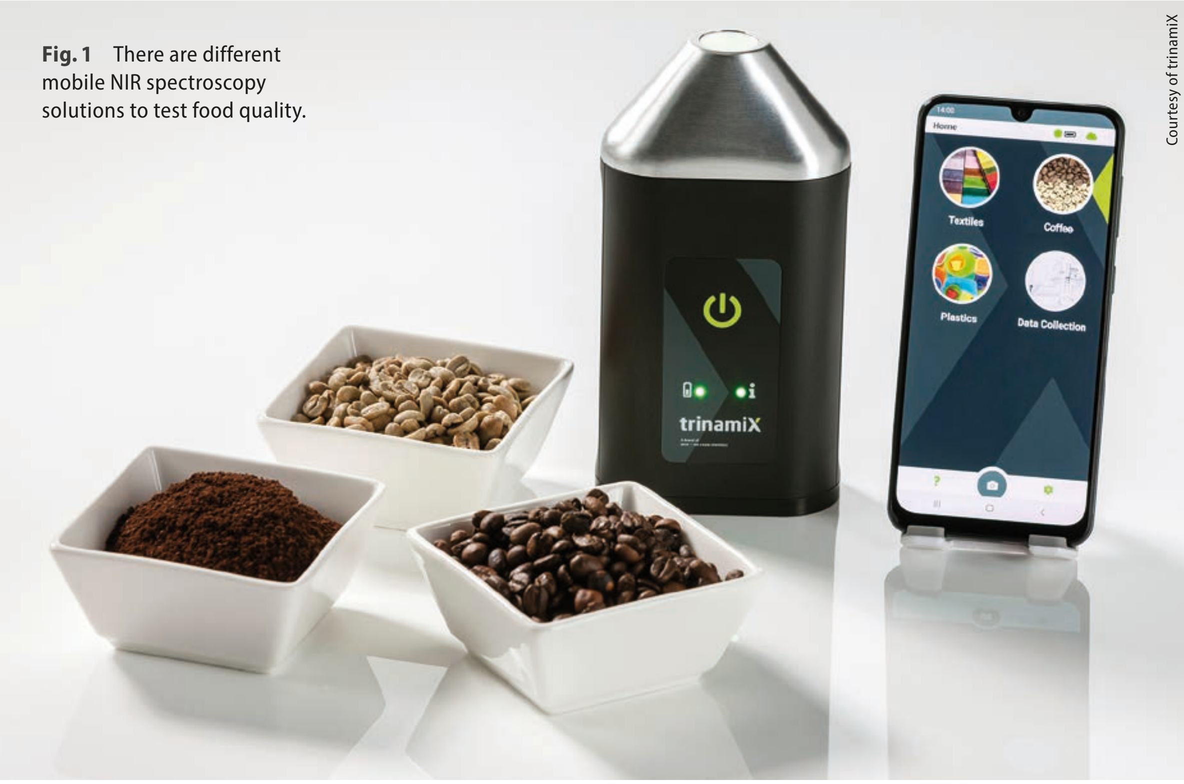

Fig. 1 There are different mobile NIR spectroscopy solutions to test food quality.

Courtesy of trinamiX

Photonics for the Food Industry

Spectroscopy revolutionizes quality, safety, integrity, and the taste of food.

Elena Beletkaia

The history of spectroscopy begins in the 17th century. A lot of technological changes have taken place since then, but the main idea stayed the same: light provides information, whether we see it or not. Advances in optics, gratings, filters, coatings, lasers, and detectors have made it possible to extend the observations from the visible part of the spectrum to the UV, NIR, MIR, and IR.

Spectroscopy has always played an important role in chemistry, physics, and astronomy and it is still gaining stronger positions in nearly every other industry. For the past couple of decades, spectroscopic methods have been increasingly 'invading' the food industry. Such technologies make it possible to characterize the ripeness of fruits, grains and vegetables, detect raw material and water quality, and control processing steps. They allow inspection for foreign objects to be performed in a non-contact and non-destructive manner. When a few spectral imaging techniques are combined with other imaging modalities and enabled by AI, applications such as digital sorting become possible directly within the production line.

