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Chemical and Functional Properties of Mahlab Tree (*Prunus mahaleb*) Exudate Gum

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ABSTRACT

Prunus mahaleb (Mahlab) is one of the gums-producing species of the Rosaceae family. The gums produced by many members of this family were extensively investigated except those of Mahlab. Hence, the work aims to study the chemical and functional properties of this gum which is produced from trees grown in Jordan. Exudate nodules were collected in the summer of 2021 from Mahlab trees and sorted according to their color into grades I, II, and III. The chemical composition, hygroscopicity, swelling index, water absorption, emulsification and foaming capacities, solubility, and foam stability of these grades were measured. Proximate composition showed significant ($P \leq 0.05$) variations between the three grades in all of their proximate components except protein. Grade I had the greatest moisture and fat content of 18.0 and 3.29%, respectively. Grade III had the highest protein (though non-significantly ($P>0.05$) different from other grades) and ash content of 1.10 and 2.91%, respectively. All grades had similar, though significantly ($P \leq 0.05$) different levels of calcium, sodium, potassium, and magnesium. Also, their HPLC - detected sugar profiles consisted of xylose (17.65-19.77% w/w), rhamnose (10.10-12.34%w/w), arabinose (53.35-62.01% w/w) and galactose (9.88-14.50%w/w). Results showed significant ($P \leq 0.05$) differences between the three grades in their functional properties, with grade III having the greatest swelling index and water absorption capacity of 7.52 and 16.52%, respectively. Grade I has the greatest hygroscopicity of 6.57% while grade II has the greatest foaming capacity of 21.02%. All grades showed a non-Newtonian-type shear-thinning behavior. Based on the results of this study, it is evident that Mahlab tree exudate gums pose chemical and functional properties typical of other known hydrocolloids.

Keywords: Mahlab, *prunus spp*., hydrocolloids, gum sugars, gum rheology.

INTRODUCTION

Plant exudate gums are obtained naturally from fruits, trunks, or branches of the trees or after mechanical injury of the plant by incision of the bark, after the removal of branches, or after invasion by bacteria or fungi (Ergin *et al*., 2018, Barak *et al.,* 2020). Plant exudate gums usually form hard nodules or ribbons upon dehydration to form a protective sheath against microorganisms (Ameh *et al.,* 2015). As an important source of hydrocolloids, plant gum exudates are of great interest to food scientists and have been widely investigated (Rezaei *et al.,* 2016). Arabic, Tragacanth, Ghatti, and Karaya gums have played

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a significant role in international trade in a variety of sectors, including the food, pharmaceutical, textile, adhesive, and paper industries (Pachuau *et al.,* 2012). Due to their sustainable, biodegradable, and bio-safe characteristics (Fathi *et al*., 2016; Abbasi, 2017), exudate gums have been used in food products, as stabilizing, suspending, gelling, emulsifying, thickening, binding, and coating agents (Sharma *et al.,* 2020).

Prunus genus is economically valuable because many of its species are sources of fruits (plums, peaches, apricots, cherries, and almonds), oil, timber, and ornamentals (Malsawmtluangi *et al.,* 2014). Recently, several studies have been conducted to investigate *Prunus spp*. gum exudates and estimate their physicochemical, structural, rheological, and functional properties as well as their eventual exploitation in the food industry as substitutes for several synthetic food agents (Aftab *et al*., 2020).

Mahlab is a large perennial shrub or deciduous small tree grown throughout Mediterranean countries, as well as central Europe and Western and Central Asia (Özçelik *et al.,* 2012). Mahlab trees secrete sizable amounts of gums that have not been studied for their properties. The complex and heterogeneous nature of plant gums in terms of their chemical composition makes it difficult to predict their properties (Ameh *et al.,* 2015). Therefore, studying their physicochemical and functional properties is essential for their application in different food systems as emulsifiers, stabilizers, flavor encapsulaters, edible coatings, and thickeners (Fathi *et al.,* 2016). Besides their food applications, exudate gums have non-food applications such as pharmaceuticals, textiles, and cosmetics (Barak *et al*., 2021). This work aims to isolate, purify, and study the chemical composition as well as some of the functional properties of Mahlab exudates gum and compare them with Acacia.

Material and methods

Mahlab exudate gum samples

Exudates were collected from the trunks and branches of Mahlab trees in the summer of 2021. Samples were graded according to their color white to amber (grade I), reddish to tan (grade II), and brown to black (grade III). (Figure 1) After grading, gums samples were hand cleaned, cut into small pieces by knife ground using mortar and pestle, sieved through 180 µm sieve, packed in polyethylene bags, and kept in the freezer until analysis. Gum Acacia was obtained from Avonchem (Cheshire, UK).

Figure 1. Different grades of Mahlab exudate.

Proximate and other chemical analyses of the exudate gums

Moisture, ash, protein, and fat content were determined following the AOAC method no. 962.08, 935.42, 978.04, and 930.09 respectively (AOAC, 2011). A standard conversion factor of 6.25 was used to determine the protein content. Nitrogen-free extract (NFE) was calculated by difference. For mineral analysis, the ash of the respective samples was dissolved in 6 M HCl and filtered in Whatman no. 3 filter paper, before injection into High-Resolution Continuum Source Atomic Absorption Spectrophotometer (HR-CS-AAS, Analytik Jena ContrAA 800, Berlin, Germany). AOAC method numbers 965.09 were followed for Ca, Mg. Fe and Zn, 983.02 for Na and K, and 957.02 for P determination (AOAC, 2011).

Samples were purified in preparation for the sugar analysis according to the method described by Sharma *et al.* (2020) with minor modifications. Briefly, the crude gum was dissolved in water and the insoluble material was separated by centrifugation at 3000 rpm for 15 min. (Hettich Zentrifugen, D- 78532 Tuttlingen, Germany).

