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Physicochemical and functional properties of *Commiphora wightii* gum-resin polysaccharides

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ABSTRACT

Mukul gum is an oleo-gum-resin secreted after scratching the bark of *Commiphora wightii*. This study aims to investigate the physicochemical and functional properties of mukul gum. The functional and physicochemical properties of the gum, including protein content, total carbohydrates, color, solution viscosity, zeta potential, solubility, water absorption capacity, oil absorption capacity, foaming ability, and emulsifying properties, were evaluated. The chemical structure of the gum was analyzed using infrared spectroscopy (FTIR), high-performance liquid chromatography (HPLC), and one-dimensional nuclear magnetic resonance (NMR) spectroscopy. The protein content of the gum was determined to be 8.15%, while its carbohydrate content was found to be 61.09%. The viscosity analysis of the gum solution indicated a shear-thinning behavior. The extracted gum exhibited a zeta potential of -26 mV. The gum's solubility was investigated at 30, 60, and 90 °C. The WAC value was 3.78 g of water in one gram of gum. The gum's ability to form a foam was 87.03% and the foam stability was calculated to be 65.83%. Likewise, the OAC value for the extracted gum was 2.33 g of oil in one gram of gum. Further analyses confirmed the gum's acceptable emulsifying capacity in concentrations of 0.5, 1, 1.5, 2, and 3%, as well as its relatively high thermal stability. Structural analyses indicated the presence of sugars (e.g., arabinose, rhamnose, fructose, glucuronic acid, and galacturonic acid) in the gum. In addition, FTIR results confirmed the presence of hydroxyl groups and, particularly, the presence of glucuronic acid, galacturonic acid, carboxylic acids, sugar alcohols, and glycosidic groups in the profile of the gum's compounds. Ultimately, HPLC analyses of the monosaccharide profile demonstrated a high content of glucose (as a hexose) and some concentrations of mannose and rhamnose.

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1- Introduction

Iran has abundant hydrocolloid resources that have been traditionally used for years. Garden cress seeds, basil seeds, quince seeds (Balangu Shirazi), and chia seeds (Daneh Marv) are among the native seeds of our country that, in addition to their medicinal properties, also possess high amounts of gum. The cheapest hydrocolloids are plant exudate gums, as they require less processing [1]. The safety and health benefits of plant gums, their nutritional and medicinal value, and the ease of production encourage further identification of these hydrocolloids. A significant portion of the gums used in the food industry are imported, which imposes a substantial cost on manufacturers. Therefore, by investigating and identifying the characteristics of new hydrocolloids, it's possible to reduce the outflow of foreign currency from the country to some extent. Due to Iran's plentiful plant resources, numerous polysaccharide compounds can be found. However, due to a lack of sufficient information, there's a perceived need to examine their extraction process, determine their physicochemical and functional properties [2].

The plant *Commiphora mukul*, belonging to the order *Balsamodendron mukul* and the family *Burseraceae*, is a source of the resin known as "guggul" or "gum guggul," scientifically referred to as *Commiphora wightii*. This resin has significant economic value and a wide range of medicinal applications. The plant itself is a shrub, double-stemmed with highly branched and knotted branches that grow in a spiral pattern, accompanied by sharp thorns. Its younger parts are covered with wax and appear glandular. This perennial plant is highly branched and thrives in arid, semi-arid, and rocky regions with minimal rainfall. It is slow-growing, has a long dormancy phase, and is deciduous in nature. Typically, it takes about 10 years for the plant to reach maturity. The plant is highly valuable as a source of guggulsterone, an important medicinal gum-resin it produces. This gum-resin is fatty and thick, used either independently or in combination with other medicinal plants to enhance their efficacy in treating certain ailments [3].

In dry climatic conditions, the branches are cut during the winter to stimulate and extract the oleo-gum-resin. Guggul is an oleo-gum-resin that exudes from the stem and branch sections of the plant when the bark is scratched using a knife. A yellowish gum oozes out from the incisions, which is left to dry and harden before being collected. Approximately 250 to 500 grams of dried gum can be harvested from a shrub in each season (22). Guggul appears as yellow to brown pieces with a bitter-aromatic odor and an acrid taste; its fresh form is yellow and sticky. The yield of guggul gum depends on various factors, including the age of the trees within the same regions, the number of trees, and the climatic conditions of the area [4].

Guggul was first introduced to the scientific world in 1966 by an Indian researcher and physician named J.V. Satyavati. In the mid-1990s, guggul entered Western markets as a lipid-lowering drug. This substance helps reduce cholesterol levels by lowering LDL and increasing HDL, ultimately leading to a very favorable LDL-to-HDL ratio, making it highly valuable from a pharmaceutical perspective. Guggul also has the ability to stimulate thyroid gland activity and increase body metabolism. The exudated guggul is a complex mixture of steroids, diterpenoids, aliphatic esters, carbohydrates, and various types of mineral ions. However, the main active compounds of this resin are guggulsterone and guggulsterol. Investigating the properties of this resin provides more opportunities for the better and wider use of this valuable plant [5]. Vani et al. (2016) conducted research on the antioxidant and antibacterial activity of guggul resin and demonstrated that this resin is a good source of natural antioxidants and exhibits significant antibacterial activity, showing potential for use in pharmaceutical and food industries [6].

Guggul gum is a native resin that, despite its numerous medicinal properties, has not yet been scientifically researched for the identification of its structural characteristics, physicochemical properties, and functional attributes. The aim of this study is to extract and investigate the chemical structure, physical properties, and functional characteristics of guggul gum.

2-Materials and Methods

2-1-Materials Used

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Guggul gum-resin was purchased from one of the herbal shops in Isfahan. Ethanol (96%) was purchased from Nasr Company. Concentrated sulfuric acid (98%), petroleum ether, phenol, 2,2-diphenyl-1-picrylhydrazyl (DPPH), nitric acid, glucose, and hydrochloric acid were obtained from Merck Company.

2-2-Extraction of Guggul Gum

First, the purchased guggul gum-resin was ground and mixed with ethanol at a ratio of 30 times its weight. It was then refluxed for 6 hours at 70°C using a Soxhlet apparatus to remove resin and other impurities soluble in alcohol. Afterward, the sample was filtered through a thin cloth to remove the ethanol and dried at room temperature. In the aqueous extraction step, 10 times the weight of the dried powder was added to water and heated for 5 hours at 30°C. Subsequently, water-insoluble compounds were separated using a cloth filter, and the solution was passed through filter paper. Finally, the solution was dried in an oven at 105°C. The obtained gum powder was stored in a sealed container and kept in the refrigerator.

2-3-Measurement of Physical Properties of Guggul Gum

2-3-1-Color

To determine the color of the powdered gum, a colorimeter (DENSHOKU Nippon model ZE6000, Japan) was used, and the L*, a*, and b* factors were measured [7].

