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Optics and photonics for food quality and nutrition

Óptica y fotónica para la calidad de los alimentos y la nutrición

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Abstract

Optical and photonic technologies (OPT) have a profound impact on many aspects of everyday life. In the agrifood sector, they have proven especially valuable for enabling precision agriculture and crop monitoring, as well as for applications such as food quality control, removal of surface contaminants, and detection of food fraud. This article briefly highlights a few examples of OPT applications in the field of nutrition. Spectroscopic techniques, in particular, are highly effective for analyzing the presence of nutrients, first in plants, then in food products, and even within the human body. Emerging innovations such as laser 3D printing and laser cooking offer promising avenues for producing customized foods tailored to individual dietary requirements. Finally, OPT-based methods provide reliable tools for assessing obesity and related health parameters.

Keywords: optics, agriphotonics, laser, food quality, nutrients, food 3D printing, spectroscopy, obesity

Resumen

Las tecnologías ópticas y fotónicas (OPT) tienen un profundo impacto en numerosos aspectos de la vida cotidiana. En el sector agroalimentario, han demostrado ser especialmente valiosas para posibilitar la agricultura de precisión y el monitoreo de cultivos, así como para aplicaciones como el control de la calidad de los alimentos, la eliminación de contaminantes superficiales y la detección del fraude alimentario. Este artículo presenta brevemente varios ejemplos de aplicaciones de las OPT en el campo de la nutrición. Las técnicas espectroscópicas, en particular, son altamente eficaces para analizar la presencia de nutrientes, primero en las plantas, luego en los productos alimentarios e incluso en el cuerpo humano. Innovaciones emergentes como la impresión 3D por láser y la cocción por láser ofrecen vías prometedoras para producir alimentos personalizados adaptados a los requerimientos dietéticos individuales. Finalmente, los métodos basados en OPT proporcionan herramientas fiables para la evaluación de la obesidad y de parámetros de salud relacionados.

Palabras clave: óptica, fotónica, láser, calidad de alimentos, obesidad, espectroscopía, nutrientes, impresión láser 3D de alimentos

Introduction

Optics is the branch of physics concerned with the study of light: its generation, propagation, interaction with matter, and detection. It encompasses both classical and quantum descriptions to explain the full range of light-matter phenomena observed in daily life. Classical optics, which relies on geometrical principles to describe the propagation of light rays (e.g., reflection and refraction) and on Maxwell's equations to account for electromagnetic wave behavior (e.g., diffraction, interference, and polarization), provides the foundation for devices such as lenses, mirrors, telescopes, and microscopes, and the related technologies.

Photonics, by contrast, is a modern, technology-driven extension of optics focused on the control and manipulation of photons for practical applications. Emerging from the convergence of optics, electronics, and quantum mechanics —especially following the invention of the laser in the 1960s— photonics encompasses diverse areas including light generation (e.g., lasers and light emitting diodes, or LEDs), optical communication through fibers, and signal modulation, amplification, and detection. Today, photonics underpins a wide range of transformative technologies, from high-speed internet and biomedical imaging to quantum computing and advanced manufacturing.

Among the many domains where optical and photonic technologies have had significant impact, applications in agriculture, the agrifood sector, and human biology have proven especially effective in delivering innovative solutions. Imaging and optical sensing, for instance, have demonstrated remarkable versatility, with applications ranging from civil engineering and water quality monitoring to plant science, food safety, and medical diagnostics. Agriphotonics —a rapidly evolving field— leverages diverse optical sensing techniques to enable precision agriculture, crop monitoring, and resource optimization, ultimately enhancing both productivity and sustainability.

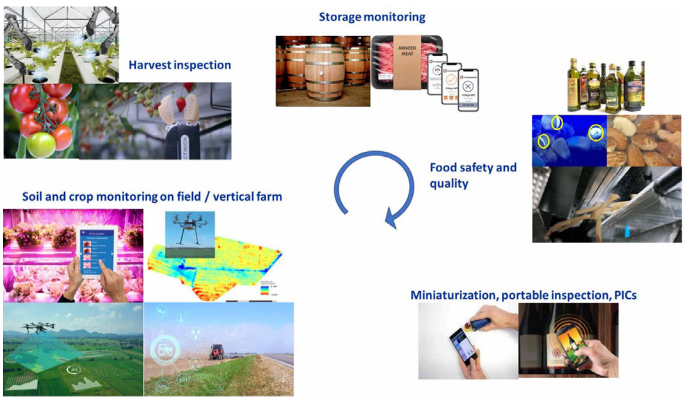

Figure 1. Potential impact of photonic technologies across the entire food supply chain. Reproduced from Smeesters et al. (2025) under a Creative Commons 4.0 License.

