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Porang Flour-Based Hydrogel as a Vitreous Substitute: Rheological, Optical, and Structural Evaluation for Biomedical Applications

Ivan Rizoputra

ivanrizo79@gmail.com

Sepuluh Nopember Institute of Technology

Sriati Wahyudi

Padjadjaran University

Niniek Fajar Puspita

Sepuluh Nopember Institute of Technology

Risdiana Risdiana

Padjadjaran University

Darminto Darminto

Sepuluh Nopember Institute of Technology

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Abstract

The transparent colloid known as vitreous humor is essential for maintaining the structural stability and optical clarity of the eyeball. Damage to this fluid requires vitreoretinal surgery with substitute materials; however, widely used substitutes such as sulfur hexafluoride gas, silicone oil, and saline buffer have drawbacks, including high cost, limited availability, and poor long-term biocompatibility. This study introduces a novel bio-based vitreous substitute in the form of a glucomannan hydrogel synthesized from porang (Amorphophallus muelleri Blume) flour, an abundant natural resource from Indonesia. The hydrogel was characterized for viscosity, pH, density, rheological properties, refractive index, transparency, and chromophore identification. The optimal formulation (stirred for 18 hours) exhibited a static viscosity of 0.516 Pa·s, pH of 7.5, and an apparent viscosity of 8.1 Pa·s under shear rate conditions, while the storage modulus (G') and loss modulus (G") were 2.602 Pa and 1.0087 Pa, respectively. UV–Vis spectroscopy confirmed the absence of chromophore groups at 250–300 nm, indicating excellent optical transparency. The physical properties of the hydrogel closely resemble those of the natural human vitreous humor, suggesting that porang-based glucomannan hydrogel is a low-cost, biocompatible, and optically suitable candidate for use as a vitreous humor substitute in vitreoretinal surgery.

1. Introduction

Consisting of randomly arranged collagen fibrils bound in a hyaluronan matrix, *vitreous humor* is a clear, colorless, hydrated, and avascular colloidal gel that makes up nearly two-thirds of the entire eye structure [1] or 80% of the eyeball volume [2, 3]. In addition to serving as a refractive interstitial medium that transmits light to the retina [2, 4], *vitreous humor*'s primary role is to maintain the eye's rigidity and structure [5]. A mass of about 4 g, a density of 1.0053–1.008 g/cm³, a refractive index of 1.3345–1.3348; a viscosity of 0.3–2 Pa.s; and a pH range of 7.0–7.5[6] are the physical characteristics of native *vitreous humor*. According to other research, *vitreous humor* has a high buffering ability that is comparable to that of blood, with a pH that tends to be constant between 7.20 and 7.30 [2, 7].

However, conditions like diabetes [8] and accidental trauma can alter the composition of vitreous fluid, leading to a number of ailments such macular holes, retinal detachment, and *vitreous* hemorrhage [9]. The vitreous humor fluid needs to be replaced with new *vitreous humor* fluid if the composition of the *vitreous humor* has changed. A vitreoretinal surgical operation, which is a surgical technique intended to enhance the condition of the retina and vitreous, is one way to replace it [4]. The choice of vitreous humor replacement material with comparable physical characteristics, such as viscosity, transparency, refractive index, and surface tension, is crucial to the procedure's success [10].

Several synthetic materials have been studied by researchers as viable replacements to *vitreous humor*. In addition to gases like sulfur hexafluoride (SF_6) [11], perfluoroethane (C_2F_6) [12], and perfluoropropane (C_3F_8) [13], these materials additionally include silicone oil PDMS (Polydimethylsiloxane) [14], saline buffer [15], and perfluorocarbon liquids (PFCLs) [16]. These materials emulsification, lower refractive

index compared to native *vitreous* fluid, and low density, which necessitates that patients lie in a specific position after surgery, are among of its drawbacks[17]. New, less costly, and biocompatible substitute materials are required because these materials are commercial, hard to obtain, and very expensive [18].