2-3-2-Viscosity Measurement

A Brookfield viscometer with spindle number 18 was used to measure viscosity. The viscosity of the gum solutions was examined at two concentrations: 5% and 10% [8].

2-3-3-Zeta Potential Measurement

To measure the zeta potential of guggul gum, a 5% dispersion of the gum in 96% ethanol was first prepared and placed in an ultrasonic bath for a few minutes. Then, using a zeta potential analyzer (ZEN3600, Horiba, Germany), the zeta potential of the gum was measured at 25°C and a voltage of 3.8 volts [9].

2-4-Measurement of Chemical Properties of Guggul Gum

2-4-1-Determination of Chemical Composition

The total moisture content, ash content, protein, and fat of guggul gum were determined using the AOAC-approved methods. Moisture content was measured by oven drying, ash content by furnace incineration, protein by the Kjeldahl method, and fat by Soxhlet extraction using petroleum ether as the solvent [7].

2-4-2-Measurement of Total Carbohydrate Content

The phenol-sulfuric acid test was used to measure the total carbohydrate content. For this purpose, a 100 ppm solution of the sample was prepared. Then, standard glucose solutions with concentrations of 25, 50, 75, and 100 ppm were prepared. To 1 mL of the prepared sample solution, 5 mL of concentrated sulfuric acid was added first, followed by 1 mL of 5% phenol. The mixture was then kept at room temperature for 30 minutes. The absorbance of the sample and standard solutions was recorded at a wavelength of 485 nm. The total carbohydrate content was determined using the standard curve [10].

2-4-3-Evaluation of Antioxidant Activity

To evaluate the antioxidant activity of the sample, 0.1 g of powdered gum was mixed with 5 mL of 96% ethanol and stirred vigorously for 3 hours at 25°C. It was then centrifuged at 3000 ×g for 20 minutes, and the supernatant was separated for antioxidant activity measurement. The DPPH method was used to measure the antioxidant activity. 100 µL of the ethanolic extract of the sample was quickly added to 1 mL of 0.1 M ethanolic DPPH solution and mixed thoroughly. The resulting mixture was kept in a dark place at room temperature for 30 minutes, after which its absorbance was read at a wavelength of 517 nm. The absorbance of the ethanolic DPPH solution was also read as a control at 517 nm, and the antioxidant activity was calculated using Equation 1 [11].

Antioxidant Activity (%) = ((Absorbance of Control - Absorbance of Sample)) / (Absorbance of Control) × 100 Eq. 1

2-4-4-Determination of Mineral Elements

To determine the mineral elements present in the sample, approximately 3 g of powdered guggul gum was weighed into a porcelain crucible and placed in a furnace for 12 hours at

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550°C. The ash obtained from the furnace step was dissolved in concentrated nitric acid and heated in a water bath for 30 minutes. It was then cooled to 25°C and filtered. The levels of elements in the extracted solution were determined using an Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) (Model Optima 7300DV, manufactured by Perkin Elmer, USA) [12].

2-5-Measurement of Functional Properties of Guggul Gum

2-5-1-Solubility Measurement

To measure the solubility of guggul gum, a 1% (w/v) solution of the gum was prepared by dissolving 90 mL of the gum in distilled water. The solution was stored in the refrigerator for 24 hours to ensure complete hydration of the gum particles. The resulting solution was divided into three equal parts, and each part was separately placed in a water bath at temperatures of 30°C, 60°C, and 90°C for 30 minutes while being stirred uniformly. Next, the solutions were centrifuged at 10,000 ×g for 20 minutes. The entire supernatant from each sample was poured into pre-weighed glass containers and heated at 105°C until a constant weight was achieved. Solubility at the desired temperatures was calculated using Equation 2 [13].

Solubility (%) = ((Weight of dried supernatant - Initial sample weight)) / (Initial weight) × 100 Eq. 2

2-5-2-Water Absorption Capacity

To measure the water absorption capacity of guggul gum, 0.5 g of powdered sample was mixed with 10 mL of distilled water in a pre-weighed falcon tube. After 15 minutes for hydration, the mixture was centrifuged at 896 ×g for 10 minutes. The clear supernatant was discarded, and the precipitate was weighed. The water absorption capacity of the gum was calculated using Equation 3 [14].

Water Absorption Capacity (g/g) = (Weight of swollen gel - Initial sample weight) / (Initial sample weight) Eq. 3

2-5-3-Oil Absorption Capacity

A quantity of 0.5 g of guggul gum was mixed with 10 mL of refined sunflower oil and stirred for one minute. The mixture was then kept at room temperature for 30 minutes and subsequently centrifuged at 896 ×g for 5 minutes. After removing the supernatant, the remaining sample at the bottom of the falcon tube was weighed. The oil absorption capacity was calculated using Equation 4 [15].

Oil Absorption Capacity (g/g) = (Weight of swollen gel - Initial sample weight) / (Initial sample weight) Eq. 4

2-5-4-Foaming Capacity and Foam Stability

To evaluate foaming capacity and foam stability, 1%, 2%, and 4% solutions of guggul gum were prepared. These solutions were homogenized for two minutes at 8064 ×g at room temperature using a homogenizer. Each solution was then transferred to a graduated cylinder, and the volume of foam present on the liquid surface was measured. Foaming capacity was calculated using Equation 5, and foam stability was calculated using Equation 6 [16].

Foaming Capacity (%) = (Foam Volume) / (Initial Sample Volume) × 100 Eq. 5

Foam Stability (%) = (Foam Volume after 15 minutes) / (Initial Foam Volume) × 100 Eq. 6

2-5-5-Evaluation of Emulsifying Properties of Guggul Gum

To prepare an emulsion, solutions of guggul gum were prepared at different concentrations (0.5%, 1%, 1.5%, 2%, and 3%). To ensure complete hydration of the gum particles, the prepared solutions were stored in the refrigerator for 24 hours. Subsequently, the desired emulsion was prepared by mixing 20% sunflower oil with 80% of the gum solution. The mixture was homogenized for 5 minutes at 13,500 ×g using a homogenizer. The prepared emulsion was stored in the refrigerator for 24 hours to stabilize the macro-molecular distribution and the oil-water interface. The emulsifying properties of the prepared solution were then evaluated [10].

To determine the emulsifying activity, 15 mL of the prepared emulsion was poured into a graduated falcon tube. The falcon tubes were centrifuged at 1300 ×g for 5 minutes. The total solution volume and the emulsion phase

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volume were measured, and the emulsifying activity was calculated using Equation 7 [10].

Emulsifying Activity (%) = (Emulsion Phase Volume) / (Total Solution Volume) × 100 Eq. 7

To measure the emulsion stability against temperature stress, the prepared emulsion was placed in a water bath at 80°C for 30 minutes. Immediately after the heat treatment, the emulsion was placed in an ice bath for 15 minutes and then centrifuged at 1300 ×g for 5 minutes. The emulsion stability against temperature stress was calculated using Equation 8 [10].