The supernatant was then used for the sugar analysis as follows: Ethanol was added at a ratio of 3 ethanol: 1 supernatant (V: V) followed by centrifugation. The precipitated sugar was then freeze-dried (Freeze Dryer -55ºC; OPERON, Republic of Korea) and used for sugar analysis following the method described by Rezaei et al. (2016) with slight modification as follows: An exact amount of 0.5 g of the purified freeze-dried samples was added to 10 ml of H_2SO_4 (4% v/v) in a test tube and heated at 100ºC for 4 h in a water bath. The solution was then neutralized by sodium carbonate and filtrated through a 0.45 µm filter paper. Finally, 5 µl of each sample was injected into Ultra High-Performance Liquid Chromatography equipped with Inertsil (NH2) (150 × 4.6) 3µm (Thermo UHPLC Ultimate 3000) column and refractive index detector and a digital integrator. Acetonitrile/water (80:20) was used as the mobile phase at an HPLC gradient flow rate of 1 ml/min, and a run time (20 min) at 35ºC. The amount of the individual sugars was expressed as a percent of the total detected sugars by the UHPLC chromatograms.

Determination of the functional properties of the exudate gums.

Hygroscopicity: One gram of exudate powder was precisely weighted and placed in a desiccator containing a solution of saturated sodium chloride (76 ±2% relative humidity) at 23.6 ±1°C. When samples reached equilibrium (Rosland-Abel *et al.,* 2020), the hygroscopicity was determined according to the following equation:

$$\text{Hygroscopicity \%} = \frac{\text{Wf-Wi}}{\text{Wi}} \times 100$$

Where W_f is the weight of powder after two weeks and W_i is its initial weight

Swelling index: One gram of gum was taken in a 100 ml graduated cylinder, and distilled water was added to the final volume of 100 ml. The volume occupied by the gum (V_i) before hydration was recorded. After 24 hours, the free water was removed, and the volume occupied by swollen gum (V_f) was also taken (Sharma *et al.*, 2020). The swelling index of all samples was calculated using the following equation:

$$\text{Swelling index} = \frac{\text{Vf-Vi}}{\text{Vf}}$$

V_i = The volume occupied by swollen gum.

V_f = The volume occupied by the gum before hydration.

3.3.3. Water absorption capacity: Water absorption capacity (WAC) was determined by the method described by Chaudhari & and Annapure (2020). Briefly, 0.5 g of gum samples were taken in previously weighed centrifuge tubes, and 10 ml of distilled water was added to each tube under constant stirring at room temperature (24.6 ± 1°C). After allowing the tested samples to stand for 15 minutes, the tubes were centrifuged (Hettich Zentrifugen, D-78532 Tuttlingen, Germany) at 2000 rpm for 10 minutes and the resulting supernatant liquid was decanted. Finally, the weights of the sediments were recorded and WHC was calculated using the following equation:

$$\text{WAC} = \frac{\text{weight of tube with sediment} - \text{weight of tube with dry sample}}{\text{weight of dry sample}} \times 100\%$$

Solubility: The solubility was evaluated using the method described by Sarkar *et al.* (2018) with slight modifications. A 0.5 g sample of gum powder was added to 50 ml of distilled water with continuous stirring then, the mixture was allowed to stand for 30 minutes in a water bath at different temperatures (20, 50, and 100 ºC). Finally, the corresponding gum solutions were centrifuged (Hettich Zentrifugen, D- 78532 Tuttlingen, Germany) at 4000 rpm for 30 min and the resulting supernatant was carefully taken and freeze-dried. Solubility was determined by applying the equation cited by Chaudhari & and Annapur (2020):

$$\text{Solubility (\%)} = \frac{\text{Initial Weight of Gum} - \text{Final Weight of Dried Supernatant}}{\text{initial weight of Gum}} \times 100\%$$

Emulsification capacity: The emulsification capacity of the gum samples was determined using the method adopted by Sharma *et al.* (2020), Solutions of tested gums at a series of concentrations (1-10% w/v) were combined with 20% (v/v) olive oil and was then homogenized for 5 min using a homogenizer (Silverson, UK). The height of the total homogenized sample was recorded. After homogenization, the sample was centrifuged (Hettich Zentrifugen, D- 78532 Tuttlingen, Germany) for 5 minutes at 2000 rpm to measure the height of the emulsion. The emulsion capacity was calculated as follows:

$$\text{Emulsification capacity (\%)} = \frac{\text{height of emulsion layer after centrifugation}}{\text{height of homogenized sample}} \times 100$$

Foaming capacity and foam stability. Foaming capacity (FC) and foam stability (FS) were determined according to Rezaei *et al.* (2016) with slight modifications. Using a homogenizer (Silverson, UK), 4% (w/w) suspension of each gum sample was vigorously whipped for 5 minutes producing foam that was gently transferred to a measuring cylinder (100 ml) and FC was measured immediately after whipping. While, FS was measured after 1 min, 10 min, 30 min, 60 min, 90 min, 120 min,5h, and 8h of whipping. FC and FS were calculated using the following equations:

$$\text{EC (\%)} = \frac{\text{(Volume after whipping - Volume before whipping) ml}}{\text{(Volume before whipping) ml}} \times 100$$

$$\text{S (\%)} = \frac{\text{(Foam volume after time (t)) ml}}{\text{(Initial foam volume) ml}} \times 100$$

Flow behavior. Different concentrations (0.5 %, 1%, 3% 5%, and 10%) of the respective gums' solutions were prepared at room temperature using distilled water and agitated overnight using a magnetic stirrer. Apparent viscosity was measured during shearing in a range of 6-60 s^{-1} using a rotational viscometer (SNB-AI Digital Viscometer, Shandong China) equipped with a spindle (C4). A minimum of three measurements were taken for each concentration.

Statistical analysis

All experiments were performed in triplicates. The obtained results were expressed as the average of the three replicates ± standard deviation (SD). Analysis of variance was run using the Statistical Analysis System, 2003 program (SAS Institute, 2002) following Randomized Block Design (RCBD) with blocking on replicates. Means were separated by the Least Significant Difference (LSD) test at the 5% level of probability (P≤0.05).

