



Food & Beverage Analysis

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Foreword

Welcome to the latest edition of our Industry Focus eBook, where we explore the evolving world of food and beverage science. As global supply chains become more complex and consumer expectations continue to rise, the need for accurate testing, sustainable innovation, and robust food safety strategies has never been greater.

Across this edition, we highlight the analytical techniques and emerging technologies helping the industry meet these challenges. From **Carbon and Nitrogen Determination in Food and Beverages** to **From Food to Reliable Analysis: The Underestimated Power of Sample Preparation**, we examine how precise measurement and careful preparation underpin confidence in product quality, nutritional value, and regulatory compliance.

Food safety is also a central theme, with advances in packaging and detection technologies offering new ways to protect consumers and preserve product integrity. Articles such as **Smart Photonic Packaging for Food Safety** and **Why Active Food Packaging Materials are Essential for Changing Food Safety Requirements** explore how intelligent materials are reshaping the way food is monitored, stored, and delivered. Meanwhile, **Nanocomposite Sensor Improves Heavy Metal Detection in Milk** demonstrates how novel sensing approaches can strengthen contaminant detection in everyday products.

This eBook also looks at sustainability and authenticity, two priorities that are increasingly shaping the future of the sector. **Leafy Vegetables as a Sustainable Mining Tool** offers a fascinating perspective on plant-based resource recovery, while **Scientists Use Algae to Convert Food Waste Into Sustainable Ingredients** highlights how circular approaches can transform waste into value. In parallel, **New DNA Tests Expose Spice Fraud Across Popular Herbs and Spices** reveals how molecular tools are helping protect trust and transparency across global food markets.

Through **Inside Food & Beverages: Engineering Quality Through Particle Analytics**, we also consider how particle-level insights can support better formulation, processing, and performance.

As you explore these pages, I hope you find inspiration in the science, innovation, and ingenuity driving the food and beverage industry forward. Thank you for joining us.

Carbon and Nitrogen Determination in Food and Beverages

Nitrogen is everywhere. It is one of the fundamental building blocks of life, continuously circulating through the environment in what is known as the nitrogen cycle. From atmospheric nitrogen fixation to plant uptake, from animal metabolism to human nutrition, nitrogen defines biological growth and energy transfer.



Image Credit: beauty-box/Shutterstock.com

In the food and beverage industry, this universal element plays a particularly important role, as it forms the foundation of proteins.

Proteins are not only essential nutrients but also key economic indicators, quality markers, and regulatory parameters. Whether in cereals, meat, dairy, plant-based alternatives, or beverages, nitrogen content directly translates into protein content. This relationship makes nitrogen determination one of the most critical analytical tasks in modern food production.

At the same time, the food industry is undergoing a transformation. The emergence of “new proteins” – including plant-based substitutes, insect protein, algae-derived ingredients, and fermentation-based products – is redefining both raw materials and finished goods. These innovations are driven by sustainability goals, economic efficiency, and changing consumer preferences.

However, they also introduce new analytical challenges. Different matrices, varying nitrogen

compositions, and alternative protein conversion factors require precise, reliable, and flexible analytical methods. In this evolving landscape, accurate nitrogen and carbon determination is not just a laboratory task; it is a cornerstone of product integrity, regulatory compliance, and economic success.

Why Carbon and Nitrogen Determination Matters

Nitrogen as an Indicator of Protein Content

Protein content is one of the most important values displayed on a food label. In the European Union, the Food Information to Consumers Regulation (EU) No 1169/2011 (LMIV) defines how protein must be declared. According to this regulation, protein content is calculated as:

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times \text{conversion factor}$$

The default conversion factor is 6.25, based on the assumption that proteins contain approximately 16 % of nitrogen. However, this factor is not universal. For example:

- Wheat and cereals often use 5.7 %
- Dairy products use 6.38 %
- Other matrices may require specific factors depending on amino acid composition

Carbon as an Indicator of Consistency

Carbon is the main structural element of all organic compounds: carbohydrates, fats, proteins, or organic acids. The amount of total carbon (TC) is, therefore, a direct indicator of the total organic content in a food sample.