Tan et al. (2019) reviewed advances in crop cultivation and harvesting enabled by three key photonic approaches: imaging, spectroscopy, and spectral imaging. The latter combines spectroscopy with photography, capturing data across multiple wavelength bands to provide rich spatial and spectral insights into agricultural scenes. More recently, the multi-chapter article by Smeesters et al. (2025) provided a comprehensive overview of photonic technologies in the agrifood sector, outlining a potential roadmap toward a more sustainable and healthier global food system. Figure 1 illustrates how photonic technologies can influence the entire food supply chain.

In this paper, following a very brief introduction to lasers, optical fibers, and optical sensors, we present a focused review of recent advances in some applications of photonic technologies to food quality and nutrition.

Lasers, fiber optics, optical sensors and applications in agrifood

The first operational laser was demonstrated by Theodor Maiman in May 1960 (Maiman, 2017), building on theoretical work developed independently in the mid-1950s by Charles Townes in the United States and Nikolay Basov and Aleksandr Prokhorov in Russia, all three recipients of the 1964 Nobel Prize in Physics. A laser (the name is the acronym of Light Amplification by Stimulated Emission of Radiation) emits highly directional and monochromatic (i.e., with a single wavelength) beams characterized by spatial and temporal coherence. Lasers are also known for the high intensity (brightness), being capable of concentrating a large amount of light energy in a small area. These unique features, arising from the stimulated emission process and amplification within an optical cavity (Svelto, 2010), distinguish laser light from conventional sources such as electric lamps. Laser diodes (LDs), compact and efficient semiconductor-based lasers, emit across a broad spectral range and are widely used across science, technology, and industry (Nasim & Jamil, 2014). Depending on the type of semiconductor, an LD may emit light of different wavelength, i.e., color, from blue and green to red and near-infrared.

Laser radiation may propagate freely in space or be guided within optical materials. Two common approaches are integrated optics (thin-film structures) (Righini & Ferrari, 2020a,b) and fiber optics (cylindrical dielectric waveguides) (Al-Azzawi, 2007). In both, light confinement is achieved via total internal reflection, making them excellent platforms for sensing applications because any perturbation in the surrounding environment alters light propagation, enabling precise detection of chemical, physical, or biological changes (Butt et al., 2022).

Optical fiber sensors, in particular, are highly versatile due to their flexibility and ability to penetrate complex biological or mechanical systems (Elsherif et al., 2022; Mignani et al., 2008). More broadly, optical sensors convert light signals or variations in optical properties into measurable electrical signals, forming the basis of countless monitoring and diagnostic tools. Numerous optical biosensors have been developed for food quality assessment (Narsaiah et al., 2012; Smeesters et al., 2025), including compact, portable, and smartphone-integrated devices (Dutta & Paul, 2023; He et al., 2025).

In the agrifood sector, lasers and optical sensors are increasingly applied in precision agriculture, crop cultivation, food processing, packaging, and food safety monitoring (Smeesters et al., 2025). Within the food industry, ensuring quality and safety from production to consumption is critical, in line with the farm-to-fork strategy (European Commission, 2020). Although laser applications in this domain are relatively recent, they have already shown considerable promise as efficient, cost-effective, and innovative alternatives to conventional methods. Table 1 summarizes potential applications of laser light in the food sector, highlighting their advantages and limitations (Chavan et al., 2023). In the following sections, selected examples are discussed in greater detail, followed by a review of applications related specifically to nutrition and obesity.

Laser technology for food processing and packaging

Fresh agricultural products, including meat, vegetables, and fruits, are the primary sources of essential nutrients for human health. Ensuring their quality and safety throughout the entire farm-to-fork process, from harvesting and processing to packaging and storage, is therefore of paramount importance.