Results and discussion

Chemical composition of the exudate gum

Proximate composition

Table 1 shows the chemical composition of Mahlab gum as influenced by grade compared to gum Acacia. Moisture content was significantly influenced by the grade and ranged between 10% in grade III and 18% in grade I which is due to the progressive dehydration of gum nodules on the tree. Similar results were reported by Abu Baker *et al.,* (2007) for *Acacia Senegal* gum nodules at different stages of dehydration. Fat content ranged between 2.59 -3.29 %, which is higher than previously reported values by Mahfoudhi *et al.* (2012), Fathi *et al.* (2016); Rezaei *et al*. (2016) and Sharma *et al.* (2020) in *Prunus dulcis*, *Prunus cerasus*, *Amygdalus communis L*. and *Prunus domestica* respectively, with values ranging between 0.12 and 0.64%. In this work, Acacia's gum protein content was 1.83 %, which is significantly higher than its levels in Mahlab gums i.e., 0.93, 0.98, and 1.10% for grades I, II, and III respectively. There was no significant difference between the three grades in their protein contents. However, these values were lower than those reported by Malsawmtluangi *et al.* (2014) for *Prunus cerasoides* gum (2.33%), Mahfoudhi *et al*. (2012) for *Prunus dulcis* gum (2.45%) and Fathi *et al.* (2016) for *Prunus armeniaca* gum (2.91%). The stabilizing and emulsifying properties of gum are influenced by its protein content (Sharma et al., 2020). The ash content of grade III nodules was close to that of Acacia gum and significantly higher than that of grades I and II which could be due to high debris and foreign inorganic matter in grade III which stayed for a longer time on the tree before picking. The ash content of the samples in the current study agrees with other reported values for different plant gums which were below the 4% maximum limit set by the Food and Agriculture Organization for Arabic gum (FAO, 1998). Nitrogen-free extract content of grades I, II, and III were 75.10, 80.97, and 83.40% respectively. Differences in the proximate composition of the three grades are most likely due to environmental conditions as grade III stays for a longer time than grades I and II on the tree, thus exposing it to more rigorous conditions of dryness, summer heat, and dust which resulted in its dark color and higher ash content.

Table.1. Proximate composition (% w/w) of three grades of Mahlab exudate and Acacia gum*.

Component	Grade I	Grade II	Grade III	Acacia
Moisture	18.00 ± 0.02^{a} **	13.14 ± 0.30^{b}	10.00 ± 0.00^{c}	10.59 ± 0.32^{c}
Fat	3.29 ± 0.00^{a}	2.53 ± 0.00^{b}	2.59 ± 0.00^{b}	1.84 ± 0.03^{c}
Protein	0.93 ± 0.08^{b}	0.98 ± 0.17^{b}	1.10 ± 0.08^{b}	1.83 ± 0.08^{a}
Ash	2.68 ± 0.00^{b}	2.38 ± 0.00^{c}	2.91 ± 0.00^{a}	3.01 ± 0.09^{a}
Nitrogen Free Extract	75.10 ± 0.10^{d}	80.97 ± 0.50^{c}	83.40 ± 0.09^{a}	82.73 ± 0.50^{b}

*Values are the means of 3 replicates ± SD.

**Means with the same superscript in the same row are not significantly different at the 5% level of probability according to the LSD test.

Minerals

Table 2 presents the mineral content of the various grades of Mahlab in comparison to Acacia gums. In general, Mahlab gums had significantly ($P \leq 0.05$) higher Ca, Mg, and Na but lower K, P, Fe, and Zn than Acacia guthe m, regardless of their grade (Table 2). The nature and number of minerals in gum are known to influence the viscosity and gelling properties of gum solutions (Malsawmtluangi *et al.,* 2014). Although Ca, Mg, K, and Na were present in significant concentrations in all grades of our gum samples and Zn, Fe, and P were in lower concentrations, there was no significant difference between the three Mahlab gum grades in their calcium content, while grade III had significantly lower Mg, K, P, and Fe than the other two grades. However, this pattern was not observed in the case of Na and Zn which is perplexing. Variations in the mineral content between the three gum grades could be attributed to variations in ash and nitrogen-free extract content discussed above. The mineral content of various *Prunus* species gums was shown by other workers (Mahfoudhi *et al*., 2012; Malsawmtluangi *et al.,* 2014 and Shabani *et al.,* 2016) to follow a similar pattern as our results i.e. Ca, Mg, K, and Na are the highest while P, Fe, and Zn are the lowest in these gums. Geographic and different soil conditions are believed to be responsible for the variations in minerals between gums (Mahfoudhi *et al.,* 2012; Malsawmtluangi *et al.,* 2014). The three grades were subjected to different environmental conditions by staying for different periods on the trees before picking i.e. grade III remained for the longest while grade I for the shortest time.

Table.2. Mineral content of three grades of Mahlab exudate and Acacia gums*.

Element	Grade I	Grade II	Grade III	Acacia
Ca (%)**	27.47± 0.05^{a}	27.47± 0.06^{a}	27.66± 0.05^{a}	22.80± 0.05^{b}
Mg (%)	12.55± 0.01^{b}	13.66± 0.02^{a}	11.64± 0.00^{c}	8.70± 0.00^{d}
K (%)	13.55± 0.06^{b}	11.30± 0.02^{c}	11.14± 0.06^{c}	15.50± 0.00^{a}
Na (ppm)	3723.35± 0.20^{c}	4605.17± 0.20^{a}	4531.75± 0.20^{b}	2486.02± 0.20^{d}
P (ppm)	318.60± 0.27^{a}	296.90± 0.40^{b}	240.91± 0.27^{c}	366.70± 0.02^{d}
Fe (ppm)	539.80± 0.10^{c}	642.16± 0.10^{b}	516.10± 0.17^{d}	2444.60± 0.10^{a}
Zn (ppm)	29.85± 0.22^{d}	38.00± 0.00^{b}	33.58± 0.22^{c}	71.01± 0.22^{a}

*Each value is the average of two replicates (N=2) ± SD representing the percentage of the corresponding element in the ash of the given grade

**Means in the same row with the same superscript are not significantly different at the 5% level of probability (P≤0.05) according to the LSD test.

