# Chapter 13
# Advancements in Edible Antennas: Design, Development, and Future Prospects in Biomedical and 5G/6G Applications

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## ABSTRACT

*This chapter presents a comprehensive survey of edible antennas, exploring their design, development, and potential applications in emerging fields such as biomedical monitoring, healthcare, and environmental sensing. Edible antennas, crafted from biocompatible, biodegradable materials, offer unique advantages in applications where traditional antennas are unsuitable, especially in scenarios requiring ingestion or close human contact. The chapter begins with a detailed review of the state-of-the-art in edible antenna technology, discussing various fabrication methods, materials used, and performance metrics such as gain, efficiency, and bandwidth. Key considerations such as antenna miniaturization, impedance matching, and specific absorption rate (SAR) compliance are examined. Moreover, this survey delves into the integration of edible antennas with next-generation communication systems, including 5G/6G networks, which promise enhanced data rates, low latency, and reliable connectivity for real-time applications. The role of advanced materials such as metamaterials in improving antenna performance is also explored, along with future research directions and challenges such as signal attenuation in body tissues, energy harvesting, and sustainability. This survey concludes with insights into the future of edible antennas and their potential impact on personalized medicine, smart healthcare systems, and*

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*the Internet of Medical Things (IoMT).*

## 1. INTRODUCTION

Edible antennas have emerged as a transformative technology at the intersection of communication engineering, biomedical sciences, and sustainable electronics. Designed from biocompatible and biodegradable materials, these antennas are safe for ingestion or close contact with human tissues, making them ideal for applications where conventional antennas are unsuitable. The growing interest in edible antennas is driven by their potential to address critical needs in healthcare, environmental monitoring, and food safety. As part of the broader Internet of Medical Things (IoMT) ecosystem, these antennas offer real-time data transmission, enabling advanced applications like non-invasive diagnostics, gastrointestinal monitoring, and smart packaging.The foundation of edible antenna technology lies in the integration of innovative materials, such as gelatin, cellulose, and edible metals, with optimized designs tailored for specific environments. Studies such as C. Chen et al. (2019) have demonstrated the feasibility of using edible antennas for health monitoring at 2.4 GHz, while others like M. Salama et al. (2021) explored their use in smart packaging. Despite these advancements, challenges such as signal attenuation in biological tissues, material degradation, and manufacturing scalability persist, limiting their widespread adoption. Addressing these challenges requires a multidisciplinary approach, combining insights from material science, electromagnetics, and sustainable design practices.

The unique advantage of edible antennas lies in their biocompatibility and ability to degrade safely within the body or environment. For instance, antennas fabricated using gelatin or cellulose not only ensure safety during ingestion but also minimize environmental impact after disposal. Such properties make them indispensable in applications like digestive health monitoring, where antennas need to perform reliably within harsh biological conditions. Moreover, the rapid advancements in materials science have allowed researchers to explore hybrid designs, integrating edible substrates with conductive materials such as gold or silver leaf. These innovations improve performance metrics like gain and efficiency, making edible antennas competitive with their traditional counterparts. Recent research has also highlighted the potential of edible antennas in environmental sensing. Edible electronics offer a sustainable alternative to traditional monitoring devices, reducing electronic waste through biodegradable components. For example, rice paper-based loop antennas, as demonstrated by Y. Wang et al. (2023), have shown promise in detecting contaminants in food packaging and water sources. Such applications align with global sustainability goals, emphasizing the need for eco-friendly technologies to tackle environmental challenges.

In the realm of healthcare, edible antennas are revolutionizing diagnostic and therapeutic procedures. Applications include real-time monitoring of pH levels, glucose levels, and gastrointestinal tract analysis. By integrating these antennas with next-generation communication networks like 5G and 6G, seamless data transmission is achievable, enabling immediate analysis and remote healthcare management. For example, ingestible antennas paired with IoMT devices can alert medical professionals about abnormal physiological conditions, such as irregular gastric pH or the presence of harmful microbes, allowing timely intervention. Energy efficiency is another critical area of focus in edible antenna research. Self-powered designs, leveraging energy harvesting technologies, are being developed to eliminate the need for internal power sources like batteries. These advancements significantly enhance the safety and sustainability of edible antennas. G. Taylor et al. (2019) introduced self-powered edible antennas capable of harvesting ambient energy, ensuring uninterrupted operation in low-power environments. This