This can be used to set [nutritional values](#) for the end customer, document batch-to-batch consistency, or detect formulation deviations. For example, stable carbon values in flour or starch products indicate consistent carbohydrate composition, which in turn stands for consistent quality. In processed foods, changes in total carbon content may reflect variations in composition, such as moisture loss or formulation differences. In certain applications, carbon analysis can support process monitoring, for example in roasted cereal products, coffee, or baked goods.

This means that accurate carbon and nitrogen measurement is the foundation of correct nutritional labeling. Errors in their determination directly translate into incorrect protein values or formulation changes, which can lead to regulatory issues, product recalls, or financial losses. Beyond labeling, carbon and nitrogen analysis plays a critical role in:

Raw Material Purchasing and Pricing

Protein content directly affects the value of commodities such as grain, soy, dairy products, and meat.

Process Control

Monitoring protein levels ensures consistency in production processes such as baking, fermentation, or extrusion.

Quality Assurance

Nitrogen plays an important role in verifying product specifications and detecting deviations, especially in batch-to-batch consistency.

Sustainability and Efficiency

Precise formulation optimizes resource use and reduces waste.

Compliance with International Standards

This includes AOAC, ISO, DIN EN ISO, and industry-specific methods.

Beyond regulatory compliance, component analysis plays a decisive role in industrial practice. In grain trading, for example, protein and carbon content determine classification and price. Even small analytical deviations can translate into significant financial differences across large volumes.

Similarly, in food production, incorrect values may lead to batch rejection or costly reformulation, particularly in tightly controlled processes such as baking or plant-based product manufacturing.

Carbon and nitrogen determination is therefore not simply an analytical parameter; it acts as a link between laboratory measurement and economic decision-making. It ensures that raw materials meet contractual specifications, that processes remain stable, and that final products comply with both internal and external requirements.

Analytical Challenges in Modern Protein Determination

As the food industry evolves, so do the challenges associated with nitrogen and protein analysis. Traditional food matrices already require careful handling, but the rise of alternative proteins introduces an additional layer of complexity: the diversity of modern food products and the importance of matrix effects increase.

High-fat samples behave differently during combustion to fiber-rich plant materials, and processed foods may contain multiple components with varying thermal and chemical properties. These differences influence combustion efficiency and gas release, ultimately affecting measurement stability.

Another limitation arises from the use of generalized conversion factors. While convenient, they do not fully account for the variability in protein composition across different sources. This becomes particularly relevant for novel protein ingredients, where standardized factors may not yet be fully established.

Taken together, these aspects highlight a key reality: protein determination is no longer a simple calculation, but a matrix-dependent analytical task that requires robust and reproducible measurement methods.

From Kjeldahl to Dumas: Evolution of Nitrogen (and Carbon) Analysis

For more than a century, the Kjeldahl method has been a reference method in many standards. The procedure requires the handling of concentrated acids, involves multiple manual steps, and typically takes several hours per analysis.