Sugar content:

Table 3 presents the monosaccharide composition of the carbohydrate component of the hydrolyzed samples; non-hydrolyzed samples did not show any peak at all, indicating the absence of free sugars from all gum samples indicating that they are composed exclusively of polysaccharides. The sugar profile of the three grades of Mahlab gum is composed mainly of four different monosaccharides namely, xylose ranging from 17.65 to 19.77%, rhamnose ranging from 10.10 to 12.34%, arabinose ranging from 53.35 to 62.01%, and galactose ranging from 9.88 to 14.50% which are significantly (P≤ 0.05) different from that of Acacia gum which contained only xylose (i.e., 5.58%), arabinose (i.e., 61.19%), and galactose (i.e., 33.21%). Exudate gum sugar composition depends on the species as Bhushette & Annapure (2017) reported only galactose, arabinose, and rhamnose in the exudate gum of *Acacia nilotica*; While Chaudhari & Annapure (2020) reported arabinose, rhamnose, and galactose in commercial Acacia gum. Different workers reported different sugar types and quantities in tree gums (Mahfoudhi *et al*.,2012; Fathi *et al*.,.2016; Shabani *et al.,*2016; Sharma *et al*.,2020), The variability in the sugar content of the three grades is probably due to variation in the age of these grades or to variations in handling and hydrolysis conditions. Arabinose is the main sugar in molar percentages of 59.86%, 62.01%, and 53.35% for grade I, grade II, and grade III, respectively. Similar results were also reported for gums of the genus *Prunus* and other plant gums such as *Prunus cerasus* (31.31%), *Prunus cerasoides* (60.99%), *Prunus dulcis* (46.82%), *Amygdalus communis* (46.52%) and *Limonia acidissima* (38.81%) by Fathi *et al.* (2016), Malsawmtluangi *et al.* (2014), Mahfoudhi *et al.* (2012), Rezaei *et al*. (2016) and Chaudhari & Annapure (2020) respectively. The monosaccharide composition of polysaccharides determines their physical properties such as solubility, flow behavior, gelling potential, and/or surface and interfacial properties (Izydorczyk *et al.,* 2005). Fructose, glucose, and sucrose were not detected in any of our samples, which is consistent with the results reported by Fathi *et al*. (2016) for *Prunus cerasus* exudate gums.

Table.3. Monosaccharides detected in the three grades of Mahlab exudate and Acacia gums*.

Sugar (%)**	Grade I	Grade II	Grade III	Acacia
Xylose	17.65±0.02[c]	17.98±0.02[b]	19.77±0.02[a]	5.58±0.02[d]
Rhamnose	10.91±0.02[b]	10.10±0.02[c]	12.34±0.02[a]	ND
Arabinose	59.86±0.04[c]	62.01±0.04[a]	53.35±0.04[d]	61.19±0.05[b]
Galactose	11.54±0.02[c]	9.88±0.03[d]	14.50±0.02[b]	33.21±0.02[a]
Fructose	ND	ND	ND	ND
Glucose	ND	ND	ND	ND
Sucrose	ND	ND	ND	ND

*Each value is the mean of two replicates ± SD on a dry matter basis. ND: Not detected.

**% sugar of the total sugar profile as detected by HPLC. Means in the same row with the same superscript are not significantly different at the 5% level of probability (P≤0.05) according to the LSD test.

Table 3 presents the monosaccharide composition of the carbohydrate component of the hydrolyzed samples as detected by HPLC following the method above; non-hydrolyzed samples did not show any peak at all, indicating the absence of free sugars from all gum samples as they are composed exclusively of polysaccharides. The sugar profile of the three grades of Mahlab gum is composed mainly of four different monosaccharides namely, xylose, rhamnose, arabinose, and galactose which are significantly (P≤ 0.05) different from that of Acacia gum which contained only xylose, arabinose, and galactose. Exudate gum sugar composition depends on the species. Bhushette & Annapure (2017) reported only galactose, arabinose, and rhamnose were found in the exudate gum of Acacia *nilotica*; while Chaudhari & Annapure (2020) reported arabinose, rhamnose, and galactose were found in commercial Acacia gum. Different researchers reported different sugar types and quantities in tree gums (Mahfoudhi *et al*., 2012; Fathi *et al.,* 2016; Shabani *et al.,* 2016; Sharma *et al.,* 2020). The variability in the sugar content of the three grades is probably due to the variation in the age of these grades or to variations in the handling and hydrolysis conditions. Arabinose is the main sugar in molar percentages of 59.86%, 62.01%, and 53.35% for grade I, grade II, and grade III, respectively. Similar results were also reported for gums of the genus *Prunus* and other plant gums such as *Prunus cerasus* (31.31%), *Prunus cerasoides* (60.99%), *Prunus dulcis* (46.82%), *Amygdalus communis* (46.52%) and *Limonia acidissima* (38.81%) by Fathi *et al.* (2016), Malsawmtluangi *et al.* (2014), Mahfoudhi *et al.* (2012), Rezaei *et al.* (2016) and Chaudhari & Annapure (2020) respectively. The monosaccharide composition determines the physical properties such as solubility, flow behavior, gelling potential, and/or surface and interfacial properties (Izydorczyk *et al.,* 2005). Fructose, glucose, and sucrose were not detected in any of the samples, which is consistent with the results reported by Fathi *et al*. (2016) for *Prunus cerasus* exudate gums.

