

An Exploratory Study on Edible Conductive Materials Using Water and Oil-based Gels for Human-Food Interaction

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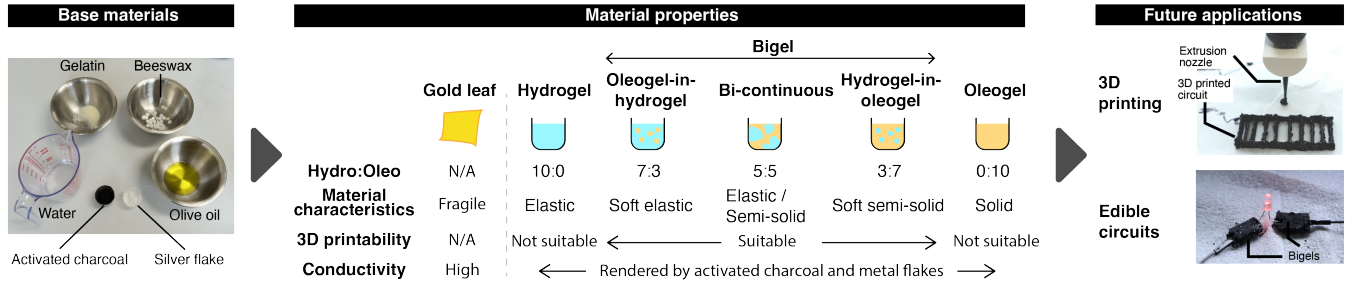


Figure 1: Overview of the Proposed Method. (Left) Conductive hydrogels and oleogels were formulated by incorporating conductive fillers. (Middle) By tuning the composition ratio of hydrogel and oleogel phases, we adjusted material properties such as texture and water/oil affinity. (Right) These bigels materials support integration into 3D food printing workflows for circuit embedding and adhere well to oil-rich foods due to their lipophilicity.

ABSTRACT

We present an exploratory study on edible conductive bigels, hybrid materials combining oil-based oleogels and water-based hydrogels. By tuning the composition ratio, we achieve 3D-printable gels with adjustable texture and compatibility across various food environments, from moist dishes to oily ones. The gels are enhanced with edible conductive fillers and designed for extrusion-based 3D food printing. Our experiments demonstrate that the material supports tunable texture, provides sufficient conductivity for sensing applications, and can be integrated into real foods, such as chocolate. This work lays the foundation for creating edible, printable, and environmentally adaptive interfaces for human-food interaction.

CCS CONCEPTS

• Human-centered computing → Interaction techniques.

KEYWORDS

digital fabrication, human-food interaction, Food sensing, Conductive biomaterials

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1 INTRODUCTION

Edible conductive materials have opened new possibilities for creating edible sensors and embedding electronics directly into food, enabling food to serve as an interactive interface. Prior approaches have used edible metals, such as gold leaf, to create conductive traces [1, 3, 6]. While such materials offer excellent conductivity, they require manual fabrication effort due to their fragility and are incompatible with automated workflows such as 3D printing.

As a more flexible alternative, researchers have explored conductive hydrogels, for example, gelatin-based gels with activated charcoal [4]. Hydrogels offer softness and ease of fabrication through casting or cutting. However, they lack mechanical strength for self-supporting extrusion, making them unsuitable for 3D food printing. Additionally, their hydrophilic nature makes this material difficult to conceal with food with oil-derived characteristics, such as chocolate, thus limiting the actual use case.

In this work, we propose a new class of edible conductive materials, namely oleogels and bigels, designed for compatibility with diverse food environments and integration into automated fabrication workflows. Oleogels, made from oils combined with gelling agents, offer oil affinity and a semi-solid consistency. Furthermore, we develop bigels by combining oleogels with gelatin-based hydrogels. By adjusting the oil-water ratio, we achieve a tunable range of textures, from flowable to shape-retaining, suitable for both oil- and water-based foods. We enhance these gels with edible conductive fillers and demonstrate their suitability for 3D printing and food integration. This work introduces a compositionally tunable, printable edible platform that enables embedding of sensing elements

into diverse foods, supporting future applications in interactive dining, personalized nutrition, and edible interfaces.

2 FABRICATION METHOD

To create a printable, edible conductive material compatible with a wide range of food environments, we formulated oleogel and bigel using food-safe components. The material properties were tuned by adjusting the oil-to-water ratio, and electrical conductivity was achieved by incorporating edible conductive fillers.

Material Composition and Mixing. Bigels were formulated by combining the oleogels (7 wt% beeswax in olive oil) with a gelatin-based hydrogel (7 wt% gelatin in water), which were premixed at 80 °C independently. To explore the effect of composition on texture and processability, we created three bigel variants by adjusting the oleogel-to-hydrogel ratios to 3:7, 5:5, and 7:3 (w/w), corresponding to oleogel-in-hydrogel, bicontinuous, and hydrogel-in-oleogel structures, respectively. Oleogels and hydrogels were blended using a hand blender for five minutes until a uniform texture was achieved.