Table 1. Some applications of laser technology in the food sector, with their pros, cons, and potential issues. Reproduced from Chavan et al. (2023) under Creative Commons 4.0 License.

Application in Food Sector	Advantages	Disadvantages	Potential Issues
Laser cooking for precise and controlled heat application.	Lasers may supply the same heat for cooking with the best possible control, reproducibility for targeted energy, and the highest resolution.	It may Thermally damage the food materials.	Risk of overcooking due to high precision requirements.
High-resolution heat processing in various food products.	High-resolution heating is possible with lasers, suitable for a wide variety of food applications.	It has a significant initial capital cost of equipment.	High upfront costs and maintenance expenditures.
Use in sterilization and decontamination processes.	Lasers may develop minimal contamination in the processed food.	Low efficiency of lasers.	Lower overall energy efficiency compared to conventional methods.
Used in non-contact cutting or engraving processes in food preparation.	The noncontact natura of lasers helps to maintain the quality of the final processed product.	When the laser is not continually employed, energy is wasted via beam dumping.	Inefficient energy usage in intermittent processes.
Precision cutting in meat or fish industries.	The primary benefit of laser light is the ability to control beam power by adjusting the current flowing through the electric discharge.	A small heat-impacted zone will form along the cut edge of parts heated during high intensity laser processing.	Changes in product quality at the cut edges.
Metal-free packaging cutting and engraving.	Laser light has the benefit of having a minimum distortion and heat impacted zone.	High laser beam reflectivity on meals. All metals cannot be cut with a laser beam due to issues with beam reflections.	Limitations with metal-containing packaging materials.
Emerging applications in custom 3D-printed foods.	Laser technology allows for the potential of 3D food printing.	The technology is still in the experimental stage and not yet widely adopted.	Consumer acceptance and regulatory considerations for 3D-printed foods.
Quality assurance and process control in food industries.	Lasers can assist in the monitoring and control of food processing parameters.	Requires complex sensor systems and data processing.	Implementation complexity and cost of sensor systems and data processing infrastructure.

Teng et al. (2021) reviewed the potential of laser technology in food processing, covering applications such as material pretreatment, drying, cooking, microbial inhibition, and laser marking. They emphasized that the success of these applications depends strongly on the operational parameters of the laser and the specific optical and thermal properties of the food product. Similarly, Chavan et al. (2023) provided a critical overview of laser-based food technologies, highlighting, among others, the potential of:

- Laser ablation for removing surface contaminants from foodstuffs.
- Laser irradiation for reducing microbial load on food surfaces.
- Laser-assisted packaging techniques, such as perforation and transmission welding, which offer environmentally friendly alternatives to conventional methods.

Several studies have demonstrated the ability of lasers to inactivate bacteria and other pathogens in food and agricultural products. For example, irradiation with blue laser diodes has been shown to effectively disinfect wastewater and raw milk (Gonca et al., 2021; Mohamed et al., 2025). Hernandez-Aguilar et al. (2024) provided a broad overview of laser effects on insects, bacteria, viruses, and fungi within agrifood systems, noting that photosensitizers can further enhance antimicrobial efficacy.

Postharvest laser processing is particularly effective for maintaining the quality of fresh fruits and minimally processed products. For example, blue diode laser irradiation (450 nm, 30 minutes) of fresh-cut potatoes prevented enzymatic browning during short-term storage at 25 °C while enhancing antioxidant activity (Wen et al., 2023). Among fresh fruits, the so-called 'soft fruits' like berries and strawberries, are highly appreciated since they are a rich source of nutrients and antioxidants; they are low in calories and can help lower cholesterol, improve blood pressure, and may reduce the risk of chronic conditions such as cancer, diabetes, and heart disease. However, for most of them, a rapid decline dramatically reduces the shelf life and raises postharvest losses. The major postharvest pathogen of strawberry is *Botrytis cinerea*, which is manifested during the postharvest phase, transit and marketing. Broad-spectrum pulsed light treatments (200–1100 nm, 1 µs–0.1 s) were shown to reduce postharvest mold incidence by 16–42% while preserving firmness and minimizing water loss (Duarte-Molina et al., 2016). Even greater benefits were achieved by combining laser treatment with nanoparticle coatings (Ali et al., 2022). The nanoparticles were produced by crosslinking chitosan, a biodegradable, biocompatible natural polysaccharide polymer with immunological and antibacterial characteristics, with an extract of Guava leaves (*Psidium guajava L.*), known for their antimicrobial and antioxidant properties.