Functional properties of Mahlab gums

Hygroscopicity, swelling index, and water absorption capacity

As shown in Table 4, results show no significant differences (*P* ≤0.05) in hygroscopicity values between the three Mahlab gums grades. However, Acacia gum's value is significantly greater than *mahaleb* gums grades I, II, and III indicating that Acacia gum has a more amorphous structure than *mahaleb* gum thus having greater hygroscopicity values (Rezaei *et al*., 2016). The hygroscopicity is strongly relevant to the sugar profile, structure, and bonds of the gum (Sharma *et al.*, 2020). These findings are consistent with the results of Rezaei *et al*. (2016) for almond gum (7.17%) and Sharma *et al*., (2020) for *Prunus domestica* (5.67%). On other hand, it is observed that the swelling index of grade III was significantly (P <0.05) higher than those of grade I and grade II which was related to the greater percentage of xylose in grade III compared to grades I and II as a result of gums aging. The increased proportion of new functional groups including O-H groups due to gums aging is believed to promote water retention resulting in a greater swelling index (Sharma *et al*., 2020). All our Mahlab grade gums had greater swelling indices (i.e., 6.20, 6.35, and 7.52% for grade I, grade II, and grade III, respectively) compared to Acacia gum which had a lower swelling index with a value of 1.25%, reflecting the hydrophilic nature of all grades of Mahlab gum. Mahlab grade results are compatible with that of Sharma *et al*., (2020) for *Prunus domestica* who reported a swelling index value of 6.42%. A significant difference was observed in the water absorption capacity between the tested gums, grade III had the highest value (16.51 g H_2O/g of gum) and Acacia gum had the lowest value (0.39g H_2O/g of gum). The WAC of gums depends on both the protein fraction present in the gums as well as the functional group of the carbohydrate contents which are hydrophilic groups. Gums may also have certain functional groups that can attach to water molecules (Sarkar *et al.,* 2018). The quantity and type of water binding sites also have an impact on the capacity of water absorption (Sarkar *et al.,* 2018). Because it differs from other gums in that it is a complex polysaccharide including calcium, magnesium, and potassium ions, acacia gum has a low WAC (Sarkar *et al.,* 2018). According to Sharma *et al.* (2020), *Prunus domestica* gum had an 8.42 (g H_2O/g of gum) water absorption capacity. Gum exudates are widely used in industry due to their high water absorption capacity (WAC), which can be used to create gels or very viscous solutions and enhance food texture (Amid & Mirhosseini, 2012; Chaudhari & Annapure, 2020). Additionally, it is crucial to assess the WAC of gum in terms of storage circumstances (Amid & Mirhosseini, 2012).

Table 4. Functional properties of Mahlab exudate and Acacia gums. *

Parameter	Grade I	Grade II	Grade III	Acacia
Hygroscopicity (%)	6.57 ± 0.04^{b} **	6.32 ± 0.38^{b}	6.23± 0.47^{b}	14.09± 0.16^{a}
Swelling index (%)	6.20 ± 0.05^{b}	6.35 ± 0.14^{b}	7.52 ± 0.08^{a}	1.25 ± 0.02^{c}
Foaming capacity (%)	7.89 ± 0.85^{d}	21.02 ± 2.61^{b}	16.38± 0.08^{c}	26.53± 0.39^{a}
Water absorption capacity (g of water/ g of gum)	5.32 ± 1.05^{c}	11.02 ± 0.30^{b}	16.51± 0.29^{a}	0.39 ± 0.00^{d}

*Each value represents the mean of three replicates (N=3) ± SD.

**Means in the same row with the same superscript are not significantly different at the 5% level of probability (P≤0.05) according to the LSD test.

Solubility

Hydration properties are influenced by swelling capacity, solubility, and water absorption capacity (Amid & Mirhosseini, 2012). Total solubility behavior is beneficial for appearance and texture thus, it is crucial to achieving the optimum solubilization to maintain this functionality (Amid & Mirhosseini, 2012). The solubility of Mahlab gums as a function of temperature is summarized in table 5. Remarkably, there is a significant difference in the solubility of tested gums at all studied temperatures. Acacia gum exhibited the highest solubility at all temperatures followed by grade I gum while, grade II and grade III gums had lower solubility values. The low solubility could be due to increasing impurity and insoluble matter levels in these gums which greatly lowered their solubility. Moreover, Amid & Mirhosseini (2012) reported that the ash can diminish the solubility, and referring to the chemical composition of graded gums discussed above we could support their explanation. As the temperature increased from 25 to 50º C, the solubility of all gums increased, this behavior is probably due to the breaking of the H bonds among polysaccharide chains, and consequently, OH-groups could be exposed to water (Sciarini *et al*., 2009). While there were no significant (P≤0.05) solubility increments for all gums as temperature increased from 50 ºC to 100 ºC which is likely to be due to their low dependence on temperature, since the polysaccharides already entirely unfold at a lower temperature, exposing their OH- groups to water. The heat-dependency of solubility differs depending on the type of gum, its molecular structure, and its function (Amid & Mirhosseini, 2012). Our results indicate that gum Acacia is almost soluble at higher temperatures (98.8%) against (86.51%) for grade I. This finding is in good agreement with that obtained by Al-idee *et al.* (2020) who characterized two types of cherry trees *(Prunus avium*) gum exudates growing in Syria. These workers also reported that increasing the temperature led to an increase in the solubility of gum exudates.