Why new technology is needed

Food is complex. Often there are multiple components mixed together: water, fat, proteins, carbohydrates, salts, sometimes special bacteria or yeast and numerous minor components. The amounts, molecular structure and interactions within food define the characteristics of food products. Undesired microbial growth or chemical and enzymatic modifications make most food products naturally perishable. These changes deteriorate the sensory and nutritional quality of most foods. About 25 to 30 percent of food is lost due to microbial spoilage. So preservation and/or processing techniques are often applied to maintain the quality and extend the shelf-life of the products.

The quality of a food product can be rated by its appearance, color, flavor, and texture as well as chemical, biological and microbial factors, like instability. Food quality and safety is an area of increasing concern both for the general public and for the food producing and processing industries. The change in eating habits and overall consumer behavior is leading to the development of devices such as hand-held spectrometers. Companies like trinamiX [1] and Bayspec already offer a number of solutions to characterize various products (**Fig. 1**). Technology development and miniaturization will very soon enable integrating these into a smartphone, allowing consumers to test the properties of food on the market or at home.

The globalization of the supply chain along with the increasing population has caused increased demand for food, which is resulting in a rise in food fraud. Food fraud includes any deliberate action altering, substituting, mislabeling, tampering or misrepresenting a food product to gain undue advantage. Fraud can occur at different stages: raw material, ingredient, final product or food packaging. This is considered to be the second most significant black-market activity in the EU. So to meet the high expectations of the consumer in the overall food quality, food fraud has to be prevented.

Spectroscopy for food industry

Inspection of food and its ingredients is carried out along the whole farm-to-fork supply chain: precision agriculture, manufacturing (raw material inspection, sorting, process control, machine vision, final product inspection), laboratory analysis, product development, and the regulatory and supply chain validation. Traditionally food quality and quality changes caused by preservatives are evaluated using sensory and microbiological analysis or physicochemical measurements. These methods, while reliable, are destructive and time consuming and do not support online assessment. There is an increasing demand for inline and online quality control and food safety, including decontamination, inspection of cleanliness on production line surfaces, in pipes etc., detection of pathogens, allergens and mycotoxins. Also, there is a need for foreign body detection, whether metal or low-density materials, such as plastic, wood, egg and nut shell, fruit stones, or glass fragments.

Courtesy of art photonics

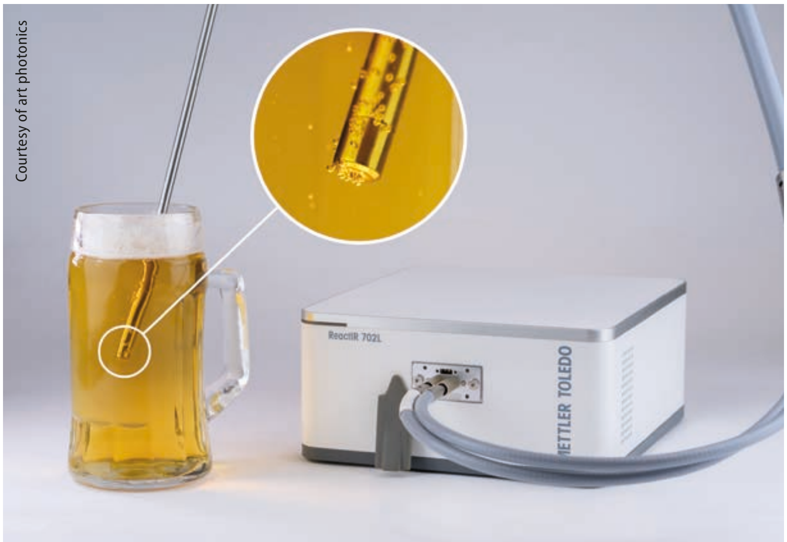

Fig. 2 Test your beer with IR-fiber spectroscopy.