Emulsion Stability (%) against Temperature Stress = (Remaining Emulsion Phase Volume) / (Initial Emulsion Volume) × 100 Eq. 8

To evaluate emulsion stability over time, the prepared emulsions were stored in the refrigerator for one month, and their stability was assessed at specific time intervals. The emulsion stability over time was calculated using Equation 9 [10].

Emulsion Stability (%) over Time = (Remaining Emulsion Phase Volume) / (Initial Emulsion Volume) × 100 Eq. 9

2-6-Measurement of Structural Properties of Guggul Gum

2-6-1-Fourier Transform Infrared Spectroscopy (FTIR)

Infrared spectroscopy is used to determine the chemical structure of various materials and to identify functional groups. To prepare the infrared spectrum, guggul gum powder was mixed with potassium bromide powder and then compressed into a thin pellet form. Finally, its spectrum was analyzed in the wavenumber range of 4000–400 cm^{-1} [8].

2-6-2-Analysis of Sugars in Guggul Gum Using HPLC

To determine the sugars present in the structure of guggul gum, 0.3 g of the gum was mixed with 3 mL of 98% sulfuric acid and left in a water bath at 30°C for 30 minutes. It was then placed in an autoclave for 2 hours. Afterward, the hydrolyzed sample was filtered and neutralized. A 25 µL aliquot of the hydrolyzed sample was injected into an HPLC system equipped with an Aminex HPX-87H column (BIORAD) and a UV-Vis detector, with a flow rate of 0.6 mL/min using water as the mobile phase. The sugar composition was determined by comparing the retention times of standard sugars eluted from the column [10].

2-6-3-Nuclear Magnetic Resonance (NMR) Spectroscopy

The extracted guggul gum powder was gradually and carefully dissolved in 99.5% deuterium oxide before NMR analysis. Subsequently, one-dimensional ^{1}H-NMR and ^{13}C-NMR spectra were recorded [17].

3-Results and Discussion

3-1-Extraction of Guggul Gum

As described in the materials and methods section, alcohol extraction was first performed. During the alcohol extraction stage, compounds such as resins, oligosaccharides, and some pigments dissolve and are removed in ethanol. After alcohol extraction from the initial guggul gum-resin, a powder was obtained, which constituted 82.47% ± 0.63 of the initial gum-resin. The remaining compounds that dissolved in alcohol, primarily resins, were left as a sticky solid after ethanol removal, accounting for 17.52% ± 0.66 of the initial gum-resin. Following the aqueous extraction step on the powder obtained from the alcohol extraction stage, guggul gum was obtained, which formed 32.89% ± 4.61 of the initial gum-resin.

3-2-Physical Properties of Guggul Gum

3-2-1-Color

The evaluation of the color of the extracted guggul gum powder yielded the following results: L* (brightness index) = 48.66 ± 4.03, a* (redness index) = 10.04 ± 0.24, and b* (yellowness index) = 20.35 ± 0.67. The brightness index for guggul gum was lower than that of gum arabic (84.68), indicating that guggul gum has a darker color compared to gum arabic [18]. The a* index represents redness or greenness; guggul gum was redder than gum arabic (3.39) [18]. Additionally, the b* index indicates yellowness or blueness; guggul gum was more yellow than gum arabic

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(11.62) [18]. In a study by Jokić et al. (2014) on flaxseed mucilage, it was reported that different extraction conditions, such as the water-to-seed ratio, extraction time, and temperature, significantly affect the final color of the mucilage powder [2].

3-2-2-Viscosity of Guggul Gum Solution

The rheological properties of hydrocolloids are particularly important when used in food products to modify or improve textural characteristics, as they are key factors in process modeling and design. The viscosity of a 5% guggul gum solution at 100 rpm was measured at 3.81 mPa·s. At a concentration of 10%, the viscosity at 100, 50, and 20 rpm was 9.6, 25, and 36.93 mPa·s, respectively. The increase in viscosity with increasing gum concentration is due to greater polymer entanglement at higher concentrations, leading to the formation of stronger structures for water retention and increased viscosity. Additionally, with increasing shear rate, shear stress increased while viscosity decreased. The gum exhibited higher viscosity at low shear rates, but viscosity decreased with increasing shear rate, indicating shear-thinning behavior. According to research by Saeedi et al. (2018) on the physicochemical properties of anguzeh gum, the viscosity of anguzeh gum solutions was low, and at temperatures above 40°C, it showed shear-thinning behavior, especially at low shear rates. As the shear rate increased, the behavior of anguzeh gum approached Newtonian characteristics [19].

3-2-3-Zeta Potential

Zeta potential indicates the stability and charge of a colloidal system. When the zeta potential of colloidal particles increases, electrostatic repulsion also increases, enhancing the stability of the colloidal system [9]. More precisely, the boundary between stability and instability of a colloid can be determined based on this test; particles with a zeta potential higher than +30 mV or lower than -30 mV are considered stable [20].

The zeta potential of guggul gum was measured at -25.96 ± 2.3 mV, indicating an anionic structure of the colloidal system and relatively good stability. The negative zeta potential of guggul gum may be due to the presence of uronic acid in its structure, as observed in the structural analysis of the gum. According to reports by Harston et al. (2006), the zeta potential of 0.1% solutions of gum arabic, carrageenan, and alginate at pH 4 were -35.4 mV, -49.2 mV, and -45.1 mV, respectively [21].

3-3-Chemical Properties of Guggul Gum

3-3-1-Chemical Composition

The chemical composition of the guggul gum-resin was examined before the extraction stage. The moisture content was found to be 7.16% ± 0.46, fat content 18.50% ± 3.24, ash content 18.89% ± 0.20, protein content 4.41% ± 0.06, and total carbohydrate content 51.04% ± 1.03. The amount of resin extracted during the alcohol extraction stage was calculated to be 17.56% ± 0.66. The chemical composition of the gum was also tested after the alcohol and aqueous extraction stages. The results showed a dry matter content of 96.19% ± 0.46, ash content of 4.35% ± 0.01, fat content of 7.16% ± 0.23, protein content of 8.15% ± 0.01, and total carbohydrate content of 76.53% ± 2.01. For better comparison of the composition of guggul gum with some other exudate gums, the chemical composition of several exudate gums is shown in Table 1 [22].

The moisture content of guggul gum was lower than that of Arabic gum and Persian gum, which could be due to the drying step of the gum powder in the oven or its lower hydrophilicity. However, the initial guggul gum-resin had moisture levels similar to those of Persian gum and Arabic gum. The ash content of guggul gum was higher than that of the other two gums. The ash content in gums is highly dependent on growth environment conditions, such as the soil in which the plant grows. The protein content of guggul gum was higher than that of Persian gum but lower than that of Arabic gum. The fat content of guggul gum was lower compared to the initial gum-resin, indicating the impact of the alcohol extraction stage. The chemical composition of hydrocolloids varies depending on several factors, including the source of the gum, different growth conditions of trees and plants, their age, extraction methods, extraction time, and purification processes.