Table.5. Solubility (%) of the tested gums at different temperatures*

Gum	**Temperature**		
	25 ºC	50 ºC	100 ºC
Mahlab Grade I	$81.14 \pm 5.10\,^{b}{}_{b}$ **	$84.66 \pm 1.88\,^{b}{}_{a}$	$86.51 \pm 0.44\,^{b}{}_{a}$
Mahlab Grade II	$50.00 \pm 2.53\,^{c}{}_{b}$	$55.31 \pm 2.46\,^{c}{}_{a}$	$55.55 \pm 0.43\,^{c}{}_{a}$
Mahlab Grade III	$38.79 \pm 4.253\,^{d}{}_{b}$	$46.62 \pm 3.92\,^{d}{}_{a}$	$54.29 \pm 0.43\,^{c}{}_{a}$
Acacia gum	$97.32 \pm 0.69\,^{a}{}_{b}$	$97.80 \pm 0.57\,^{a}{}_{a}$	$98.80 \pm 1.12\,^{a}{}_{a}$

*Each value represents the mean of three replicates (N=2) ± SD.

**Means in the same column or row with the same matching superscripts or subscripts respectively are not significantly different at the 5% level of probability (P≤0.05) according to the LSD test.

Emulsification capacity

One of the most important functionalities of natural hydrocolloids is emulsion capacity. Several studies have investigated the emulsification properties of different hydrocolloids, including those produced by the *Prunus* genus as peach gum (Qian et al., 2011), *Prunus dulcis* (Mahfoudhi *et al.,* 2012), and *Prunus domestica* (Sharma *et al*., 2020). The emulsifying capacity increases with increasing gum concentration to achieve a maximum emulsion capacity of 100 and 52.31% for Mahlab gum and Acacia gum, respectively (Figure 2). This behavior may be linked to the absorption of gums at the oil-water interface (Sharma et al., 2020), which is responsible for the formation of stable emulsions and their ability to form structured interfacial films (Mahfoudhi *et al*., 2015). Different grades of Mahlab gum showed emulsion capacities that were superior to those of Acacia gum. As shown in figure 2, the emulsification capacity of all grades of Mahlab gums reached the maximum (100%) at a concentration of 3% and remained constant up to 10% concentration. The performance of these gums with this respect remained superior to that of Acacias at all concentrations. The emulsifying power of gums was attributed by some workers to their protein content (Qian *et al*., 2011); however, no correlation was observed between protein content and this parameter in the case of Mahlab grades; In addition to our results shown in table 1(1.86%), Acacia gum has been reported by other workers to contain higher protein contents (Chaudhari & Annapure,2020), yet it had a lower emulsifying capacity at all concentrations (Figure 2). Qian et al. (2011) suggested a good correlation between high molecular weight, the highly branched substitution of gum polysaccharide, and its emulsification properties. Emulsion capacity curves of Mahlab exudate gum studied in this work and *domestica* gums investigated by Sharma *et al.* (2020) follow the same behavior; the emulsifying capacity increases as the gum concentration increases.

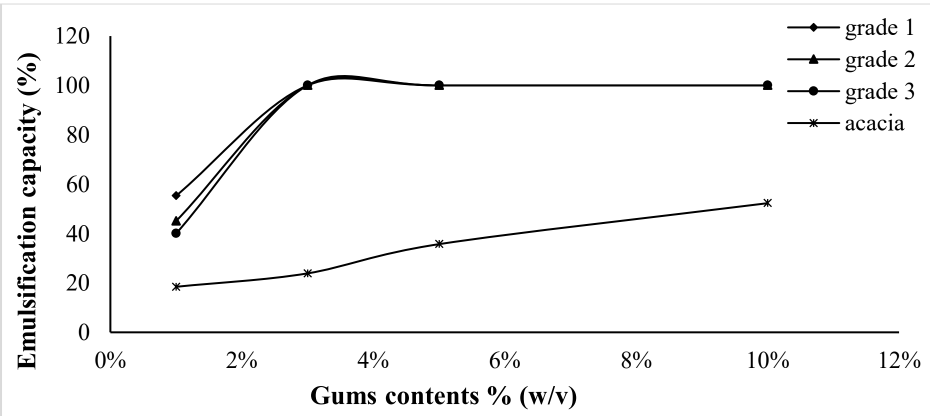

Figure.2. Emulsifying capacity of different Mahlab grades gum and Acacia gum.

Foaming capacity and foam stability.

Foams are dispersion systems that generate aerated structures in food ingredients by trapping gaseous phases in continuous matrices (Ebrahimi *et al.,* 2020). The Properties of foam are evaluated by foaming capacity (FC) and foam stability (FS) (Lomakina & Míková, 2006). In our work, Acacia gum showed higher foam capacity (Table 4), though lower foam stability than that of Mahab gum grades at similar concentrations (Figure 3), which may be associated with the highest protein content in Acacia gum which can be efficiently absorbed in the air-water interface and forms a continuous viscoelastic network due to its hydrophilicity and hydrophobicity nature (López-Barraza *et al.,* 2021). However, its foam stability was the lowest after 120 min. *Prunus* gum solutions are more viscous than Acacia gum at the same concentration therefore, the differences in stability between the Mahlab foam and Acacia's foam can be partly explained by differences in the viscosity of the continuous phase (Koocheki *et al.,* 2013). The increased viscosity phase is expected to contribute to foam stability by the creation of a network that prevents the coalescence of air bubbles (Koocheki *et al.,* 2013; Rezaei *et al.,* 2016). Foaming capacity values of different Mahlab exudate grades significantly varied with ranges between 7.89 % to 21.02 % which are lower than the results reported by Rezaei *et al.* (2016) for almond gum (i.e., 30%). During the first 90 minutes of storage at ambient temperature, the foam volumes of the four samples did not change significantly while, at eight hours of storage, we obtained 16.82 %, 44.95%, and 35.02 % from initial foam volume for the grades I, II and III respectively, at the same time the foam of Acacia gum disappeared. Thus, it can be concluded that Mahlab gum, especially grade II has high foam stability (Figure 3). Our results showed that solutions of grade I gum had the lowest foaming capacity as well as foam stability, this could be related to the high-fat content of the gum compared to grade II and grade III gums, which may act as antifoaming agents (Febryantara *et al.,* 2018).