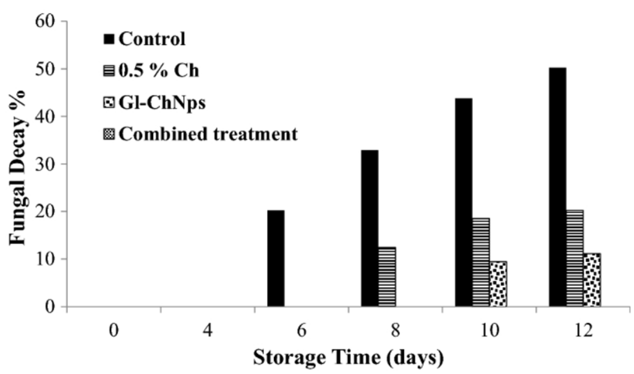

Figure 2. Fungal decay of strawberries subjected to different coating treatments during 12 days of cold storage at 10 °C and 85–90% RH. The combined chitosan–laser treatment completely suppressed fungal infection. Reproduced from Ali et al. (2022) under Creative Commons 4.0 License.

For long-term storage, freeze-drying (lyophilization) is widely used to preserve nutritional, structural, and sensory quality (McHugh, 2018). CO_2 laser microperforation of fresh strawberries reduced primary freeze-drying time by 20%, enhancing process efficiency and product quality (Pinto et al., 2024). CO_2 lasers (emitting in the IR at 10.6 μm) have been used in food processing for decades (Puertolas, 2024); CO_2 microperforation was also used for blueberries, yielding improved freeze-drying performance and product attributes (Fujimaru et al., 2012; Munzenmayer et al., 2020).

Laser cooking and 3D food printing

Since prehistoric times, diverse heating sources have been used for cooking, from open fire to modern microwave and infrared (IR) heating. Light absorption in biological tissues, be of plants or animals and humans, is a crucial interaction process involving the different molecular components and producing various results, like heat, chemical changes, or phosphorescence. IR heating, in particular, is highly effective for surface treatment of foods due to strong absorption by proteins, fats, and water, though penetration depth is limited to a few millimeters. For example, IR heating has been applied to maintain French fries at serving temperature without further internal cooking (McCarter, 1999).

Over the past decade, laser cooking has emerged as an innovative method offering unprecedented control over food texture, flavor, and nutritional content. By exploiting the high spatial precision and tunable penetration depth of laser beams, software-controlled laser systems can heat foods at millimeter resolution. Pioneering work at Columbia University (Creative Machines Laboratory) demonstrated selective baking of dough using blue lasers and surface browning with IR lasers (Blutinger et al., 2018, 2019). Later studies showed that combining multiple wavelengths allows simultaneous internal cooking and external browning (Blutinger et al., 2021).

In parallel, 3D food printing has gained momentum as a digital gastronomy technology. In general, 3D printing may be defined as the process of joining materials to make objects from 3D model data, usually layer upon layer. Using layer-by-layer deposition of edible "inks," this method enables highly customizable foods in terms of structure, flavor, and nutritional composition (Thangalakshmi et al., 2021). The first commercial 3D food printer was Choc Creator, a chocolate printer, released in 2012 by a spin-off of Exeter University, U.K., and the technology has since advanced considerably. Comprehensive reviews have been provided by Neamah et al. (2024) and Spence and Velasco (2025). Critical to the process is the availability of suitable 'inks', which may be liquids, powders or paste-like, to be introduced in the 3D printing machine; Figure 3 illustrates examples of 3D-printed edible objects fabricated from vegetable-based inks (Fujiwara et al., 2025).

The integration of laser cooking and 3D food printing offers opportunities for personalized nutrition and sustainable food production (Blutinger et al., 2025; Fujiwara et al., 2025; Gracia Julià, 2019). Research at the Universitat Autònoma de Barcelona demonstrated the feasibility of incorporating a CO_2 laser into a 3D food printer, producing foods with microbiological and sensory properties comparable to traditionally cooked products (Gracia Julià, 2019). Fujiwara et al. (2025) described the "Laser Cook Fusion" system, which employs blue laser cooking to fabricate customized foods tailored to individual dietary needs such as adjusting nutritional content or texture for specific health conditions, such as dysphagia or diabetes. Moreover, the system allows the use of food powders derived from waste products, thereby contributing to ingredient upcycling and sustainability.