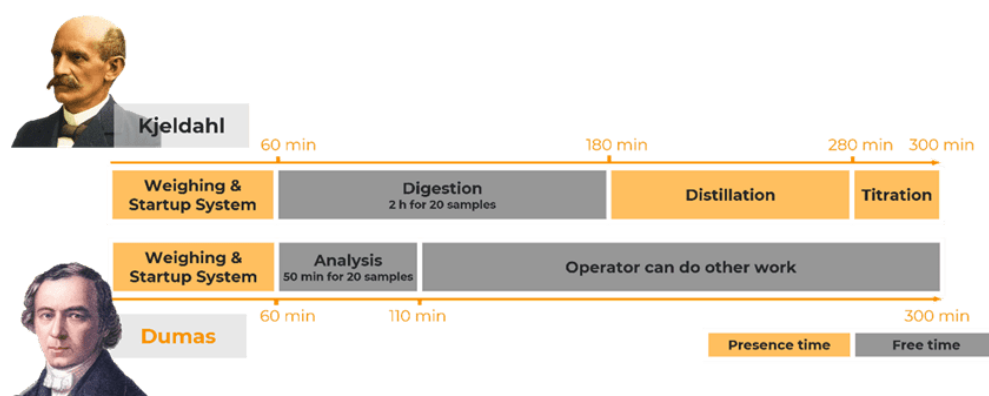


Figure 1. Comparison of nitrogen analysis with the Kjeldahl and the Dumas method. Analysis time for Dumas is based on using an ELEMENTRAC CN-r from Eltra. Image Credit: ELTRA

The Dumas combustion method, on the other hand, represents a modern, automated alternative. By combusting the sample at high temperature in an oxygen atmosphere and directly measuring the resulting gases, the method eliminates the need for hazardous chemicals and significantly reduces analysis time.

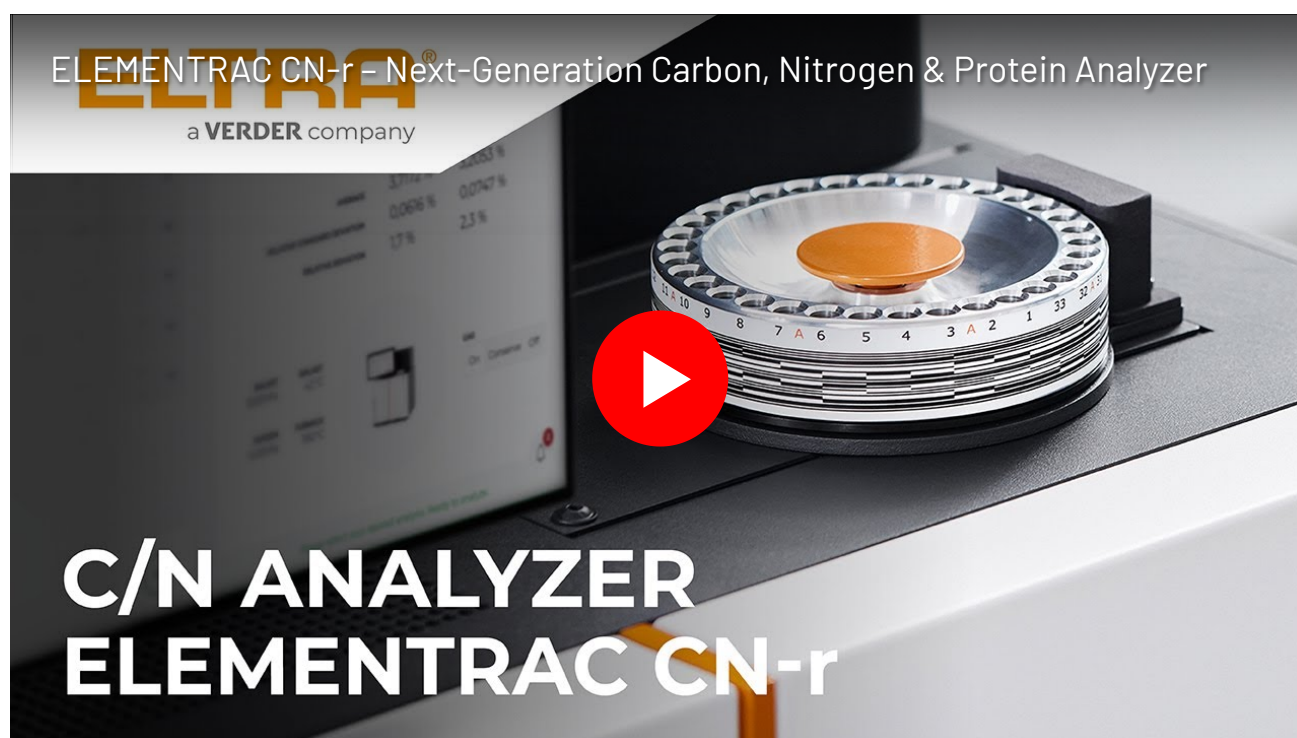
It additionally enables the simultaneous determination of carbon and nitrogen. Results are typically available within minutes, enabling high-throughput operation in routine laboratories.