Table 1- Chemical composition of *Commiphora wightii* gum in comparison with two other exudate gums [22]

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Chemical composition (%)	*Commiphora wightii* gum	Zedo gum	Arabic gum
Moisture	3.81±0.80	8.5-12.2	5-10
Ash	4.35±0.01	1.3-2.59	1.81-5
Protein	8.15±0.01	0.2-0.7	0.95-10
Fat	7.16±0.23	Trace	0-0.37
Total carbohydrate	61.10±2.10	87-89	65-89

3-3-2-Mineral Elements in Guggul Gum

The mineral elements present in guggul gum are shown in Table 2. Additionally, for better comparison, the mineral elements of two other exudate gums are also listed in the table. Guggul gum contained almost all mineral elements. The results showed that calcium and sodium are the most abundant minerals in guggul gum. Sulfur, potassium, and magnesium follow in subsequent rankings. The sodium content of guggul gum was higher than that of Persian gum and Arabic gum, and the calcium content of guggul gum was also higher than that of Arabic gum [23]. The calcium content in gums is considered by many researchers as one of the key factors affecting gel formation [24]. According to Anderson and Wang (1991), the composition and concentration of minerals in plants are largely related to the soil in which the plants grow [25].

Table 2- Elements of *Commiphora wightii* gum in comparison with two other exudate gums [22]

Elements (%)	*Commiphora wigihti* gum	Zedo gum	Arabic gum
Al	1.78	-	-
Ca	37.36	74.11	0.7
Fe	1.02	0.1	0.001
K	12.99	17.94	0.95
Mg	8.93	7.73	0.2
Na	25.18	0.1	0.01
S	10.56	-	-
Sr	0.20	-	-
Zn	0.97	0.02	-
Ti	0.12	-	-
Mn	0.41	-	-
Ba	0.04	-	-
Cu	0.04	-	-
B	0.37	-	-
Li	-	-	-

3-3-3-Evaluation of Antioxidant Activity of Guggul Gum

The evaluation of the antioxidant activity of guggul gum using the DPPH method showed no antioxidant activity for the gum. However, after examining the antioxidant activity of the gum-resin and calculating it using the DPPH method, an activity of 36.36% ± 7.42 was obtained. This phenomenon can be explained by the fact that during the extraction of the gum using ethanol as a solvent and at a temperature of 50°C, the phenolic compounds present in the gum-resin, which are responsible for antioxidant activity, were dissolved in ethanol and subsequently removed. In several studies, raw polysaccharides extracted showed significant antioxidant activity, but after purification steps, the final purified polysaccharide exhibited low antioxidant activity. In other words, it can be said that other compounds present in the raw polysaccharide, such as pigments, flavonoids, peptides, proteins, and polyphenols, which have antioxidant activity, were removed during the purification stage [20].

3-4-Functional Properties of Guggul Gum

3-4-1-Solubility

The solubility of guggul gum was examined at three temperatures: 30°C, 60°C, and 90°C, and the results are reported in Figure 1. Overall, it can be stated that the solubility of this gum in water is low, and solubility increases with rising temperature. The low solubility of this gum in

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water is due to the presence of hydrophobic elements in its structure. Two important and determining factors for the solubility of polysaccharides are their structure and molecular weight. In similar gums, solubility often increases as molecular weight decreases. The separation of high molecular weight particles and subsequent water penetration into them takes longer compared to particles with lower molecular weight. As a result, the dissolution of materials with high molecular weight occurs more slowly. Structural characteristics (linear structure, type of glycosidic bonds, high molecular weight, and other structural properties) that enhance intermolecular connections among polysaccharides lead to reduced solubility. Linear polysaccharides with highly organized structures, which possess a crystalline structure, are often insoluble or sparingly soluble in water. However, branched structures exhibit higher solubility. In polymers with low water solubility, intermolecular connections between polymer molecules dominate, leading to aggregation and, ultimately, precipitation of the molecular structure [20].

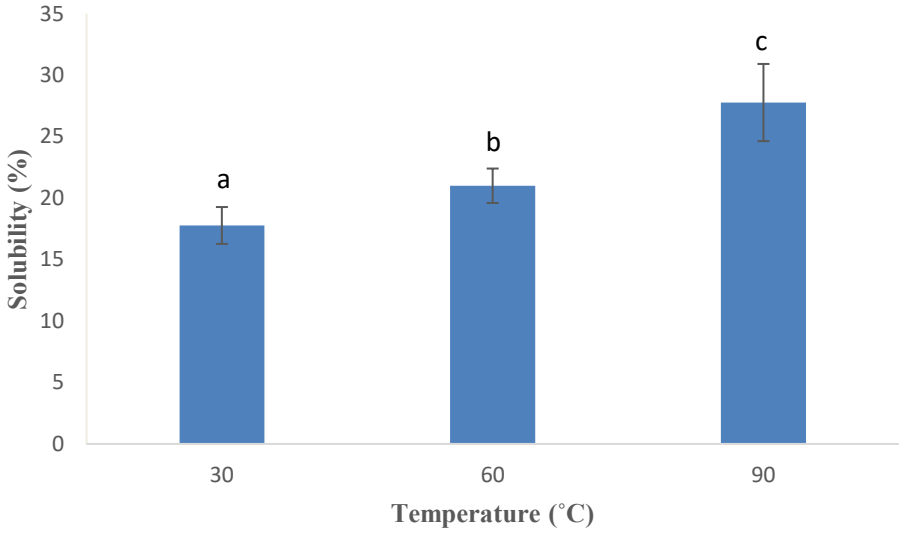

Fig. 1- *Commiphora wightii* gum solubility at different temperatures
Different letters show significant differences between samples ($p < 0.05$)

In studies conducted by Khalesi et al. (2012), it was shown that the solubility of Persian gum is dependent on temperature changes, increasing from 58.05% at 30°C to 77.5% at 90°C [3]. Regarding xanthan gum, solubility increased with a rise in temperature from 30°C to 60°C. However, the use of heat to enhance solubility limits the ability to use hydrocolloids extensively in heat-sensitive processing applications [9].

3-4-2-Water Absorption Capacity

The water absorption capacity indicates the ability of a substance to interact with small amounts of water. The water absorption capacity of guggul gum was evaluated at 25°C, and it was found to be 3.78 ± 0.78 grams of water per gram of gum. The low water absorption capacity may be due to the presence of proteins in the polysaccharide structure of the gum, which increases its hydrophobicity. Water retention capacity in gums depends on various factors, including extraction and purification conditions. These factors influence the contact surface area between the hydrocolloid and water. Water absorption capacity is also dependent on parameters such as the intensity of interactions between protein, polysaccharide, and water molecules, hydrophilic sites, environmental conditions, and the spatial configuration of the protein [24].

