Protocatechualdehyde-Enhanced Injectable Oxidized Pectin–Gelatin Hydrogels for Advanced Wound Healing and Tissue Regeneration

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BACKGROUND

- Hydrogels with dynamic **Schiff base linkages** offer biocompatibility, self-healing, and promote cell adhesion, making them ideal for biomedical use.
- This study presents a **dialdehyde-functionalized pectin** (OP) - gelatin hydrogel, where both polymers support bioactive delivery, tissue regeneration, and tissue adhesion. **Protocatechualdehyde** (PA) reinforces the system with antioxidant, antibacterial, and anti-inflammatory effects .
- **Procaine** (PC) is incorporated for localized and **sustained release**, contributing both anesthetic and antioxidant functions [1] .

OBJECTIVES

This study aims to develop an **injectable**, **self-healing**, and **tissue-adhesive scaffold** based on Schiff base linkages among OP, gelatin, and PA, aiming to achieve high **antioxidant capacity**, controlled PC release, and promotion of **angiogenesis**.

METHODOLOGY

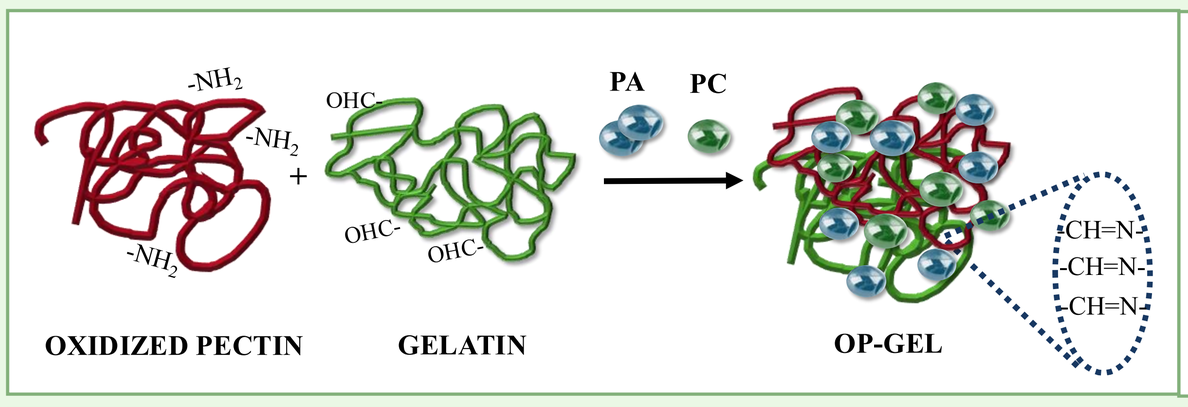

Figure 1. Oxidized pectin-gelatin crosslink formation and Protocatechualdehyde Structure

