OR3

An Electrically Conductive Oleogel Paste for Edible Electronics

Pietro Cataldi, Leonardo Lamanna, Alessandro Luzio, Mario Caironi
Center for Nano Science and Technology @PoliMi, Istituto Italiano di Tecnologia, Via Giovanni Pascoli, 70/3, Milano, 20133 Italy
pietro.cataldi@iit.it

Ingestible electronics (IE) was introduced as a powerful tool to control physiological parameters and drugs delivered in a specific intestinal tract. IE ensures high performance since it uses standard electronics components but simultaneously faces limitations because it is limited by the rigidity of its constituents materials, the risk of retention after ingestion, and the need to collect the device after expulsion, which is made of non-degradable and long-lasting and environmentally hazardous materials.[1,2]
Edible electronics, which bridge ingestible with green electronics, propose to shift from swallowable to digestible and/or not harmful components, ensuring a safe administration without medical supervision and enabling the degradation of the device in the body/environment after performing a specific function.[1,3] This technology, to thrive, requires a library of materials that are the basic building blocks for eatable platforms. Edible electrical conductors fabricated with green methods and at a large scale and composed of food derivatives, ingestible in large amounts without risk for human health, are needed.
Here we present a conductive composite paste made with materials with a highly tolerable upper intake limit (≥ mg per kg body weight per day).[3] The matrix is constituted by a biodegradable oleogel of food-grade beeswax and vegetable oil, and the electrical conductivity is provided by adding micrometric-sized activated carbon particles, as shown in Figure 1.

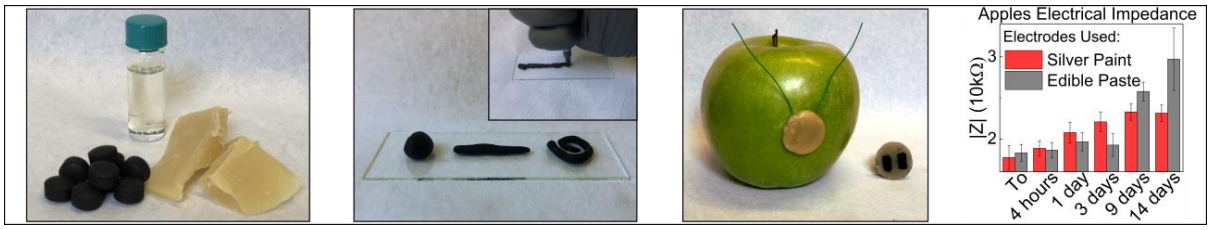

Fig. 1. From left to right. Raw materials that constitute the composite paste: sunflower oil, beeswax, and activated carbon (AC). Pliability of the edible conductor and demonstration of its potential for direct ink writing techniques (inset). Sensor for the detection of aging of apples through impedance measurements. Time-dependent impedance of the apple at 100 kHz recorded with the edible tag (gray column) and using silver paint (red column) as a comparison.

The composite paste is the first designed specifically for edible electronics. This conductor, displaying a resistivity in the order of 100 Ω cm, is fabricated without employing solvents and at low temperature, not exceeding 100 °C, ensuring green manufacturing. The paste exhibits tunable electromechanical features and adhesion depending on the composition. The different formulations of the composite are potentially compatible with large-scale production processes such as direct ink writing (see Fig. 1), extrusion, and injection molding and thus are ideal for an industrial scale-up. Moreover, the paste shows antibacterial activity and is hydrophobic, thus avoiding eventual food contamination when used in contact with it and possessing electrical properties robust to air and aqueous environments. To provide an example of the many possible practical uses of the proposed edible conductive paste, we have demonstrated that it enables effective edible contacts for food impedance analysis, to be integrated in smart fruit labels for aging monitoring, as displayed in Fig. 1.

References

[1] Bonacchini G. E. et al., "Tattoo-Paper Transfer as a Versatile Platform for All-Printed Organic Edible Electronics" Advanced Materials **30,** 1706091 (2018).

OR3

[2] Mimee M. et al., "An ingestible bacterial-electronic system to monitor gastrointestinal health", Science **360,** 915-918 (2018).
[3] Cataldi P. et al., "An Electrically Conductive Oleogel Paste for Edible Electronics", Advanced Functional Materials**,** 2113417 (2022).