Water absorption capacity is considered one of the important factors for the widespread industrial application of exudate gums, as it contributes to the production of gels or highly viscous solutions. According to the results obtained by Khalesi et al. (2012), the water absorption capacity for Zedo gum was

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determined to be 10.2 g/g, indicating relatively good water absorption properties that remain stable across temperature changes [26].

3-4-3-Oil Absorption Capacity

The oil absorption capacity of guggul gum was found to be 2.33 ± 0.22 grams of oil per gram of gum. Oil absorption by polysaccharides occurs through both physical and chemical mechanisms. Physical absorption is due to the physical interaction of oil on the surface of gum powder particles, while chemical absorption arises from chemical interactions between oil and carbohydrates, proteins, and fats in the gum structure (mainly due to hydrophobic and van der Waals bonds). The amount and type of hydrophobic structures present in the polysaccharide determine the extent of oil absorption [18].

The oil absorption capacity of this gum was high. The gum-resin contained a significant percentage of fat in its composition, which increased the hydrophobic groups and, consequently, the oil absorption capacity of the gum. This property makes the gum particularly valuable for use in the food industry and formulations containing oils. High oil absorption capacity has significant technological importance. For example, gums with high oil absorption capacities can stabilize the texture of high-fat emulsions. Additionally, from a physiological perspective, they can reduce fat absorption in the body by binding dietary fats [7].

The high oil absorption capacity of gums is attributed to the presence of hydrophobic groups located on their surface, which can adsorb fat molecules. The oil absorption capacities of almond gum and gum arabic have been reported as 0.87% and 0.92%, respectively. These values are lower than the oil absorption capacity of guggul gum, likely due to the fewer hydrophobic groups in these two gums compared to guggul gum [18].

3-4-4-Foaming Capacity and Foam Stability of Guggul Gum

The foaming capacity and foam stability of guggul gum at concentrations of 1%, 2%, and 4% are shown in Figure 2. The highest levels of foam production and foam stability were achieved at a concentration of 4%, with values of 87% and 65%, respectively. Guggul gum demonstrated good foaming ability, which may be attributed to the presence of protein in its structure. Proteins are highly effective agents in foam formation and stabilization. The foaming capacity of guggul gum was almost similar to that of *Althaea officinalis* root gum [1].

Foaming properties play a crucial role in creating desirable rheological characteristics in food products, such as bread texture, cakes, whipped cream, and ice cream. Therefore, foam stability is considered an important criterion for the quality of food products. Generally, polysaccharide gums are not recognized as surfactants. However, research findings indicate that gums can be used to enhance foam production in food products. Gums positively affect foaming properties due to their tendency to position themselves at the interface, reducing surface activity because of gum molecules and increasing viscosity. According to reports by Hassanpour (2018), the foaming capacity of a 1% solution of pennyroyal gum was determined to be 28% [27].

The foaming capacity of Persian gum solutions at concentrations of 1% to 5% was investigated by Amini (2016), who observed no foam formation at concentrations below 3%. At concentrations of 4% and 5%, only negligible foam was produced, which quickly dissipated and was not measurable. The researcher reported that the low protein content in Persian gum was the primary reason for its lack of foaming ability [28].

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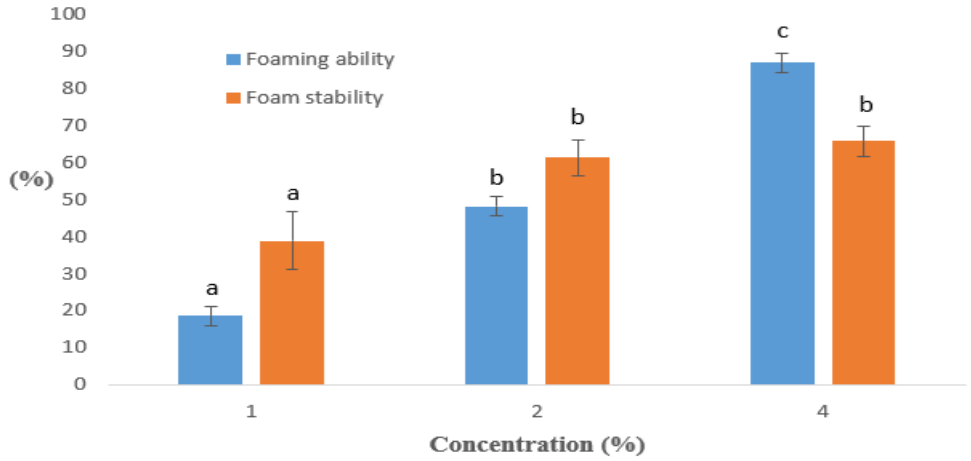

Fig. 2- Foaming properties of *Commiphora wightii* gum
Different letters show significant differences between samples in each test ($p < 0.05$)

3-4-5-Emulsifying Capacity of Guggul Gum

The emulsifying activity of guggul gum was examined at concentrations of 0.5%, 1%, 1.5%, 2%, and 3% (Figure 3). The results indicated that this gum has the ability to produce a relatively good emulsion. The findings showed that concentration significantly affects the emulsifying activity of guggul gum, such that the emulsifying activity increased with increasing gum concentration. This is attributed to the increase in viscosity and the higher protein content in the composition. As the gum concentration increases in solutions, water absorption and viscosity also increase, which reduces the mobility and displacement of fat particles, thereby decreasing the likelihood of particle collisions and improving emulsion stability [10].

In research by Dickinson et al. (2009), it was determined that if the hydrocolloid concentration in an emulsion is below a certain threshold, the hydrocolloid cannot fully cover the dispersed phase particles. Consequently, collisions and aggregation of the dispersed phase particles increase, leading to larger fat particles and a higher probability of fat separation, resulting in phase separation of the emulsion. Conversely, at higher hydrocolloid concentrations, greater viscosity and complete coverage of the dispersed phase particles prevent fat separation from the emulsion. According to investigations by Saeedi et al. (2018), as the concentration of anguzeh gum increased, the emulsifying activity index rose from 6.6 ± 0.8 m^2/g in a 5% gum solution to 18.7 ± 0.1 m^2/g in a 20% gum solution. In other words, the more stable an emulsion is, the reduced Brownian motion of oil particles coated with gum leads to increased turbidity, resulting in a higher emulsifying activity index [19].