Applying glucomannan polysaccharides extracted from porang flour is one of them. The main component of porang flour is the porang tuber plant (*Amorphophallus muelleri* Blume), which is part of the *Araceae* family, which has significant quantities of glucomannan (15–64%) of the dry weight. Porang tubers also contain glucomannan, although it is often taken from dried tubers, such as *konjac* tubers. Porang tuber plants are widely found in Indonesia and thrive in subtropical climates, with their tubers containing glucomannan that is typically extracted from dried tubers such as konjac [19].

Glucomannan is a neutral polymer that is primarily made up of D-glucose and D-mannose linkages via β-1,4 glycosidic bonds. It is derived from konjac tubers and has a molar ratio of roughly 1:1.6 for D-glucose to D-mannose [20].

Figure 1 depicts the glucomannan chain's structure. In terms of physical characteristics, glucomannan is advantageous since it can absorb water up to 100 times its dry weight, produce gels, and have a high level of adhesiveness [21]. Porang flour's high glucomannan content can be used in a variety of medical applications, especially for hydrogel products such as wound dressings [22], scaffold support for body tissue engineering applications [23], cartilage tissue substitutes [24], wound dressings [25], drug delivery [26], antibacterial [27], regulating intestinal inflammation [28], 3D tissue engineering [29], and bone tissue frameworks [30]. This is because hydrogels, which are non-toxic, have rheological characteristics that are compatible with their use, and have strong biocompatibility characteristics [31].

In previous research, a purifying method was used to raise the amount of glucomannan and decrease the amount of oxalic acid in porang flour [32]. Previous studies have also used the stirring and dissolving approach with DI-Water to synthesize hydrogel from porang flour [28, 29].

2. Material and methods

The materials used for the synthesis and characterization process were porang flour from Nganjuk Regency, East Java, water or aquades solvents, and 70% ethanol alcohol. The study began with a purification technique using the maser method, as described in the journal [32], which involved soaking porang flour in a 70% ethanol solution for up to 7 days. The hydrogel synthesis process from glucomannan flour extracted from porang flour was dissolved using DI-Water at a 1:40 ratio, with stirring periods of 6 hours, 12 hours, 18 hours, and 24 hours using a magnetic stirrer with a rotational speed of 300 rpm. The hydrogel's physical properties as a substitute for vitreous humor are characterized, including pH, viscosity, refractive index, density, trans-parent using UV-Vis spectroscopy, and rheology properties.

3. Result and Discussion

3.1. Physics properties Hydrogel

Based on the results of measurements of pH, viscosity, refractive index, and density of the porang flour hydrogel that has been purified by the soaking method for 7 days. Shown in Table 1.

Table 1
Results of measurements of physics properties of the porang flour hydrogel

Hydrogel material	**Time stirrer (Hour)**	**pH**	**Viscosity (Pa.s)**	**Refractive Indeks**	**Density (g/cm^3)**
Hydrogel VH [6]		7.0-7.4	0.3-2	1.3345–1.3348	1.0053–1.008
Hydrogel I	24	7.6	0.536	1.3356	0.972
Hydrogel II	18	7.2	0.516	1.3356	0.976
Hydrogel III	12	7.5	0.405	1.335	0.911
Hydrogel IV	6	6.7	0.423	1.3353	0.976

Based on variances in stirring times, the hydrogels we obtained were divided into four types: hydrogel I had a stirring time of 24 hours, hydrogel II had an 18-hour stirring time, hydrogel III had a 12-hour stirring time, and hydrogel IV had a 6-hour stirring time. The refractive index obtained still above the *vitreous* fluid standard, according to observations of the hydrogel samples' starting properties from various stirring time variations.

Based on table.1, it can be inferred that, at an 18-hour stirring time, the pH and viscosity values obtained have satisfied the requirements as a substitute for *vitreous humor*, but the refractive index obtained is still too high and the density obtained is still too low in comparison to the reference data.

3.2. Rheology Properties Hydrogel

The rheological spectrum of the shear rate of the hydrogel from porang flour as a substitute for *vitreous humor* fluid can be seen in Fig. 2 and Table 2.

