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Effect of gamma irradiation on rheological properties of polysaccharides exuded by *A. fluccosus* and *A. gossypinus*

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ABSTRACT

In this study, Iranian gum tragacanth (GT) exudates from *Astragalus fluccosus* (AFG) and *Astragalus gossypinus* (AGG) were irradiated at 3, 7, 10 and 15 kGy. Fourier transform infrared spectroscopy (FTIR) data showed that irradiation did not induce changes in the chemical structure of either type of gum. Although particle size distribution and both steady shear and dynamic rheological properties were considerably affected by the irradiation process, the magnitude of the effect of irradiation on each of the rheological and size variables was different for the hydrocolloids. For instance, for AGG, increasing the irradiation dose from 3 to 10 kGy, the $d(0.5)$ and $D[3,2]$ values were reduced by one-sixth to one-eighth fold. Colour measurement revealed that the radiation process led to an increase in the yellow index and b* values for both types of GT in powder form, but it was more pronounced for AGG samples. Irradiation led to an approximate 13-fold increase in redness in AFG. Surface and shape changes of the gum crystals were studied by scanning electron microscope (SEM) and a smoother surface for irradiated samples was detected. The notable changes in functional properties of each variety of irradiated gum should be taken into consideration before using the radiation technology as a commercial tool for sterilisation.

1. Introduction

Food irradiation has been profoundly investigated, but mainly initiated as an ultimate minimal processing technology. Food is commonly irradiated with microwaves; however, the term food irradiation is used to describe a process in which food is exposed to ionising energy [1]. Sufficient energy that breaks chemical bonds is "ionising irradiation" [2]. Gamma rays involve very high-energy radiation and are able to break chemical bonds when absorbed by material [3]. The application potential of specific ionising radiation is very diverse, from inhibition of sprouting of tuber and bulb crops to production of commercially sterile food products [1]. Irradiation in doses up to 10 kGy has been approved by the IAEA, the WHO, and the FAO (IAEA, 2003) [4]. Additionally, doses as high as 75 kGy have been approved for some products (WHO, 1981) [4]. Specific applications of food irradiation are approved by national legislations in over 55 countries worldwide [1]. As commercial applications of food irradiation become more accepted, the technology is increasingly applied not only to agricultural products but also to food ingredients and ready-to-eat meals. Irradiation is often viewed as being the last process, after packaging, used to control spoilage from pathogenic organisms. Furthermore, gamma irradiation, as an ionic and non-thermal process, has received more attention as a functional modification agent in polymer research and application. It has been applied as a physical modification method for natural polysaccharides such as starch [5]. Gamma irradiation treatment, compared to microwave, UV, ultra-high hydrostatic pressure and hydrothermal treatment, is rapid, convenient and more extensive, because ionising energy rapidly penetrates through the polysaccharide granules [6].

Polysaccharide gums provide a wide variety of functionality in foodstuffs, which includes gelling, thickening, emulsifying, and stabilising [7]. The function of polysaccharides in foods generally originates from chain entanglement, formation of junction zones between the ordered polysaccharide chains and subsequent aggregation. These effects are essentially governed by the molecular properties (e.g., molecular weight, degree of branching, chain rigidity, and functional groups) of polysaccharides and factors such as the concentration of polysaccharide and the quality of solvent, which is usually affected by the presence of sugars or salts [7]. Many studies have shown that treatments such as heating, ultrasonication and irradiation can induce inverse changes in the desired quality of the end product by influencing the structure and functional properties of the polysaccharides. For example, increasing the irradiation dose in gums such as agar, guar, alginates and carrageenan induced a decrease in the viscosity of their solutions [8–10], but for other gums, this reduction occurred only after an initial increase in the viscosity [11]. However, it was reported that

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the rheological characteristics of pectin and salep did not change much with irradiation [10]. The most important change caused by irradiation in polysaccharide solutions or their solid state [12] is the depolymerisation of basic units through the breakage of glycosidic bonds, which yields the radiolytic product's smaller polysaccharide units and results in softer gels [8]. In fact, polysaccharides are degraded by ionising radiation with cross linking as a possible side reaction via free radical mechanisms, depending on the water content. Radiolysis occurs with all doses of irradiation and is sometimes accompanied by an initial increase in viscosity. Low doses are an effective means of obstructing aggregation [11]. It appears that, to a certain degree, gamma irradiation modification can be useful for improving viscosity stability during storage time [6].

In this study, the effect of gamma irradiation on two varieties of GT was investigated. GT is defined by the Food Chemical Codex as the 'dried gummy exudation obtained from *Astragalus gummifer* Labillardiere or other Asiatic species of *Astragalus* (Fam. *Leguminosae*)' [13]. It is a plant exudates collected from *Astragalus* species shrubs grown in the Middle East, which is a complex, heterogeneous, anionic polysaccharide of high molecular weight [14]. GT consists of a water-soluble component, tragacanthin, and the insoluble, albeit swelling component, bassorin [15]. It was shown that various species of GT had different chemical compositions, physicochemical properties and rheological behaviours [16]. GT has been used as a stabiliser, emulsifier and thickener in food and has been used in technical applications in the pharmaceutical and cosmetic industries for many years. Its more outstanding characteristics, however, are its high degree of stability under strong acid conditions and its use as a bifunctional stabiliser [17]. Previous studies have researched the effect of gamma irradiation on the viscosity of GT with unknown botanical sources [18,19]. However, to the best of our knowledge there is no report on how the structure and viscoelastic properties of GT dispersions are influenced by gamma irradiation. Here, an attempt has been made to study the effect of gamma irradiation on steady shear and oscillatory rheological properties, functional groups, particle size distribution, colour parameters and the surface and shape of crystals of two varieties of GT.