In addition, the cost per sample is generally lower with the Dumas method compared to Kjeldahl. While Kjeldahl requires significant amounts of chemicals (such as concentrated acids and catalysts) as well as labor-intensive handling, the Dumas method mainly relies on consumables like carrier gases and combustion tubes, resulting in reduced operating costs over time.

A further advantage becomes evident when considering laboratory throughput. Within an eight-hour working day, the Kjeldahl method typically allows for the analysis of approximately 40–80 samples, depending on the level of automation and parallel digestion capacity.

In contrast, a modern Dumas analyzer such as the **ELEMENTRAC CN-r** can process roughly 160 samples in the same time frame, as each analysis only takes a few minutes and requires minimal manual intervention. This makes the Dumas method particularly attractive for high-throughput routine laboratories.

Dumas Combustion Designed for Food Laboratories



ELEMENTRAC CN-r – Next-Generation Carbon, Nitrogen & Protein Analyzer. Video Credit: ELTRA

The **ELEMENTRAC CN-r** applies to the Dumas principle in a way that is particularly suited to the demands of food and beverage laboratories. Food samples are often heterogeneous, containing varying proportions of proteins, fats, carbohydrates, and moisture. The integrated ballast and aliquot system ensure that the measured gas fraction is representative, which significantly improves reproducibility even for complex matrices.

At the same time, the use of excess oxygen ensures complete combustion, independent of the sample type. Combined with the absence of wet chemical reagents, this contributes to a safer and more sustainable laboratory environment. The short analysis time of two-and-a-half minutes per sample allows laboratories to integrate carbon and nitrogen determination directly into production and workflows.

Application in Food Matrices: From Sample to Result

The reliability of carbon and nitrogen determination depends heavily on how the sample is prepared. Regardless of whether the material is a cereal, a meat product, milk, wine, or a plant-based alternative, the goal is always the same: to obtain a representative and homogeneous sample.

In routine laboratories, this often means grinding solid samples to a defined particle size, typically between 800 and 1000 μm (e.g., for wheat analysis according to DIN EN ISO 16634-2). This ensures consistent combustion behavior and stable analytical signals. At the same time, care must be taken to avoid excessive heat during grinding, as this can alter the sample composition.

For more complex matrices such as meat or high-moisture products, thorough homogenization is essential. For example, in milk analysis, proper homogenization is essential, as milk is a complex oil-in-water emulsion consisting of dispersed fat globules within an aqueous protein phase. Such samples are particularly sensitive to storage effects, which is why analysis should ideally be carried out immediately after preparation.

Eltra - CN-r Corn



Once the sample is prepared, an operator simply weighs the sample into tin foil or tin capsule, places it in an autosampler, and the analyzer does the rest. The ELEMENTRAC CN-r is built for continuous high-throughput operation: its maintenance mode allows rapid replacement of consumables and reagents in about 15 minutes—all while the analyzer remains in a ready state.



Image Credit: ELTRA

In high-throughput laboratory environments, analytical performance is not only defined by measurement accuracy, but also by operational efficiency. Routine analysis often involves large sample volumes across diverse matrices, making instrument uptime a critical factor. For this reason, maintenance procedures must be fast, simple, and reproducible. This ensures continuous operation and reduces downtime, allowing nitrogen determination to be fully integrated into daily laboratory workflows without becoming a bottleneck.

For example, exchanging regular consumables in the ELEMENTRAC CN-r like the crucible, is done within one minute, and exchanging the whole combustion quartz tube only takes about two minutes. Exchanging all consumables takes about 15 minutes, while the analyzer is in a ready state.