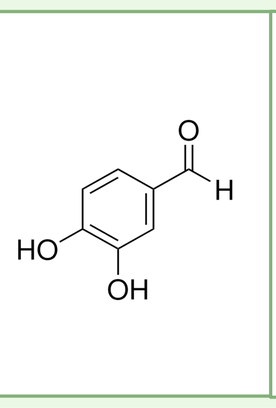

Figure 2. Protocatechualdehyde

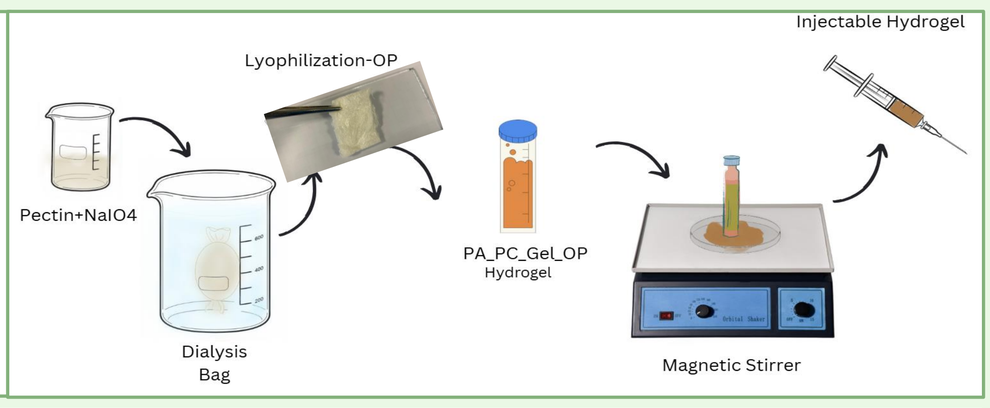

Figure 3. Schematic representation of the experimental procedure

RESULTS

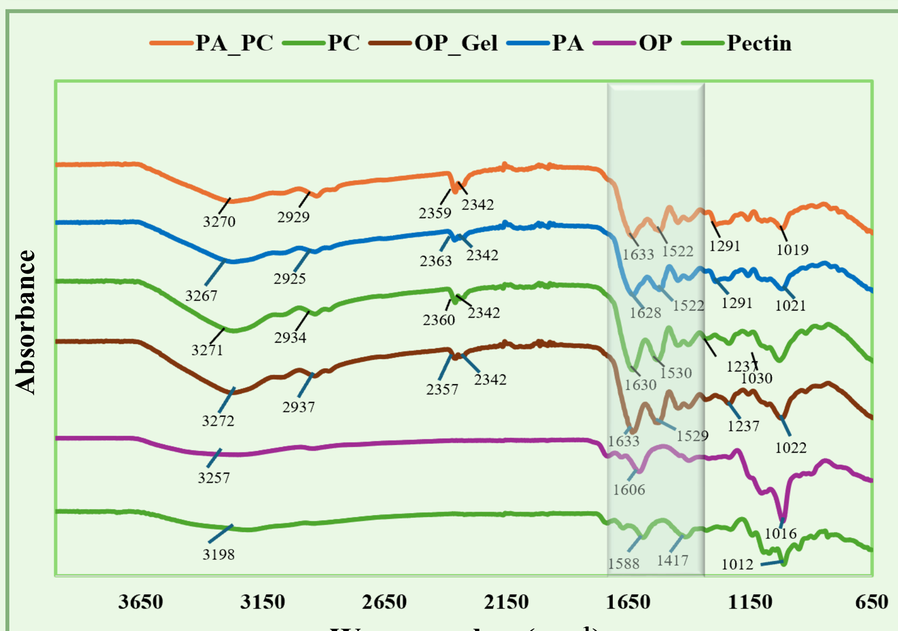

Figure 4. FTIR spectrum

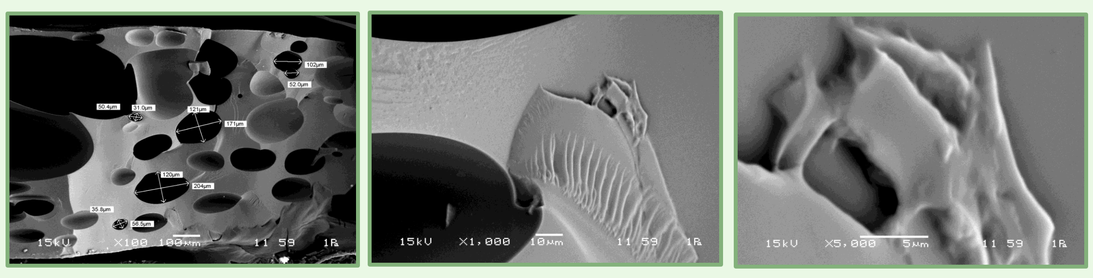

Figure 5. SEM images of PA_PC Hydrogel complexes.