Examples of 3D laser-cooked foods are shown in Figs. 4 and 5. Figure 4 presents a multi-ingredient cake fabricated via 3D printing and blue laser cooking (Blutinger et al., 2023), while Figure 5 illustrates Japanese-style confectionery designed using the Laser Cook Fusion system (Fujiwara et al., 2025).

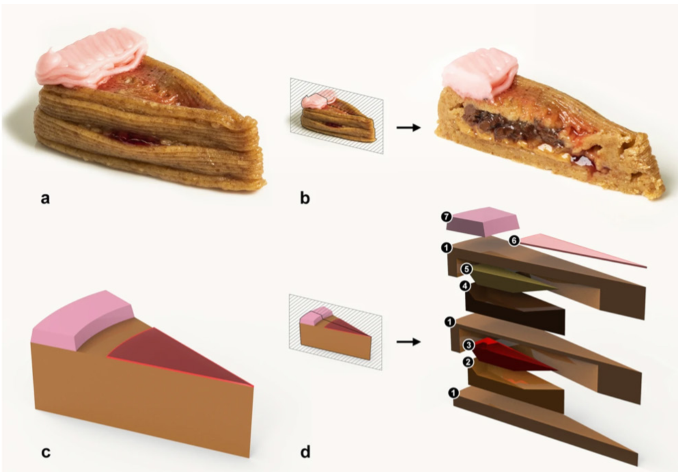

Figure 4. Multi-ingredient cake produced by 3D printing and laser cooking. (a) Final printed product. (b) Cross-section showing internal layering. (c) 3D model rendering. (d) Ingredient distribution: (1) graham cracker paste, (2) peanut butter, (3) strawberry jam, (4) Nutella, (5) banana purée, (6) cherry drizzle, (7) frosting. Reproduced from Blutinger et al. (2023) under a Creative Commons 4.0 License.

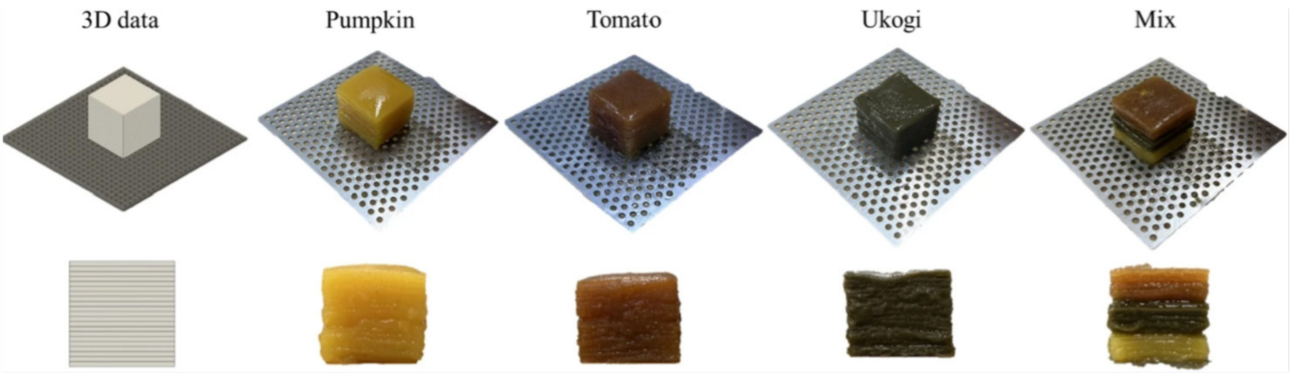

Figure 3. Examples of 3D-printed edible products from the correspondig inks: pumpkin, tomato, ukogi, and a composite print combining all three inks. Dimensions of printed objects: 21 × 21 × 21 mm. Reproduced from Fujiwara et al. (2025) under a Creative Commons 4.0 License.

Figure 5. Japanese-style sweets fabricated with the Laser Cook Fusion system. From left to right: single-color floral design, three-color floral design, and three-color hollow structure. Reproduced from Fujiwara (2025) under a Creative Commons 4.0 License.

