.487, and 1.08, respectively (Neukom 1989), which were almost the same with the experimental values for commercially available gums (1.0065 for guar gum and gum tragacanth, and 1.0045 for gum ghatti and gum arabic). The differences in values (ranged from 1.0035 to 1.0065) were not significant between the gum samples (Table 4) since specific gravity is a constant that varies slightly for any given kind of carbohydrates. It is of little value in determining the purity of the sample and it can only be used in the characterization of a given sample.

Viscosity values of gum isolates, gum tragacanth, gum Arabic, and gum ghatti at 0.5% and 0.75% concentration of gum solution are not statistically significant from each other, with the exception of guar gum (Table 4). Viscosity values at 1% concentration shows that Arenga gum from the most mature nut sample, gum ghatti, and gum tragacanth are not significantly different from each other, while the viscosity value of sample A is not significantly different to gum arabic. Guar gum had the highest viscosity among the samples. There was no significant difference in viscosity between and among the 3 Arenga samples at 2% concentration. However, the values are significantly different from the other gum samples, with guar gum as the highest and gum arabic the lowest. It can be observed that viscosity of the gum isolates increases with concentration and upon maturity.

Water-holding capacity is the ability of the gum to hold water and is equal to the moisture content of the gum after equilibrium has been established under a given condition. The water-holding capacity of the gum isolates increased with nut maturity from 42.55% to 47.28%, with more mature samples (16–18 mo old and 22–24 mo old) being significantly different from the young sample (8–12 mo old). However, the A. saccharifera gum had about 50% lower capacity to hold water compared to guar gum but had about seven (7) times greater capacity to hold water than gum Arabic. Its water holding capacity is also comparable to that of gum ghatti, which is also a galactomannan (Hirst and Jones 1948; Tischer et al. 2002). The water binding capacity of gums does not only depend on the functional group of carbohydrates that are hydrophilic but also to the proteins present in the gums since they also contain functional groups that are able to bind with water molecules (Jaurigue 1981).

Gelatinization temperature is a range of temperature within which a gum starts to swell irreversibly in hot water until the solvent (liquid) has been absorbed due to swelling of the gum and finally becomes immobilized (Glicksman 1969). Table 4 shows the gelatinization temperatures of Arenga gum isolates and some commercial gums. The 3 Arenga gums (at 2% solution) had gelatinization temperature from 30–70°C and formed gels at room temperature. Similarly, the commercial samples (2% solution) except for gum arabic also had gelatinization temperature starting at 30°C up to 60 to 65°C and, thus, also formed gel at room temperature. Gelatinization temperature is influenced by the structure of gums as well as its solubility behavior. The formation of viscous solutions of various gum samples even at room temperature could be due to the degree of branching and monomer units that make up these gums (Stoloff 1958). Gum arabic is totally soluble or is not viscous even up to 2% concentration of gum solution due to some neutral salts present in its structure which are highly soluble (Meer 1977). This gum can form viscous solution at 40–50% concentration.
Formation of gel is an important characteristic of hydrocolloids in food industry such as texture improvement and stabilization of food products.

**Chemical properties**

Percent total sugar content of the gum isolates slightly increased with increasing maturity of the nut: young (8–12 mo old), 59.6%; mid mature (16–18 mo old), 65.6%; and mature (22–24 mo old), 68.6%, and were significantly different from commercial gums except for gum Arabic (Table 5). Guar gum had the highest total sugars (98.2%) followed by gum tragacanth (88.4%), gum ghatti (85.2%), while gum arabic had the lowest percent sugar (70.4%).

The percent reducing sugar of gum isolates (young, 3.69%; mid mature, 3.87%; and mature, 3.94%) did not change significantly with maturity (Table 5). For commercial gums, gum ghatti (1.43%) had the lowest reducing sugar while gum tragacanth (3.79%) had the highest but was not significantly different from gum isolates.

Protein content of *Arenga* gums ranged from 1.36 to 2.11%, lower than the 3.69% and 4.38% of guar gum and gum tragacanth, respectively, and similar to the 1.03% and 1.64% of gum Arabic and gum ghatti.

Elution profile of the mixed standard containing rhamnose, arabinose, xylose, mannose, galactose, glucose, and myo-inositol is shown in Figure 3. Retention times of individual standards are 3.734 (rhamnose), 4.561 (arabinose), 5.394 (xylose), 9.672 (mannose), 10.511 (galactose), and 11.257 (glucose).

Monosaccharide composition of the gum isolates at different stages of maturity is shown in Table 6. All

**Table 5.** Chemical properties of the different gum isolates and some commercially available gums

<table>
<thead>
<tr>
<th>Samples</th>
<th>Total sugars (%)</th>
<th>Total reducing sugars (%)</th>
<th>Total protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (young)</td>
<td>59.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.36&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>B (mid-mature)</td>
<td>65.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.67&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>C (mature)</td>
<td>68.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.94&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Guar gum</td>
<td>98.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.69&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gum Tragacanth</td>
<td>88.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.38&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gum Arabic</td>
<td>70.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.03&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gum Ghatti</td>
<td>85.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.64&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup>Means followed by a common letter are not significantly different at 5% level by DMRT