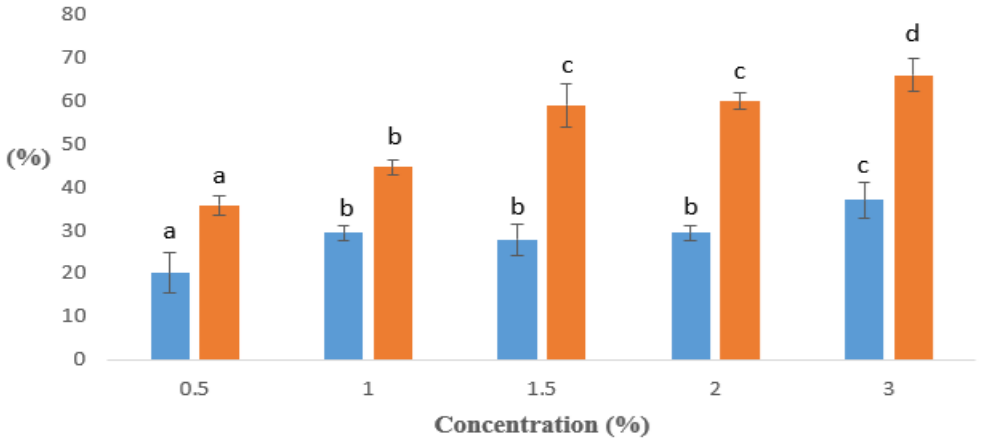

Fig. 3. Emulsion activity and emulsion stability against temperature of *Commiphora wightii* gum

[DOI: 10.22034/FSCT.22.163.31]

Different letters show significant differences between samples in each test ($p < 0.05$)

Since emulsions do not resist temperature changes due to thermodynamic instability and their functional properties are altered during processes such as pasteurization, sterilization, and drying during production, storage, and consumption, a thermal stability test of emulsions is conducted. The data obtained from this test are shown in Figure 3. The results indicate that concentration significantly affects the thermal stability of the emulsion. Investigations show that increasing the gum concentration in the preparation of the emulsion enhances its thermal stability, which is attributed to the increase in viscosity and reduction in the coalescence rate of the emulsion. According to Stokes' law, the velocity of dispersed phase droplets is inversely related to the viscosity of the continuous phase. Therefore, increasing the viscosity of the continuous phase of the emulsion contributes to its stability against phase separation.

The results obtained by Salehi (2017) at a 1% concentration of cactus fruit gum showed that this gum had an emulsifying property of 55.83% with a thermal stability of 92.17%, and the stability increased with higher gum concentrations [29]. Similarly, investigations by Niknam (2017) on fenugreek seed gum demonstrated that increasing the concentration of this hydrocolloid from 0.3% to 1% (w/v) enhanced the stability of the prepared emulsion from 17.46% to 46.59% [30].

Chemical and biochemical reactions that occur over time may lead to phase separation and emulsion instability. The emulsion prepared from guggul gum was stored in a refrigerator at 4°C for four weeks. The results of these investigations are presented in Table 3. Different gum concentrations also resulted in varying emulsion stability over time.

Table 3. Emulsion stability of *Commiphora wightii* gum during time

Time (weak)	Concentration (%)				
	0.5	1	1.5	2	3
First	29.55 ± 2.20^{a}	16.55 ± 4.50^{cd}	19.77 ± 4.50^{bcd}	24.66 ± 2.30^{abc}	19.77 ± 4.50^{bcd}
Second	26.22 ± 0.80^{ab}	13.33 ± 0.00^{d}	16.55 ± 4.50^{cd}	24.66 ± 2.30^{abc}	19.77 ± 4.50^{bcd}
Third	26.22 ± 0.80^{ab}	13.33 ± 0.00^{d}	16.55 ± 4.50^{cd}	24.66 ± 2.30^{abc}	19.77 ± 4.50^{bcd}
Fourth	26.22 ± 0.80^{ab}	13.33 ± 0.00^{d}	16.55 ± 4.50^{cd}	24.66 ± 2.30^{abc}	19.77 ± 4.50^{bcd}

Different letters show significant differences between all samples ($p < 0.05$)

The results obtained from one month of storage of the emulsion samples in the refrigerator did not indicate significant instability. The observed instability was not in the form of creaming, and no oil separation was observed on the surface. However, some water accumulated at the bottom of the container. At concentrations of 0.5%, 1%, and 1.5%, the emulsion volume decreased from the second week onward and then stabilized. At concentrations of 2% and 3%, the stability remained constant from the first to the last week. The highest emulsion stability over time was observed at a concentration of 2%, which is considered the optimal concentration for preparing a good emulsion using this gum. The reduction in emulsion stability over time may be due to increased contact between droplets, leading to aggregation (coalescence) and merging of oil droplets as the dispersed phase. Therefore, a relationship can be established between viscosity and stability against fat phase separation. In samples with higher concentrations and viscosities, reduced particle displacement and movement toward the surface decreased fat separation, enhancing stability against fat phase separation. In research conducted by Jafari et al. (2008), the effect of adding angum and arabic gums on emulsion stability was investigated. The results showed that using angum gum at a concentration of 3% (w/v) created a stable emulsion with almost no phase separation observed. However, arabic gum, even at high concentrations of 5%, did not yield satisfactory results [31].

3-5-Analysis of Structural Properties of Guggul Gum

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3-5-1-Fourier Transform Infrared Spectroscopy (FTIR)

Infrared spectroscopy is used to identify and determine the functional groups of compounds. The range between wavenumbers 950–1200 cm^{-1} is recognized as the fingerprint region for carbohydrates and serves as a good indicator of structural differences among various gums. The FTIR absorption spectrum of guggul gum is shown in Figure 4. The results obtained from the FTIR evaluation of the gum sample indicate a prominent band in the wavenumber range of 3300–3500 cm^{-1}, which is attributed to the presence of multiple hydroxyl groups (OH^-). This broad and intense band is caused by the stretching vibrations of OH groups. The presence of hydroxyl groups primarily confirms the existence of glucuronic acid, galacturonic acid, carboxylic acids, sugar alcohols, and glycosidic groups in the compound profile of the sample. Absorption bands in this range may also correspond to OH groups in water, amino acid groups, stretching vibrations of hydroxyl groups involved in intramolecular hydrogen bonding in polysaccharide alcohols, and C-H bonds in proteins [32].

Two additional bands were observed at approximately 1700 cm^{-1}, indicating double bonds between carbon and oxygen (C=O, ketone functional group) and simple carbon-hydrogen (C-H) bonds. The presence of protein in the sample may also contribute to absorption in this region, resulting from amide H-N bonds and bending vibrations of OH bonds. Other observed bands appeared primarily at wavenumbers below 1100 cm^{-1}, which are related to hydrocarbon groups present in the gum sample. Additionally, a band was observed in the wavenumber range of approximately 2800 cm^{-1}, which may correspond to simple carbon-hydrogen (C-H) bonds or amino groups (N-H). For instance, compounds such as chitosan, chitin, and some other polysaccharides and hydrocolloids like carrageenan and even pectin exhibit this band in this range [2].