Nutrition, obesity and photonics

Optics and photonics are increasingly and successfully employed in the agrifood sector, while also contributing significantly to advances in food science and human nutrition. It is well established that every individual, human or animal, requires a balanced diet to maintain health, ensuring adequate intake of all essential nutrients. Nutrients are typically classified as macronutrients —carbohydrates, fats, and proteins— which provide energy, and micronutrients —vitamins and minerals— which support metabolic functions. Water and dietary fiber are also crucial: fiber aids digestion, while water facilitates nutrient transport throughout the body. Photonic technologies are highly effective for evaluating both micro- and macronutrient content in plants and foods.

The nutritional quality of plants, including their bioactive compound concentrations, depends on healthy growth conditions. Ensuring well-balanced plant nutrition is therefore fundamental to cultivate healthy crops. Nutrient deficiencies induce stress in plants, which can be detected by optical methods. Spectroscopic techniques, by measuring the optical wavelengths absorbed, reflected, or scattered by samples, are especially effective. More detailed molecular information can be obtained through Raman spectroscopy (RS). In this technique, photons from a laser induce molecular vibrations in the sample, resulting in energy exchanges that cause shifts in the frequency (and thus wavelength) of the scattered light. When photons lose energy to the molecule, the scattered light has a longer wavelength (lower energy), known as Stokes emission; conversely, when photons gain energy from molecular vibrations, they exhibit a shorter wavelength (higher energy), known as Anti-Stokes lines. Each Raman spectrum serves as a molecular fingerprint, as each peak corresponds to a specific compound. Numerous applications of Raman spectroscopy in biological studies are reviewed comprehensively by Chandra et al. (2024). Figure 6 summarizes the key features of Raman spectroscopy applied to biological systems.

Several examples demonstrate the application of Raman spectroscopy to nutrient analysis in plants. Gupta et al. (2020) developed a portable leaf-clip Raman sensor for various vegetable crops, providing farmers and botanists with an effective tool for early diagnosis and real-time monitoring of plant stress in the field. Acosta et al. (2023a,b) applied visible-to-near-infrared (vis-NIR) spectroscopy to citrus (Citrus clementina Hort. ex Tan.) and persimmon (Diospyros kaki Thunberg) leaves, confirming the potential of this technique for rapid, non-destructive prediction of foliar macro- and micronutrient content. Karnachoriti et al. (2025) analyzed aqueous nutrient solutions replicating bioreactor media for Chlorella vulgaris, focusing on nitrate, sulfate, glucose, and phosphate. Payne et al. (2021) reviewed RS applications in digital farming, demonstrating its potential for plant stress diagnostics, pathogen resistance assessment, and species identification.

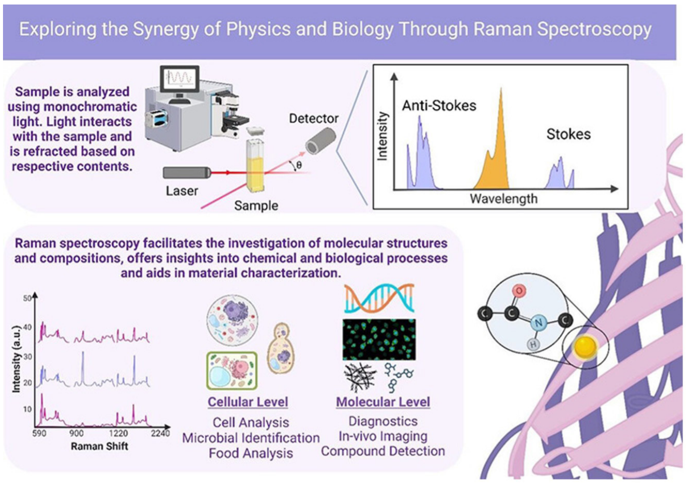

Figure 6. Schematic illustration of a Raman spectroscopic system and of its applications in biology. Reproduced from Chandra et al. (2024) under Creative Commons 4.0 license.