2. Materials and methods

2.1. Gum tragacanth

GT exuded by two species of *Astragalus* (*gossypinus* and *fluccosus*) was collected from plants growing in different provinces of Iran. The plants were tapped with a knife by making careful longitudinal incisions in the tap root and the bark of the branches [17]. The gum readily exuded from these cuts in the form of 'ribbons' that became brittle on drying. Taxonomic identification of the specimens was done by Dr. Ali Masoumi, an academic member of the Forest, Range, and Watershed Management Organisation of Iran.

2.2. Preparation of samples

The raw GT was powdered in a high-speed mechanical blender and later sieved to obtain uniform samples. Powdered gum with a mesh size between 200 and 500 μm was used in this study.

2.3. Irradiation

The powder form of two varieties of GT were irradiated at 3, 7, 10 and 15 kGy at ambient temperature and at a fixed dose rate of 5.4 Gy/s from a Co-60 gamma irradiator (Gammacell 220, AECL) at Nuclear Science and Technology Research Centre (Tehran, Iran). The gamma irradiator was calibrated using the Fricke dosimeter. A cobalt-60, manufactured in Nordion International Co. Ltd., Ottawa, ON, Canada, was used for γ-ray source. The samples were kept in sealed polyethylene bags at room temperature.

2.4. Rheological measurements

GT powder (1 g), both irradiated and non-irradiated, was accurately weighed and dispensed into 100 g of pure deionised water. Deionised (Milli-Q) water was used for all experimental work. The whole gum dispersions were kept on a magnetic stirrer at room temperature and gently stirred overnight, which led to complete hydration of the biopolymer. Steady state, as well as oscillatory shear measurements, were performed with a Physica MCR 301 rheometer (Anton-Paar, GmbH, Graz, Austria) using a serrated plate-and-plate system (40 mm in diameter, 0.6 mm gap). Temperature control was carried out with a Peltier system equipped with a fluid circulator. In the experiments, the samples were covered with a solvent trap to prevent evaporation. Flow curves were obtained at shear rates of 0.1–1000 (1/s). Before the steady and dynamic shear rheological measurements, all samples were left standing for 4 min at 25 °C to allow for structure recovery and temperature equilibrium. The rheological measurements were performed in triplicate.

The power-law model was used to describe the rheological properties of AGG dispersions over mid-range shear rates. Logarithmic plots of shear stress versus shear rate were used to calculate the consistency coefficient (m) and the flow behaviour index:

$$\sigma = m\dot{\gamma}^n \tag{1}$$

Eq. (2) was used to evaluate the Hershel–Bulkley model consistency coefficient, m' and flow behaviour index and n' values for AFG dispersions:

$$\sigma = \sigma_o + m'\dot{\gamma}^{n'} \tag{2}$$

A satisfactory fitting of data are provided with the Cross equation, using shear rate as the independent variable:where η_0 and η_∞ are the asymptotic values of the viscosity at zero and infinite shear rates, respectively, λ is the characteristic time and k rules the shear dependence in the power-law region [20].

$$\eta = \eta_\infty + \frac{\eta_o - \eta_\infty}{1 + (\lambda\dot{\gamma})^k} \tag{3}$$

Strain sweep tests were performed at (0.01–1000%, 1 Hz) to determine: (1) the limiting value of the linear viscoelastic range (LVE or γ_L); (2) the structural strength (G' at LVE); (3) the resistance to mechanical force or yield stress (τ_y), which is also a measure of structural strength and can be calculated from the limiting value of LVE range in terms of shear stress; (4) the flow point (τ_f), the stress at which the internal structure breaks to the extent that it causes the material to flow ($G' = G''$); and (5) the damping factor ($\tan\delta$) or the ratio of loss modulus to elastic modulus to provide a direct view of whether the samples behaved as liquids or solids [21]. Frequency sweep tests were performed using a frequency ramp from 0.01–100 Hz. All experiments were performed at 25 °C.

2.5. Colour measurement

The L*a*b* values and yellowness index were determined for gum powders with a Colour-Eye 7000A reflectance spectrophotometer. The instrument has $d/8°$ geometry with a 6-inch integrating sphere and a pulsed xenon lamp. Reflectance data were collected over the full wavelength range of the instruments (360–750 nm, 10-nm interval) with a specular component included through a SAV aperture size. The results were expressed in accordance with the CIELAB system with reference to illuminate D65 and a visual angle of 10°. CIE L*a*b* space uses three terms L*, a* and b* to represent colour. L* represents lightness; 100 represents a perfect white sample, and 0 represents a perfect black.