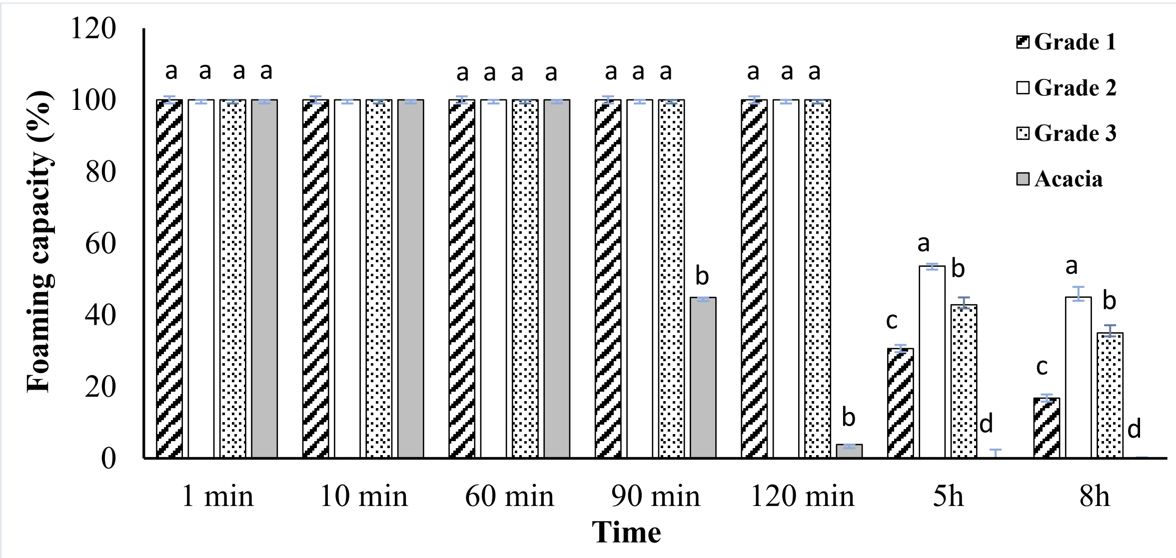

Figure.3. Foaming stability of different Mahlab grades gum and Acacia gum.

Apparent viscosity of Mahlab gums

The viscoelastic characteristics of gum influence the processing parameters and final product quality; texture and mouthfeel are important organoleptic properties of food products that are related to gum viscosity (Koocheki *et al*., 2013; Chaudhari & Annapure, 2020). Figure 4 depicts the concentration dependence of apparent viscosity for four gum solutions at 25 ºC (Figures 4 a, b, c, and d). At low Mahlab gum concentrations, the viscosity of all Mahlab gum solutions decreased with the increase in shear rate (1/s), indicating a non-Newtonian-shear thinning flow behavior type regardless of the gum grade. This behavior is expected for polysaccharide solutions due to their polymeric structure and high molecular weight (Sharma *et al.,* 2020; López-Barraza *et al.,* 2021). As the shear rate increases, the arbitrarily positioned chains of polymer molecules get aligned in the flow direction, producing less viscous solutions. This drop in viscosity at high shear rates (i.e., shear-thinning behavior) was linked with a decrease in the number of chain entanglements (Fathi *et al.,* 2016). This observation could also be attributed to the attractive intermolecular forces of molecules (Chaudhari & Annapure, 2020). When the apparent viscosity of Mahlab gum was compared to that of commercial Acacia gum at a concentration of 10% as shown in Figure 4 (e), the viscosity of all grades of Mahlab gum was noticeably higher than that of Acacia gum, which could be attributed to higher hydration properties of Mahlab gums. Moreover, different grades of *Prunus* gum solutions showed similar flow behavior characteristics of *Prunus* gum exudates (Qian *et al.,* 2011), almond gum (Rezaei *et* *al*., 2016), *Prunus cerasus* (Fathi *et al.,* 2016), *Prunus dulcis* (Mahfoudhi *et al*., 2015) and *Prunus domestica* (Sharma *et al.,* 2020) gums. Similarly, Pachuau *et al*. (2012) and Chaudhari and Annapure (2020) demonstrated the non-Newtonian-shear thinning flow behavior of Albizia procera and *Limonia acidissima L* exudates gum respectively.