Table 2
Comparison of shear rate rheology of glucomannan hydrogels

Hydrogel material	**Time stirrer (Hour)**	**Share rate (s^{-1})**	**Viscosity (Pa.s)**
Hydrogel VH [33]		0.01–1000	$20 - 10^{-3}$
Hydrogel I	24	0.99–1000	0.6 – 0.25
Hydrogel II	18	0.99–1000	8.1–0.44
Hydrogel III	12	0.99–1000	51-0.49
Hydrogel IV	6	0.99–1000	56.6 – 0.53

Based on Fig. 2. On Table 2 It can be concluded that the porang flour hydrogel with a stirring time of 12 hours and 6 hours has a shear rate and viscosity value that is greater than the viscosity of 20 Pa.s and a shear rate of 0.01 s^{-1} to a viscosity of 0.001 Pa.s with a shear rate of 1000 s^{-1} but is consistent around 50 Pa.s and 0.99 s^{-1} until a viscosity of 0.5 Pa.s is obtained with a shear rate of 1000 s^{-1}, a very large shear rate value compared to previous data. Therefore, based on the rheological characterization of the shear rate, it can be said that the hydrogel with stirring times of 12 and 6 hours has not fulfilled the requirements as a candidate hydrogel to replace *vitreous humor* fluid. The change in rheology viscoelastic of glucomannan hydrogel based on the graph in Fig. 3 can be analyzed in Table 3.

Table 3
Comparison of viscoelastic rheology of glucomannan hydrogels

Hydrogel material	**Time stirrer (Hour)**	**Storage Modulus (Pa) (G' ± ΔG')**	**Loss Modulus (Pa) (G" ± ΔG")**
Hydrogel VH [34]		5.09 ± 1.86	1.81 ± 0.98
Hydrogel I	24	1.5010 ± 0.0064	0.5486 ± 0.0037
Hydrogel II	18	2.6020 ± 0.0042	1.0087 ± 0.0014
Hydrogel III	12	1.1009 ± 0.0056	0.3764 ± 0.0037
Hydrogel IV	6	1.4133 ± 0.0057	0.5230 ± 0.0035

Based on the results of the rheological characteristics of the viscoelastic modulus in Table 3, it can be concluded that the hydrogel samples in the plateau area with a frequency of 0.1–10 rad/s have a storage

modulus value G’ lower than the loss modulus value G” which indicates that the gel is predominantly melting [35].

3.3. Characterization spectroscopy UV-Vis.

The UV-Vis spectrum graph for the characterization of the glucomannan flour hydrogel that has been extracted from porang flour can be seen in Fig. 4.

4. Conclusion

More experiments are needed to verify this complicated flow topology. Based on the synthesis variation method used, the 18-hour stirring time of the porang flour was proven to produce a hydrogel with properties close to those of the original vitreous humor, based on characterization results such as pH, viscosity, and rheology. However, it did not meet the transparency criteria based on UV-Vis characterization, refractive index, and density.

Declarations

Institutional Review Board Statement

Not applicable

Informed Consent

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Author Contribution

I.R.: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing.S.W.: Methodology, Software, Data curation, Writing – original draft, Writing – review & editing. N.F.P.: Investigation, Resources, Data curation. R.D.: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing. D.R.: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing.

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Data Availability Statement:

Not applicable.