Raman spectroscopy can also be extended to the study of nutrients in foods, as well as in animals and humans. Rodriguez and Kurouski (2023) demonstrated that RS can quantify carbohydrates, gluten, carotenoids, and fats in baked foods, enabling personalized nutrition monitoring and quality control. Furthermore, Raman-based sensors allow noninvasive, rapid assessment of carotenoid nutritional status in humans (Zidichouski et al., 2009). The authors suggested that handheld Raman sensors could be used routinely in restaurants and grocery stores for real-time food quality assessment.

Finally, spectroscopic methods, including near-infrared (NIR), mid-infrared (Mid-IR), and Fourier transform infrared (FTIR) spectroscopy, offer rapid, non-invasive, and cost-effective physicochemical tools to identify food authenticity and fight food frauds (Pirhadi, 2024).

Dietary control

Today, the world faces a dual nutritional challenge: hunger and obesity (often coexisting within the same regions, households, or even individuals) driven by the common factor of malnutrition. According to the Global Nutrition Report 2022 (GNR, 2022), nearly one-third (29.3%) of the global population, approximately 2.3 billion people, were moderately or severely food insecure in 2021. Simultaneously, over 40% of adults and 20% of children (more than 3 billion individuals) were overweight or living with obesity due to unhealthy diets. It is now recognized that undernutrition and overnutrition can coexist within the same community, a phenomenon termed the double burden of malnutrition, stemming from food systems that fail to provide healthy, safe, affordable, and sustainable diets for all.

According to 2025 UNICEF Child Nutrition Report, the global prevalence of obesity among school-age children and adolescents has now surpassed that of underweight for the first time (UNICEF, 2025). Looking at malnutrition among school-age children (5-19 years), the modelled estimates indicate thinness in 10% of them versus overweight in 20% of the total (world averages). As a further example, 21% of the adolescents aged 10-14 years, namely 141 millions of individuals worldwide, are affected by overweight and obesity.

Overweight and obesity are chronic conditions arising primarily from unbalanced, carbohydrate- and fat-rich diets. Consequently, effective public health policies are urgently needed. Optical and digital technologies can play a supporting role by enabling real-time calorie and nutrient measurement systems, helping individuals and dietitians monitor food intake. The rapid development of computational tools (computer vision, machine learning, deep learning, and artificial intelligence) has created transformative opportunities in nutritional science (Armand et al., 2024; Borugadda & Kallouri, 2025; Sosa et al., 2024). For example, algorithms leveraging smartphone images captured before and after meals can accurately identify food portions and, using nutritional databases, calculate caloric and nutrient intake (Pouladzadeh et al., 2014). Further advances include automatic food recognition and nutrition analysis systems, such as that described by Jiang et al. (2020), which can analyze a single photo to identify food items, estimate their nutritional content, and provide comprehensive dietary assessments. A detailed review of image-based food recognition and volume estimation systems is provided by Konstantakopoulos et al. (2024). The workflow is summarized in Figure 7.

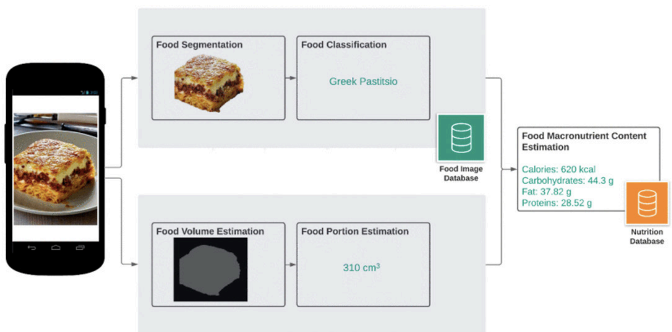

Figure 7. Example of a meal image and corresponding dietary assessment output. Reproduced from Jiang et al. (2020) under a Creative Commons 4.0 license.

Automated image-based nutrition estimation methods hold great promise for monitoring daily nutrient intake, providing real-time feedback to promote healthier dietary choices. Continuous improvements in image acquisition and analysis technologies are being reported (Han et al., 2023; Liu et al., 2025; Wang et al., 2024).

In medical research, Raman spectroscopy also shows potential for studying nutrient metabolism. Hong et al. (2025) reported that RS can detect diet-induced metabolic changes in mice by analyzing skin spectra. Diets were shown to alter the chemical structure, composition, and integrity of collagen, and RS successfully detected these changes (Juarez et al., 2025).