**Table 6.** Physical and chemical properties of the gum isolates

<table>
<thead>
<tr>
<th>Properties</th>
<th>Samples</th>
<th>A (young)</th>
<th>B (mid-mature)</th>
<th>C (mature)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>&gt;2M</td>
<td>&gt;2M</td>
<td>&gt;2M</td>
<td></td>
</tr>
<tr>
<td>% Branching&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.61&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Monosaccharide composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galactose (M/G)</td>
<td>Gal (29.94%)</td>
<td>Gal (21.99%)</td>
<td>Gal (15.04%)</td>
<td></td>
</tr>
<tr>
<td>Man (64.08%)</td>
<td>Man (66.87%)</td>
<td>Man (74.08%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of monomer units&lt;sup&gt;1&lt;/sup&gt;</td>
<td>7013&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7720&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8072&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Mannose:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galactose (M/G) ratio</td>
<td>2:1</td>
<td>3:1</td>
<td>5:1</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Means followed by a common letter are not significantly different at 5% level by DMRT
gum isolates regardless of age showed 2 peaks as shown in Figure 4 corresponding to mannose (64.08% for the young sample; 66.87% for mid mature sample; and 74.08% for mature sample) and galactose (29.94% for the young sample; 21.99% for mid mature sample; and 15.04% for mature sample) and myo-inositol (internal standard). High values of percent hydrolysis indicate that the samples undergo complete hydrolysis. Mannose was found to be the predominant sugar, which implies that the backbone of the carbohydrate is a mannan chain (1,4-linked) and galactose molecules are probably present as side chains (1,6-linked). These results indicate that the polysaccharide in Arenga gum is galactomannan, similar to the observation of Kooiman (1971). The mannose:galactose (MG) ratio (2:1 for the young sample; 3:1 for mid mature; and 5:1 for mature) increased upon maturity, which implies that the degree of branching decreases as nuts of sugar palm matures. This also indicates that the galactomannan in more mature nuts would be less water-soluble than the galactomannan in younger endosperm. In mutant and normal coconut, the MG ratio of galactomannan was 3 at different stages of maturity (Samonte et al. 1987) These results agree with the result as the degree of branching (see below). The above results also suggest that gum from older Arenga nuts may have different food and pharmaceutical uses.

**Physical characteristics**

The 3 gum isolates of *Arenga* eluted starting at the void volume of Sephadex G-200, indicating that their molecular weights were greater than or equal to 2 million Daltons and could consist of molecules of varying sizes (Figure 5). Gums are reported to be high molecular weight molecules (e.g. 840 kDa for gum tragacanth, 580 kDa for gum Arabic, and 220 kDa guar gum) (Whistler and Miller 1958).

In the case of gum isolates, the water-binding capacity or hydration and viscosity increases upon maturity possibly due to the fact that mature sample (22–24 month old nut) is a longer molecule and less substituted as indicated by results in periodate oxidation. Although *Arenga* gum isolates had higher molecular weight (~2,000 kDa) than commercially available gums as stated above, their viscosities and water-holding capacity were lower possibly because commercially available gums are more highly branched than the gum isolates.

The degree of branching was determined by analyzing the number of terminal residues, which are oxidized by periodate to formic acid (HCOOH) which is measured by titration with sodium hydroxide (NaOH). The *Arenga* samples had 2.31%, 1.61%, and 1.13%,

![Figure 4](image-url)
respectively, for the young, mid mature, and mature samples, respectively (Table 6).

The total number of monomer units (average chain length) did not differ significantly among the 3 samples (Table 6). This is in agreement with the approximate molecular weight value and viscosity values (2% concentration) obtained for 3 gum samples. In general, as the gum increased in size, viscosity increased, too. The degree of branching, on the other hand, had an opposite effect on viscosity. When the molecular size increased (longer molecules) with decrease in degree of branching decreases, viscosity also increased.

Results of this study showed that the various physicochemical properties of Arenga gum makes it a suitable replacement for other widely used gums such as gum ghatti in food, drug, and cosmetic applications primarily as stabilizer for oil-in-water emulsion (Glicksman 1969). Gum ghatti is also used to replace gum arabic as emulsification agent in pharmaceutical formulations (Mantell 1947). It has been used in the preparation of dry, stable, oil-soluble vitamin product made by combining the active ingredients with gum ghatti and drying and pulverizing the blend (Dunn 1959). In foods, ghatti is effectively utilized as the emulsifier and stabilizer in maple syrups containing butter for use in pancakes and waffles (Topalian and Elsesser 1966). Also, the Arenga gum isolates have an advantage over gum ghatti because Arenga gums are white and thus do not impart colored components to food.

The health uses of Arenga gum isolates should be studied because recent studies on commercially available gums showed biomedical importance aside from food uses. Some of the reported beneficial health effects of gums are: anticancer and high antioxidant activities [guar gum (Gamal-Eldeen et al. 2006); Gum tragacanth (Pierrefiche et al. 1993); Gum Arabic (Ali et al. 2004); probiotic properties [ guar gum (Giannini et al. 2006); gum ghatti (Salyers et al. 1977).

Thus, the food and health uses of Arenga gums or galactomannans from the young and mature endosperms should be studied to widen the applications of this underutilized plant resource.

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REFERENCES