Conductive Filler Integration. To render the gels electrically conductive, we added 30 wt% activated charcoal, a known edible conductive filler that exceeds the percolation threshold. Additionally, 0.04 wt% edible silver flakes were incorporated to improve particle connectivity and reduce overall resistance [2]. The fillers were thoroughly dispersed in the gel matrices using a magnetic stirrer to ensure homogeneity before molding or printing.

3 EXPERIMENT

Textural Characterization Based on Composition Ratio. Bigels has tunable texture properties by adjusting the ratio between oleogel and hydrogel phases. We fabricated conductive bigels at three different weight ratios, 3:7, 5:5, and 7:3 (oleogel:hydrogel), and qualitatively evaluated their elasticity and rigidity. At a 3:7 ratio, the bigels exhibited high elasticity and soft gel. As the oleogel content increased, the material transitioned into a firmer, more paste-like consistency. These trends are visually illustrated in Figure 2(a) and summarized in Figure 1. At 5:5 composition, it was subsequently utilized for 3D printing.

Electrical Conductivity Measurement. We assessed the electrical conductivity of both oleogels and bigels using a commercial LCR meter (Sanwa), following the formulation procedures described earlier. The measured resistance for all samples was ranged from 20,000 to 30,000 $\Omega \cdot \text{cm}$, indicating sufficient conductivity for low-power applications such as touch sensing and simple LED activation. Additionally, incorporating 0.04 wt% edible silver flakes further reduced resistance to 5,000 - 10,000 $\Omega \cdot \text{cm}$, suggesting the material's potential for edible wiring or circuit-based food interfaces.

4 APPLICATIONS

To explore potential use cases for our edible conductive gels, we examined their applicability in two scenarios: 3D food printing and integration with oil-rich foods.

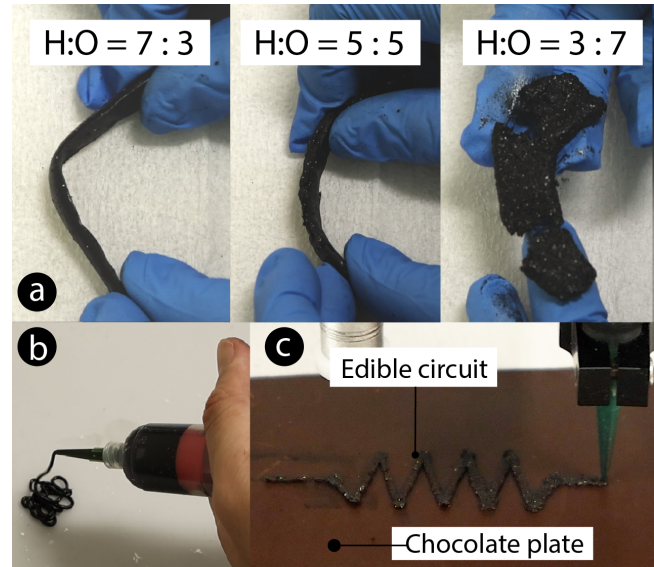


Figure 2: (a) Visual appearance of bigels with varying composition ratios. (b) A bigel prepared for 3D printing. (c) An edible circuit decorated on a chocolate plate.

4.1 3D food printing

The bigel formulation with a 5:5 oleogel-to-hydrogel ratio demonstrated a favorable balance of elasticity and viscosity, making it well-suited for extrusion-based 3D food printing (Figure 2(b)). This composition retained its shape after deposition while remaining flowable enough for consistent extrusion.

The printability of the gel enables the fabrication of custom-designed edible components with embedded conductive regions, such as edible circuits, touch-responsive food surfaces, or spatially controlled sensing zones. This property offers new opportunities for creating interactive food experiences through computational design and automated manufacturing.

4.2 Integration with Oil-Derived Food Textures

We found that the perceived texture of our gels could be tuned through composition to better align with oil-derived foods (Figure 2(c)). In particular, oleogel-rich formulations exhibited smoothness and mouthfeel comparable to oil-based foods like chocolate or cheese, in contrast to the perceptually distinct, water-dominant textures of hydrogels. This similarity enhances the plausibility of embedding interactive elements without disrupting the eating experience, a key consideration in edible interface design. By selecting appropriate gel compositions, edible electronics can be seamlessly integrated into real foods not only functionally but also perceptually and gustatorily.

5 DISCUSSION

These edible conductive gels enable interactive food systems by embedding functional elements into traditional foods. By tuning the composition ratio, they preserve the food's sensory appeal, and their 3D printability allows embedding circuit structures without

compromising visual aesthetics [5]. Although this remains an initial stage, future work should focus on user acceptance and the development of design tools. Such materials may support interactive dining, like flavor-releasing bites or touch-activated desserts.

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