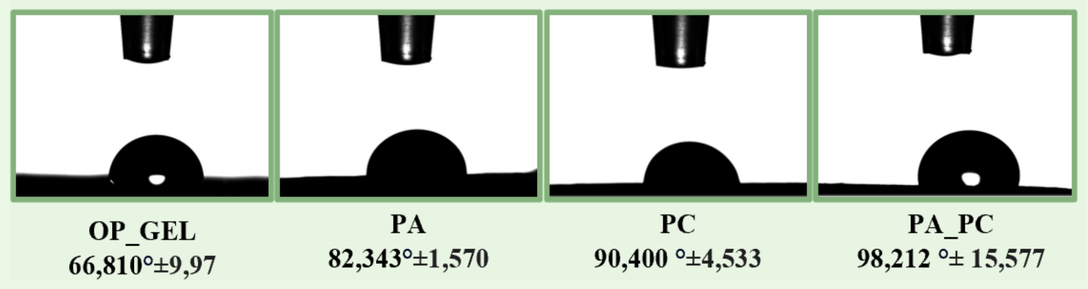

Figure 6. Contact Angle Measurement

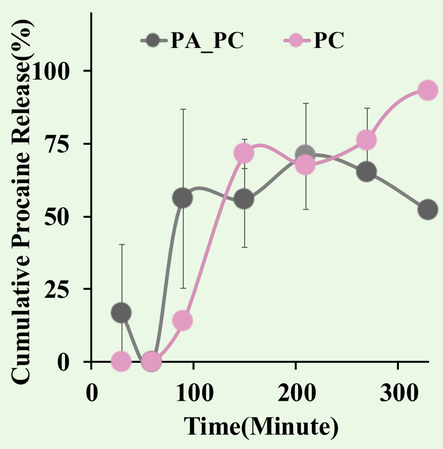

Figure 7. Procaine Release

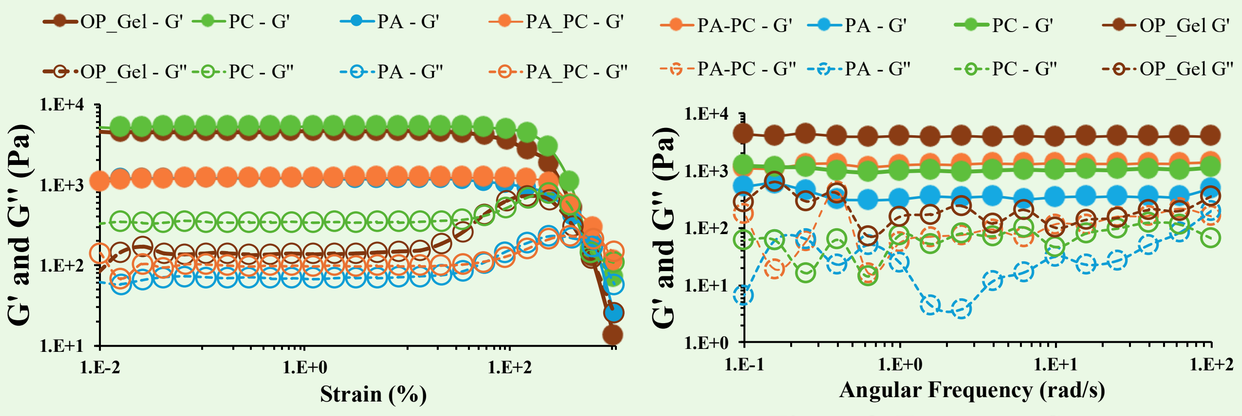

Figure 8. Amplitude Sweep

Figure 9. Frequency Sweep

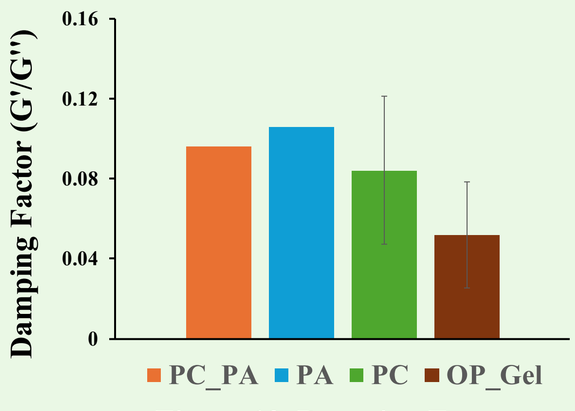

Figure 10. Damping Factor

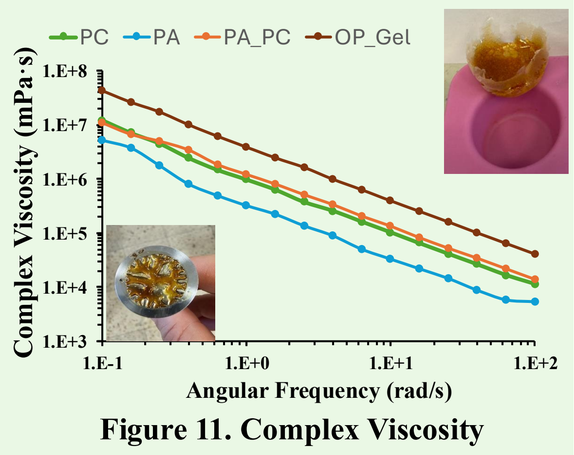

Figure 11. Complex Viscosity

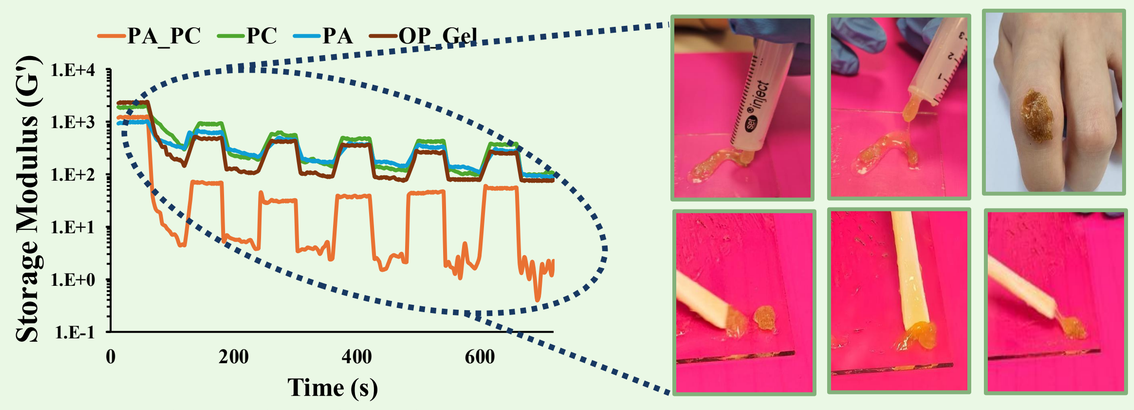

Figure 12. Self Healing

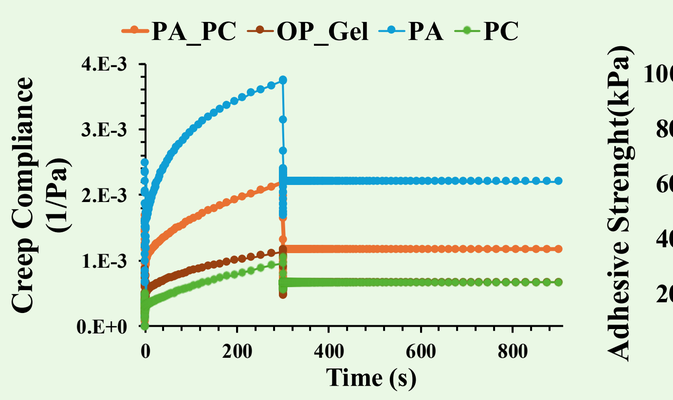

Figure 13. Creep

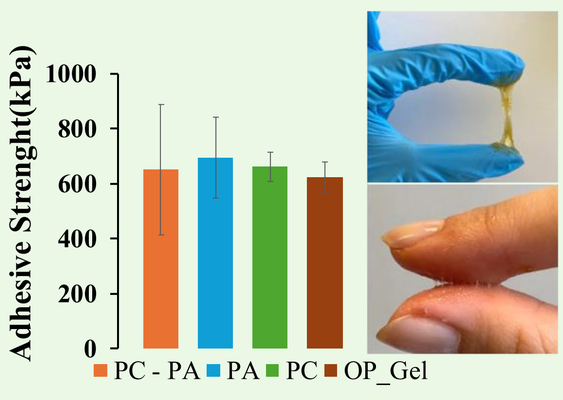

Figure 14. Adhesive strength

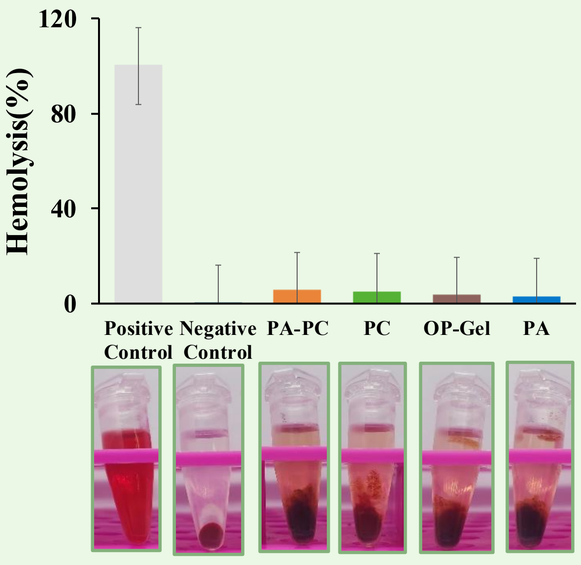

Figure 15. Hemolysis Analysis

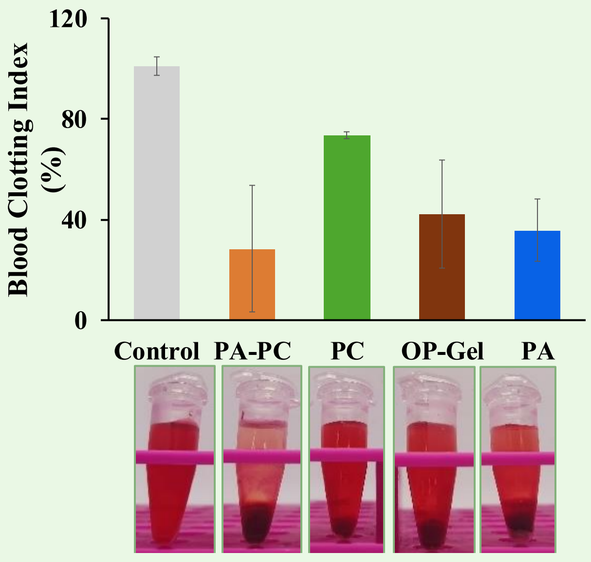

Figure 16. Hemostatic Activity of The Hydrogels

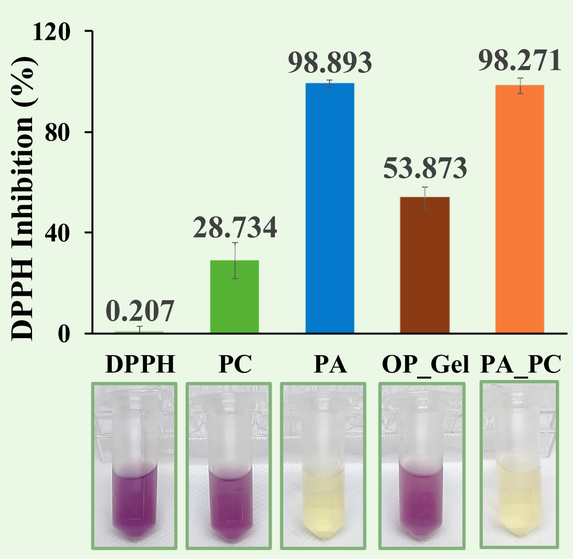

Figure 17. DPPH Analysis

CONCLUSION