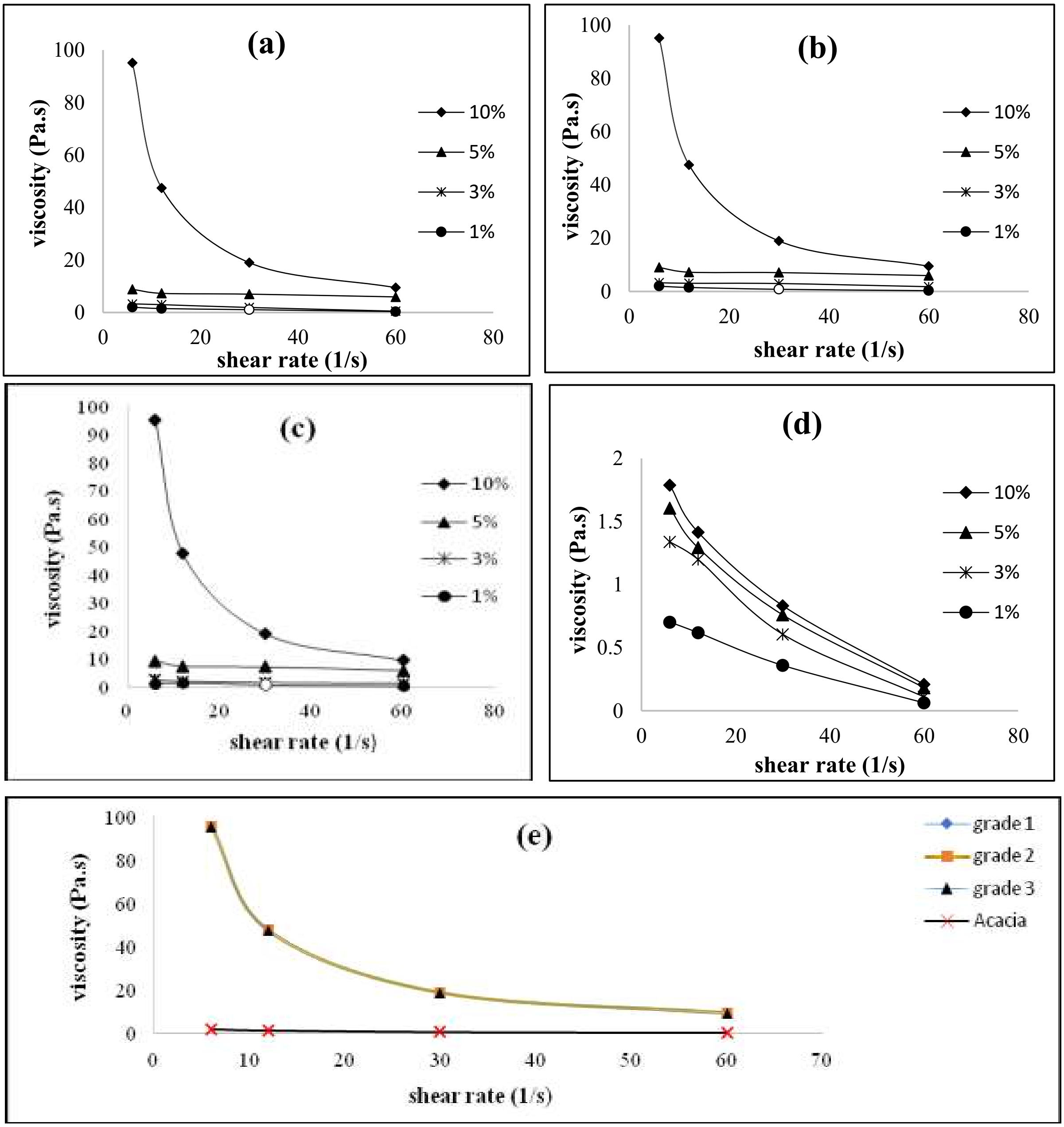

Figure.4. The effect of different concentrations on the apparent viscosities of grade I (a), grade II (b), grade III (c), and Acacia (d); and the apparent viscosities of the same four gums at the 10% concentration (e) at 25 °C.

Conclusions

This work is the first attempt to characterize three grades of Mahlab exudates gum and study their chemical and functional properties compared to gum Acacia. Proximate analysis showed significant variations in moisture, ash, fat, and nitrogen-free extract but not protein content between the three grades. HPLC analysis revealed that all grades of Mahlab exudate gum had similar sugar profiles, typical to other documented *Prunus spp*. gums, which consisted mainly of arabinose, xylose, rhamnose, and galactose. All grades of crude Mahlab exudate exhibited non-Newtonian-type shear thinning behavior, and good functional properties especially emulsification capacity which was superior to that of Acacia gum. It can be concluded that Mahlab exudate gum has functional properties comparable to those of other industrial gums which makes it suitable for use as an emulsifying, foaming, and thickening agent in different food preparations.

Declaration of Conflict of Interest: The authors declare no conflict of interest in the preparation of this work.

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الخصائص الكيماوية والوظيفية لصمغ شجرة المحلب (*Prunus Mahaleb*)

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ملخص

تعتبر أشجار المحلب Prunus mahaleb أحد الأنواع المنتجة للصمغ الذي لم تتم دراسة خصائصه الكيماوية والوظيفية. لذلك فإن هذا العمل يهدف إلى دراسة الخصائص الكيماوية والوظيفية لصمغ شجرة المحلب. تم تقدير التحليل التقريبي لهذه الدرجات إضافة الى الخواص الوظيفية والكيميائية ومعامل الانتفاخ وامتصاص الماء والاستحلاب وسعة الرغوة والذوبان وثبات الرغوة. أظهرت نتائج التحليل التقريبي وجود اختلافات معنوية (P ≤0.05) بين الدرجات الثلاث في جميع مكوناتها التقريبية ما عدا البروتين. كانت الدرجة الأولى أعلى محتوى رطوبة ودهون بنسبة 18.0 و3.29٪ على التوالي. احتوت الدرجة الثالثة على أعلى محتوى من البروتين (على الرغم من عدم اختلافه بشكل معنوي عن الدرجات الأخرى، P> 0.05) والرماد 1.10 و2.91٪ على التوالي. احتوت الدرجات الثلاث على مستويات متشابهة، وإن كانت مختلفة معنوياً (P≤ 0.05) من الكالسيوم والصوديوم والبوتاسيوم والمغنيسيوم. كذلك وجد بأن محتواها من السكر الذي تم تقديره بال HPLC بشكل أساسي من الزيلوز (17.65-19.77٪) والرامنوز (10.10-12.34٪) والأرابنوز (53.35-62.01٪) والجلاكتوز (9.88-14.50٪). أظهرت النتائج وجود فروق معنوية (P ≤0.05) بين الدرجات الثلاث في خواصها الوظيفية، حيث كان للدرجة الثالثة أكبر معامل انتفاخ وسعة امتصاص للماء 7.52 و16.52٪ على التوالي. تتميز الدرجة الأولى بأعلى نسبة استرطاب تبلغ 6.57٪ بينما تتمتع الدرجة الثانية بأعلى سعة إرغاء تبلغ 21.02٪. أظهرت جميع درجات الصمغ سلوك سريان اللزوجة الخفيف غير النيوتوني. بناءً على نتائج هذه الدراسة، اتضح أن صمغ إفرازات شجرة المحلب يظهر خواصًا كيماوية ووظيفية نموذجية للغرويات المائية الأخرى المعروفة.

الكلمات الدالة: محلب، اللوزيات، الغرويات المائية، سكريات الصمغ، ريولوجيا الصمغ.

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