Spectroscopic methods provide fast, accurate and reliable solutions. Molecular and ultraviolet-visible (UV-vis) spectroscopy are among the most commonly used spectroscopic techniques in food testing or food adulteration problems. Infrared (IR) and near-infrared (NIR) spectroscopy are fast and easy-to-use and, thus, have long been used for food applications. Fourier transform infrared (FTIR) spectroscopy is also routinely used in cases of suspected food fraud.

IR technologies

Infrared technologies can yield both qualitative and quantitative information for the investigation of the chemical composition and food ingredients. IR spectroscopy is commonly used in the dairy industry. Applying broadband NIR spectroscopy with a discrete-filter-based NIR analyzer, the production of different types of cheese can be monitored. Fiber-optic NIR sensors, such as those developed by art photonics, provide the information from product bulk and can therefore be applied to monitor processes such as yoghurt incubation.

NIR technology used with a diode array delivers results in seconds rather than several hours as many traditional chemical analysis methods do. Such time reduction enables the collection of a large number of spectra and still performs a multicomponent analysis in seconds. Moisens developed by art photonics combines specific wavelength LED-sensors with individual IP-addresses in a fiber probe, enabling data collection in the iCloud and process optimization in real time (**Fig. 2**).

NIR spectroscopy has a huge potential for meat quality assessment due to its non-invasive analytical advantages. It rapidly detects freshness, protein and fat content, predicts sodium content in commercially processed meat and in vacuum-dried ham slices. It is also widely used for grains and flours, chocolate and syrups, herbs and spices, coffee, tea, mineral water and many other foodstuffs.

Mid-infrared (MIR) spectroscopy is a valuable technique for food-related research and quality control purposes in the food industry. FTIR is most commonly used because it is a fast, non-destructive and reliable technique for authentication analysis. For example, an FTIR spectrophotometer could detect adulteration in honey using glucose/fructose solutions with a detection accuracy of 95 %. FTIR spectra also often help to authenticate fats and oils, for instance. However, it is important to use chemometrics as an analytical data treatment to convert the information from FTIR spectra into understandable data.

Raman and fluorescent spectroscopy

Conventional Raman spectroscopy exhibits a small scattering cross section for many materials. Nevertheless, the advances in electronics, lasers, optics, and nanotechnology have made Raman spectroscopy applicable in many areas. A Raman spectrometer can be used for monitoring and quality control in industrial food processing, food safety in agricultural plant production as well as inspections through different types of packing. Like IR spectroscopy, Raman spectroscopy allows quantification and characterization of the lipid components of food and the quantitative analysis of the degree of unsaturation. In addition, it enables the characterization of polymorphism and chain packing, the monitoring of interactions with other food components or changes which are induced by processing or storage (as auto-oxidation or isomerization).

Fluorescence spectroscopy can be used for the identification, classification, quantification, and optimization of different parameters during food handling, processing, and storage. However, the technique is usually linked with liquid chromatography in the food industry. Such a combination is advantageous for detecting extremely low concentrations of contaminants such as toxins (mycotoxins), pathogenic microbes (bacterial species: salmonella, escherichia coli), antibiotics (penicillin, tetracycline, oxytetracycline), and food additives (aspartame, salicylates). Other important applications of fluorescence are the identification and quantification of components, contaminants and additives.

While the spectroscopy techniques described and others benefit many processes in the food industry, the diversity of techniques and parameters renders implementation a challenge. In some cases, a complex and comprehensive software solution is required to combine information from different measuring methods. In other cases, the required solutions can be very customer dependent. There is no unique standard to provide a comprehensive characterization of food parameters.

[1] *F. Schmidt, N. Christiansen*, and *R. Lovrincic,* PhotonicsViews **17**, 56 (2020)

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