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Figures

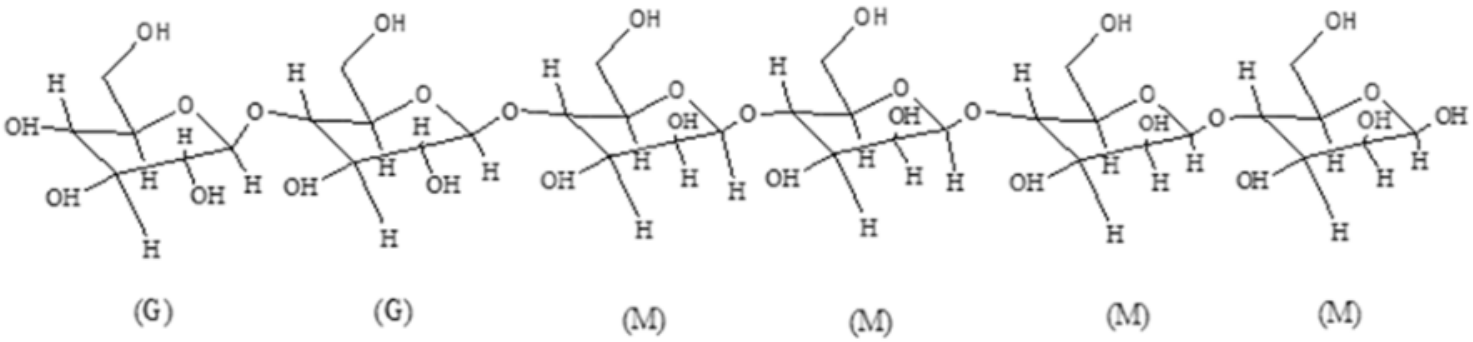


Figure 1

Glucomannan structure

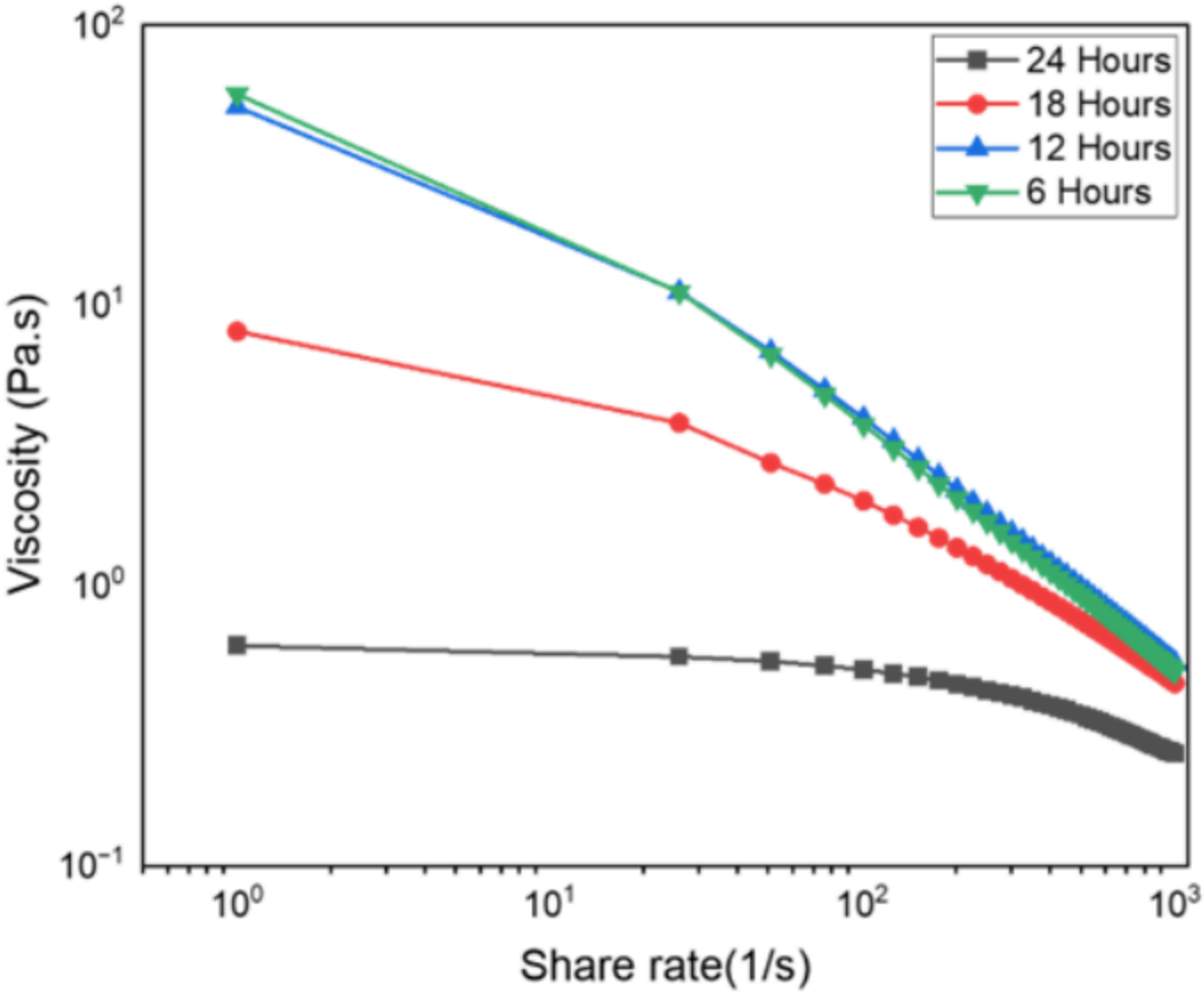