- ✓ FTIR analysis confirmed the oxidation of pectin by the disappearance of the 1588 cm^{-1} ester carbonyl peak and the appearance of a new peak at 1606 cm^{-1} corresponding to aldehyde C=O stretching [2] .In the hydrogel structure, the formation of new peaks at 1630 cm^{-1} (C=N/C=O, amide I) and 1633cm^{-1} (N–H bending, amide II) indicated successful Schiff base crosslinking between oxidized pectin and gelatin [3] .
- ✓ **The porous and interconnected microstructure** observed under SEM provides a favorable environment for fluid absorption, nutrient exchange, and diffusion-controlled molecule transport. Micro-scale surface roughness and occasional cracks may contribute to enhanced mechanical interactions and controlled release behavior.
- ✓ Rheological measurements demonstrated high storage modulus ($G' > G''$) in the linear viscoelastic region, low damping factor ($\tan\delta$), and a steep decrease in complex viscosity ($n \approx 0.999$) with increasing angular frequency. These results **confirm strong viscoelastic behavior and shear-thinning** properties, enabling injectability and mechanical responsiveness.
- ✓ The hydrogel exhibited efficient **self-healing** behavior due to dynamic Schiff base bonds, and moderate **tissue adhesion** strength based on lap shear testing, indicating structural integrity and potential interface stability in wound environments.
- ✓ Approximately 70% of the encapsulated PC was released in a **controlled manner** within 4 hours. Additionally, **antioxidant capacity** significantly increased in PC and PA-modified formulations, with DPPH inhibition rising from 58.87% (OP_Gel) to **98.89%** (PA-PC), highlighting its therapeutic potential.
- ✓ Hemolysis results confirmed safe blood compatibility. **Hemostatic activity** improved in PA-PC and PA groups due to fluid uptake and the porous structure that concentrates clotting factors.

ACKNOWLEDGEMENT

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REFERENCES