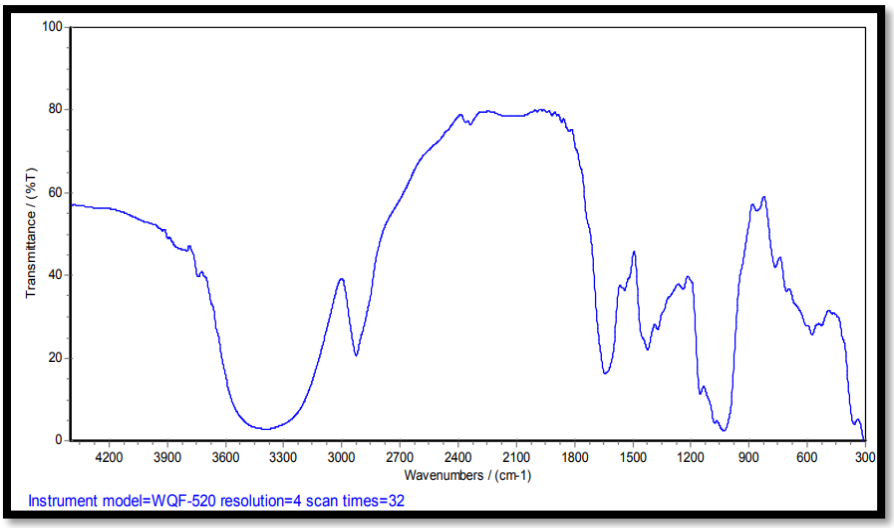

Fig. 4. FTIR spectra of *Commiphora wightii* gum

3-5-2-Nuclear Magnetic Resonance (NMR) Spectroscopy

The signals obtained from H-NMR, due to their higher abundance and sensitivity compared to carbon-13 signals, are more suitable for quantitative analysis in certain applications. Although most proton signals appear within a chemical shift range of less than 2 ppm, this can lead to significant signal overlap. Therefore, using one-dimensional proton NMR alone to resolve the structural issues of a complex polysaccharide or oligosaccharide can be challenging. In the carbon-13 spectrum, signals from anomeric carbons appear in the range of 85–90 ppm, while non-anomeric carbons are located between 60 and 85 ppm. The H-NMR spectrum of guggul gum is shown in Figure 5.

[DOI: 10.22034/FSCT.22.163.31]

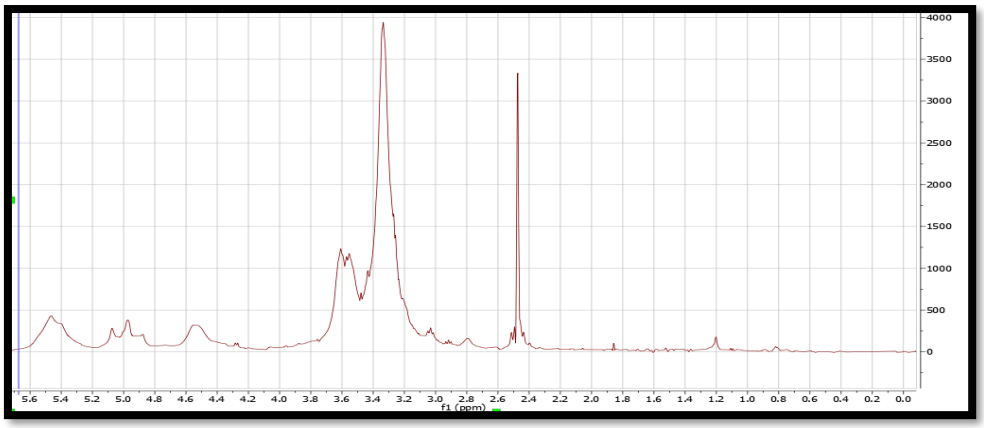

Fig. 5. H-NMR spectra of *Commiphora wightii* gum

Carbohydrate signals in NMR spectra, particularly in H-NMR, are typically concentrated within a narrow range, which in the H-NMR spectrum lies below 2 ppm, specifically between 3–5 ppm. The anomeric protons of monosaccharides produce specific signals depending on whether they are in the alpha or beta configuration. Based on the results obtained from the H-NMR evaluation, the peak observed in the range of 3.5–5.5 ppm corresponds to the alpha-L-rhamnopyranosyl end group or the anomeric proton associated with glucose or galactose. The peak appearing in the range of 4.4–4.8 ppm is primarily attributed to the H-2–H-5 signals of rhamnose. The peak observed at 3.5 ppm corresponds to methyl protons attached to carbon number 6 of beta-D-galactose. Protons on carbon number 4 appear in the range of 3.9–4.3 ppm. Additionally, the peak observed at 1.5 ppm is associated with methyl protons and cyclic pyruvate [20].

The C-NMR spectrum of guggul gum is shown in Figure 6. In the spectrum, carbohydrate carbon signals show anomeric carbon signals in the range of 90–110 ppm, while non-anomeric carbons appear between 60 and 85 ppm. The C-NMR results also indicate that the peak obtained in the range of 100 ppm represents the C-2–C-5 linkage of the mannose or rhamnose end group. Anomeric signals in the range of 101–103 ppm confirm the presence of pyranose sugars, while resonance in the range of 109.1–109.8 ppm confirms the presence of furanose sugars. Additionally, two major carbon resonance signals were observed in the ranges of 80–90 ppm and 70 ppm, corresponding respectively to carbon number 1 of beta-D-galactose, the anomeric carbon of D-galactose or galactose pyruvate, and galactose sulfate. The peak in the 70 ppm range may also be related to carbon number 5 of rhamnopyranosyl [23].

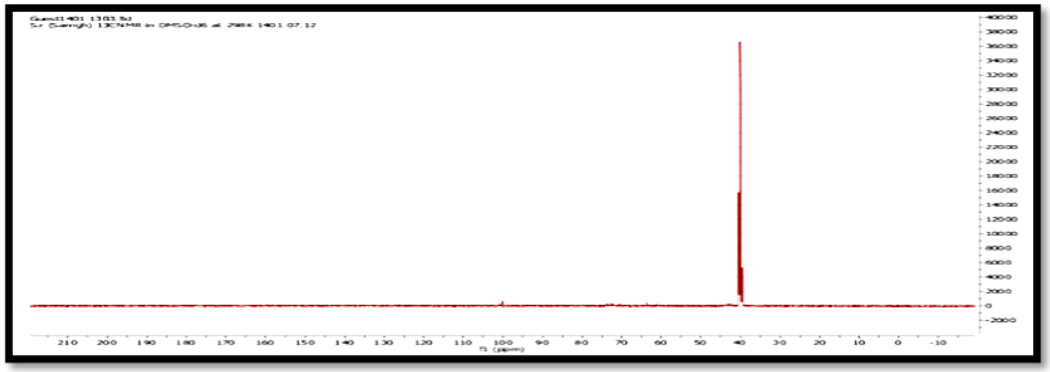

Fig. 6. C-NMR spectra of *Commiphora wightii* gum

3-5-3-Monosaccharides of Guggul Gum

The results of the monosaccharide analysis of guggul gum, determined by HPLC, are shown in Figure 7. Overall, this gum consists of monosaccharides such as mannose, rhamnose, glucuronic acid, galacturonic acid, fructose, glucose, xylose, and arabinose. The evaluation of the monosaccharide profile in the gum sample indicates that glucose is present as the

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predominant hexose, followed by mannose and rhamnose. The presence of glucuronic acid and galacturonic acid enhances electrostatic interactions outside the polysaccharide chain due to the presence of carboxyl and hydroxyl groups, along with their tendency to form bonds with positively charged ions. This characteristic facilitates the identification of this gum.