Figure 2

Graph rheology share rate hydrogel glucomannan

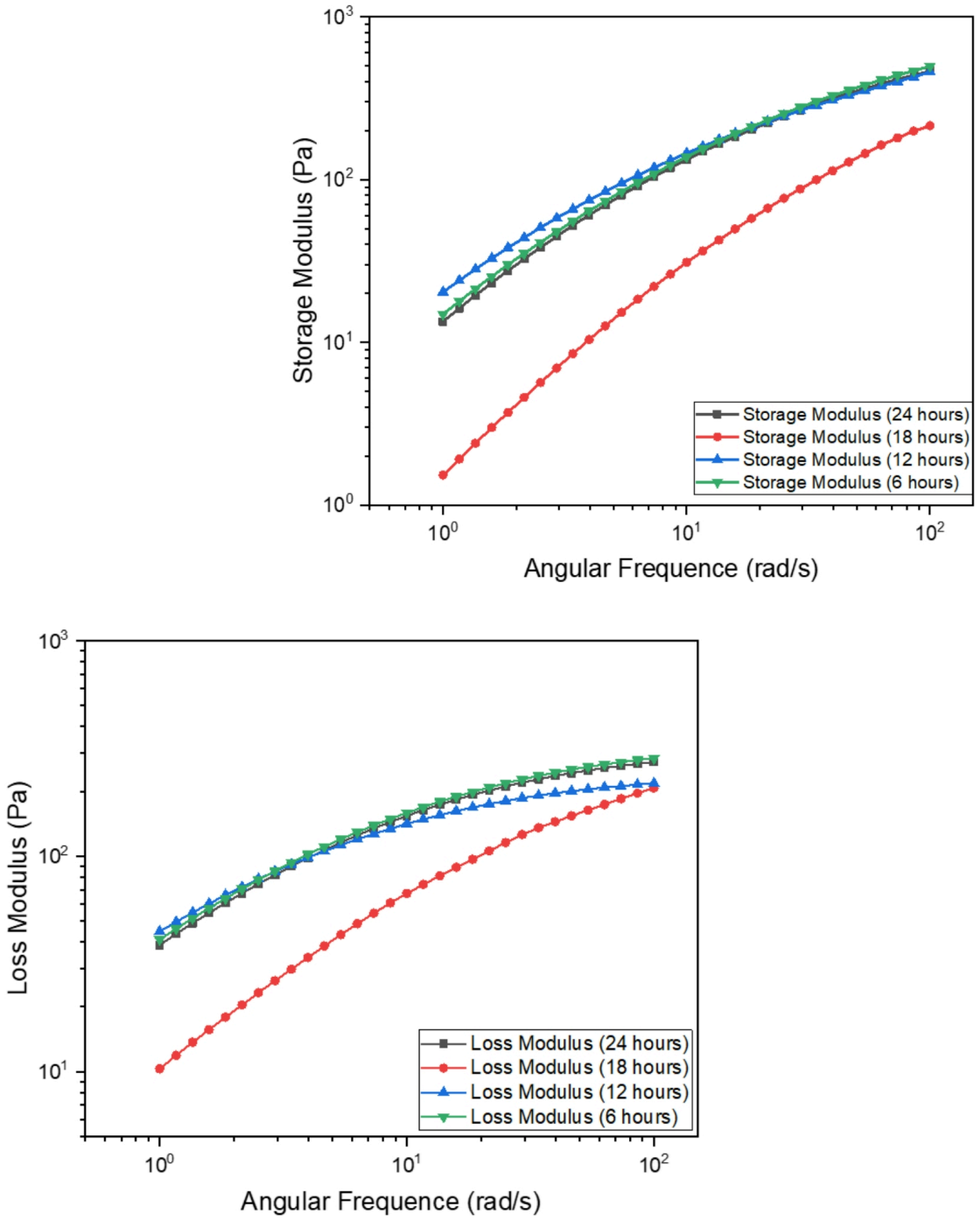


Figure 3

Graph rheology viscoelastic storage and loss modulus hydrogel glucomannan