However, nutrient intake is not the sole determinant of healthy eating patterns. Micro-level eating behaviors, such as meal duration, chewing frequency, and number of eating episodes, are also strongly associated with obesity and metabolic risk. To monitor these factors, wearable optical sensors have been integrated into eyeglasses to record facial muscle activity during eating (Stankoski et al., 2024; Zhang et al., 2018). Earlier systems used surface electromyography (EMG), while more recent designs employ non-invasive non-contact OCO™ optical sensors based on optomyography. These sensors are integrated into special optical glasses and properly positioned to detect movements of the temporal and zygomaticus muscles, which control jaw motion and mouth movement, respectively. Figure 8 shows the facial muscles and the position of sensors. Laboratory and real-world tests confirmed that this device can accurately detect chewing activity, demonstrating strong potential for dietary monitoring.

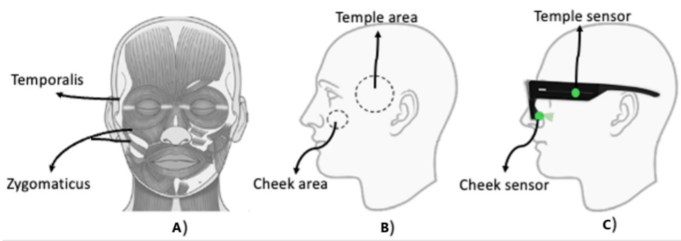

Figure 8. Smart eyeglasses for real-time monitoring of chewing activities: A) facial muscles involved in chewing; B) monitored face areas; C) sensor placement in OCO™ glasses. Reproduced from Stankoski et al. (2024) under Creative Commons 4.0 license.

Obesity assessment cannot rely solely on body mass index (BMI); waist circumference provides additional insight, but it is a one-dimensional measure. Three-dimensional (3D) optical modeling of body shape provides more precise diagnostic information. Advances in photonics and computational modeling have enabled accurate reconstruction of body topography using projected light and mathematical algorithms. Although proposed decades ago (Wells et al., 2008), whole-body 3D optical (3DO) scanning has recently gained traction as a clinical and fitness tool. Modern 3DO systems are increasingly affordable (USD 2,000–15,000, depending on their accuracy and reliability) and widely used in sports and wellness centers. A collaborative study among various American Universities involving 188 participants of various ages and ethnicities demonstrated that 3DO body composition estimates closely matched results from dual-energy X-ray absorptiometry (DEXA), the current gold standard (Bennett et al., 2022). The system used —the Styku S100 scanner— costs approximately USD 9,000–13,000; at the time of the article (2021-2022) this scanner was likely available in over 1000 locations across 30 countries. Services that use the Styku scanner were also available for individual scans (e.g., $25-$35 per scan). Tinsley et al. (2020) further evaluated several commercial 3DO scanners, comparing their outputs with a four-component model based on DEXA, air displacement plethysmography, and bioimpedance spectroscopy. All systems showed good reliability, with root mean square coefficients of variation (RMS-%CV) of

2.3–4.3% for body fat percentage, 2.5–4.3% for fat mass, and 0.7–1.4% for fat-free mass. Similarly, a Swiss study involving 201 adults (aged 18–90 years) confirmed that 3DO-based models outperformed standard anthropometric methods in predicting body composition (Guarnieri Lopez et al., 2023).

Conclusions and prospects

Optical and photonic technologies are now pervasive across science and industry, with major impacts on the agri-food and nutrition sectors. Laser-based methods, in particular, hold great promise for innovation in food processing, packaging, and quality control. In nutrition research, photonic techniques, especially Raman spectroscopy, enable real-time, non-destructive monitoring of nutrient composition in plants and processed foods.

Optical systems also facilitate noninvasive monitoring of eating behaviors and rapid 3D laser scanning of human bodies, providing reliable estimates of body composition and indicators of metabolic health. Many of these advances are driven by artificial intelligence (AI) and deep learning, which enhance image acquisition, analysis, and diagnostic precision.

Future progress will depend on the development of large, diverse, and well-annotated datasets for training AI models. It is hoped that this review will stimulate further research into integrated dietary assessment systems combining photonics, imaging, and intelligent analytics for improved nutrition monitoring and management

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