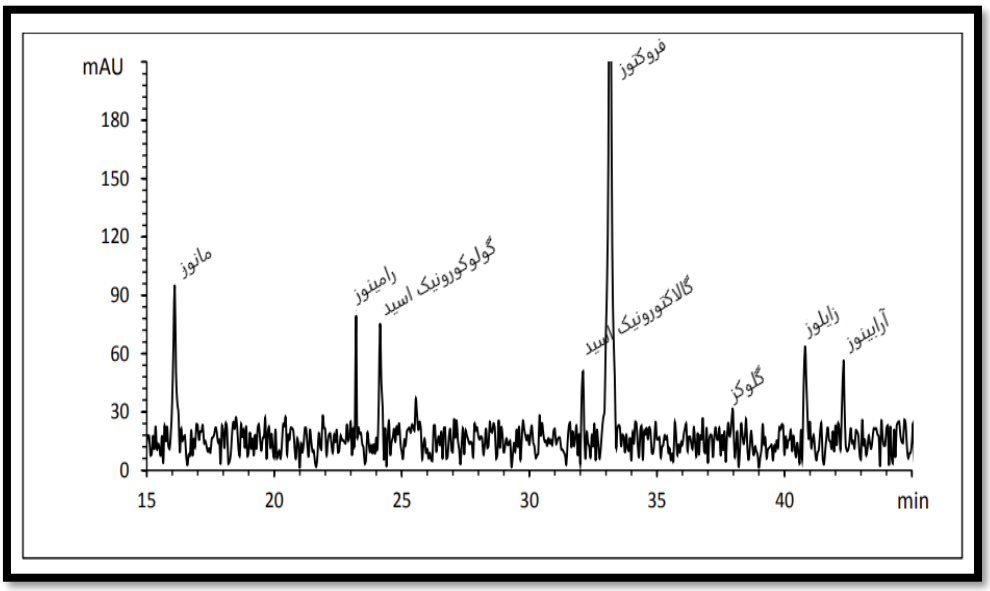

Fig. 7. HPLC analysis of *Commiphora wightii* gum

The research by Niknam (2017) on fenugreek mucilage showed that this gum contains eight types of monosaccharides, including glucose (6.76%), fructose (1.92%), xylose (10.46%), rhamnose (21.84%), galactose (2.46%), arabinose (52.61%), and glucuronic acid (3.69%). Therefore, the most abundant monosaccharide in this gum is arabinose, followed by rhamnose [30]. Salahiy Garaqilı (2020) analyzed the sugar composition (monosaccharides) of *Althaea officinalis* root gum. The results indicated that glucose and mannose, with 50% and 45%, respectively, are the predominant sugars forming the polysaccharide structure of *Althaea officinalis* root gum. This finding clearly demonstrates that *Althaea officinalis* root gum belongs to the glucomannan family. The glucose-to-mannose ratio in this gum is 1.1:1. In contrast, this ratio in basil seed gum is 3.3:1, meaning that the higher this ratio, the greater the solubility and water absorption capacity of the gum [1].

4-Conclusion

In this study, the physicochemical, functional, and structural properties of guggul gum were investigated. Overall, based on the analyses conducted, it can be concluded that guggul gum is a branched polymer with moderate solubility, belonging to the arabinogalactan group. Due to the presence of galacturonic acid in its structure, it is considered an anionic hydrocolloid. The presence of methyl groups and a high protein content in guggul gum imparts hydrophobic properties, which contribute to its good emulsifying ability. As a result, it can potentially be used as an emulsifier in the food industry.

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خواص فیزیکوشیمیایی و عملکردی پلی ساکاریدهای صمغ-رزین مقل

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چکیده

مقل یک اولئو صمغ رزینی است که در اثر خراش پوست گیاهCommiphora wightii ترشح می شود. هدف از این تحقیق بررسی خصوصیات فیزیکوشیمیایی و عملکردی صمغ گیاه مقل می باشد. خصوصیات عملکردی و فیزیکوشیمیایی صمغ مقل مثل میزان پروتئین، کربوهیدرات کل، رنگ، ویسکوزیته محلول، پتانسیل زتا، حلالیت، ظرفیت جذب آب، ظرفیت جذب روغن، خصوصیت کف کنندگی و امولسیون کنندگی صمغ بررسی شد. ساختار شیمیایی صمغ به روش های طیف سنجی مادون قرمز، کروماتوگرافی مایع با کارایی بالا و رزونانس مغناطیس هسته ای تک بعدی آنالیز گردید. میزان پروتئین صمغ ۸/۱۵ درصد و میزان کربوهیدرات آن ۶۱/۰۹ درصد بدست آمد. بررسی ویسکوزیته محلول صمغ مقل، رفتار رقیق شونده با برش را نشان داد. صمغ استخراج شده دارای پتانسیل زتای ۲۶- میلی ولت بود. حلالیت صمغ در سه دمای ۳۰، ۶۰ و ۹۰ درجه سلسیوس بررسی شد. ظرفیت جذب آب نیز حدود ۳/۷۸ گرم آب در یک گرم صمغ محاسبه گردید. قابلیت تشکیل کف صمغ۸۷/۰۳ درصد و پایداری کف آن ۶۵/۸۳ درصد اندازه گیری شد. میزان جذب روغن محاسبه شده برای صمغ مقل ۲/۳۳ گرم روغن در یک گرم صمغ بود. پس از بررسی ویژگی های امولسیونی صمغ مقل مشاهده شد که این صمغ توانایی امولسیون کنندگی خوبی در غلظت های۰/۵، ۱، ۱/۵، ۲و۳ درصد دارد و همچنین از پایداری حرارتی و انجمادی تا حدود بالایی برخوردار است. آنالیزهای انجام شده بر روی خصوصیات ساختاری صمغ مقل وجود واحدهای قندی مانند آرابینوز، رامنوز، فروکتوز، گلوکورونیک اسید وگالاکتورونیک اسید را نشان می‌داد. وجود گروه هیدروکسیل در طیف FTIR موید حضور گلوکورونیک اسید، گالاکتورونیک اسید، اسیدهای کربوکسیلیک، الکل قندها و گروه های گلایکوزیدی در پروفایل ترکیبات موجود در نمونه بود. ارزیابی پروفایل مونوساکاریدی با HPLC در نمونه صمغ بیانگر وجود گلوکز به عنوان یک هگزوز با حداکثر مقدار بود و پس از آن نیز مانوز و رامنوز قرار داشتند.

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