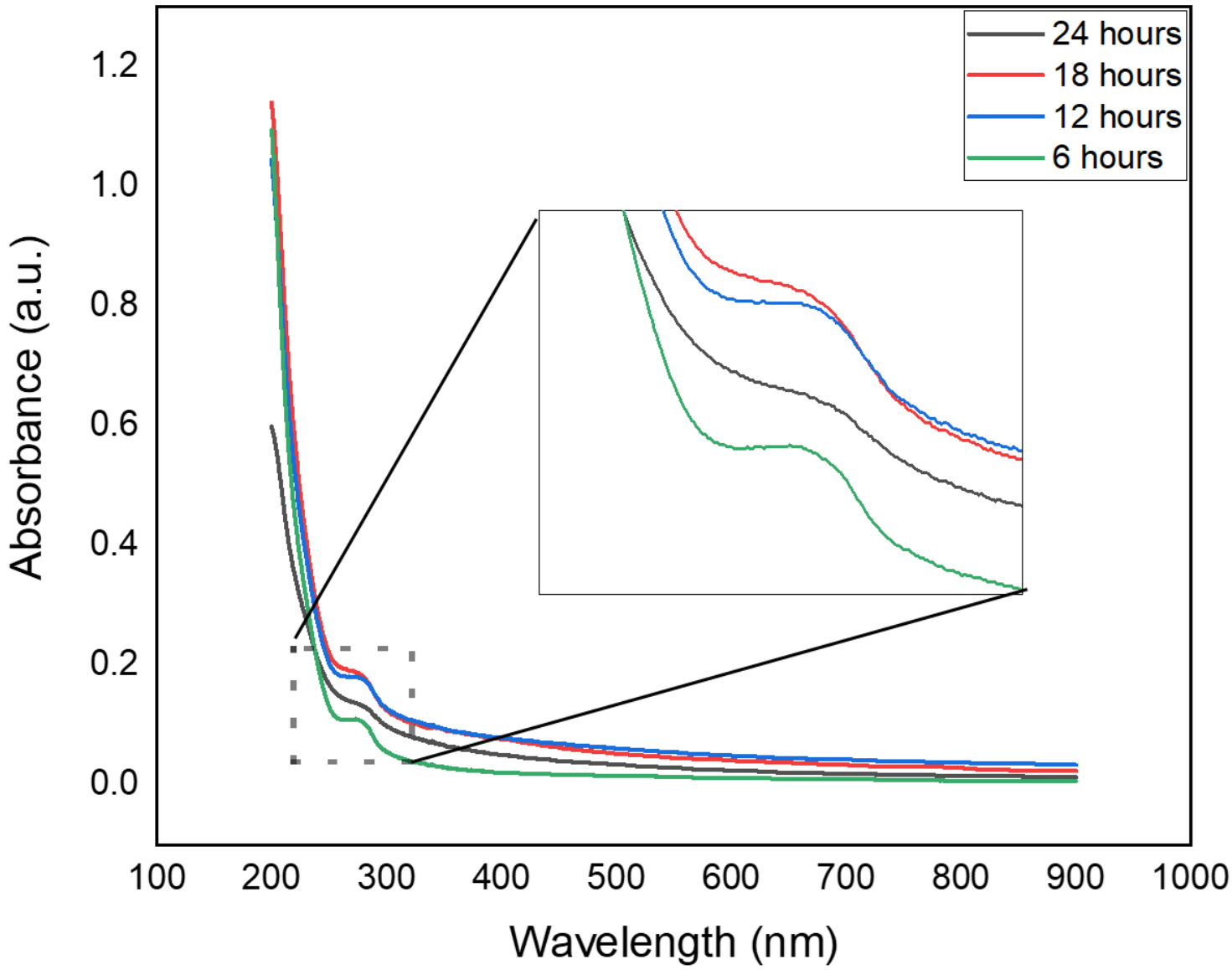


Figure 4

UV-Vis graph of the glucomannan hydrogel

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