ELTRA - CN-r Maintenance of Combustion Tube



Video Credit: ELTRA

Sustainability and Efficiency from a Circular Perspective



Image Credit: ELTRA

The discussion of nitrogen in food systems ultimately returns to its origin: the nitrogen cycle. As industries move toward more sustainable production methods and alternative protein sources, analytical techniques must also evolve.

Modern combustion methods contribute to this transition by reducing the need for chemical reagents and minimizing waste. Faster analysis times not only improve laboratory efficiency but also reduce energy consumption per sample. More importantly, precise carbon and nitrogen determination enable better control of formulations, helping to avoid overuse of raw materials and reduce food waste.

In this way, analytical accuracy becomes part of a larger system of resource efficiency. It connects raw material use, process optimization, and final product quality, closing the loop between environmental responsibility and industrial performance.

As food systems evolve, analytical precision becomes more than a lab metric. Discover how advanced combustion methods are helping connect sustainability, efficiency, and product quality.

Talk to Eltra's experts about solutions tailored to your application [here](#).

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Leafy Vegetables as a Sustainable Mining Tool

[The Brassicaceae Advantage](#)

[Thallium and Its Industrial Value](#)

[Inside the Leaf: Crystals at the Nanoscale](#)

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For most people, kale belongs in a salad bowl, not a metallurgical lab. However, research suggests that certain leafy vegetables are biologically equipped to extract valuable metals from contaminated soils. This process, known as phytomining, involves special plants that absorb metals through their roots and concentrate them in their leaves, creating a harvestable bio-ore.



Image Credit: YuRi Photolife/Shutterstock

These plants, called hyperaccumulators, can tolerate and accumulate metals at levels far beyond what typical plants can handle. For example, certain *Brassica* species can absorb

thallium at concentrations hundreds of times higher than the usual threshold.^{1,2}

The Brassicaceae Advantage

The Brassicaceae family, which includes kale, cabbage, broccoli, cauliflower, mustard, and Brussels sprouts, stands out for its documented capacity to hyperaccumulate the heavy metal thallium. Researchers at the [University of Queensland's Sustainable Minerals Institute](#) confirmed that these crops accumulate thallium through mechanisms evolved, drawing the metal from polluted soil via their roots and transporting it upward into leaves.¹

What makes this family particularly compelling is the combination of fast growth, wide geographic distribution, and readily available seeds. Indian mustard (*Brassica juncea*), among the most geographically distributed Brassicaceae species, can tolerate high thallium concentrations while offering potential for phytoextraction and bioprospecting. These practical agronomic traits make *Brassica* crops ideal test subjects for scaling up phytomining operations.³

Thallium and Its Industrial Value

Thallium occupies an unusual position in the periodic table of economic significance. Although extremely toxic, it commands a market price of approximately \$8,800 USD/kg, driven by its use in medical isotopes, optical glass manufacturing, and superconductors. That combination of toxicity and value creates a compelling argument for plant-based extraction from contaminated land rather than leaving the metal to leach uncontrolled through soil and water.³

The scale of potential yield is quantifiable. Based on an estimated four tons of *Biscutella laevigata* biomass with 425 µg of thallium per gram and 50 plants per square meter, thallium yields of 1.7 kg per hectare per year would generate approximately \$14,960 USD. For *Iberis linifolia* with 10 tons of biomass at 800 µg/g, the annual yield rises to 8 kg/hectare, valued at \$70,400 USD before production and refining costs.³

Inside the Leaf: Crystals at the Nanoscale

A 2026 study published in the journal *Metallomics* by Corzo-Remigio et al. provided an unprecedented view of where and how thallium is stored inside kale leaves. Using simultaneous micro-X-ray fluorescence (µXRF) and micro-X-ray diffraction mapping (µXDM) at the PETRA III synchrotron facility in Germany, the researchers confirmed that thallium concentrates along the leaf margins, particularly near vascular bundles, forming dense clusters of cubic thallium chloride (TlCl) crystals approximately 5 µm in size.³

This crystallized form of thallium has direct implications for metal recovery. Thallium chloride crystals are potentially compatible with metallurgical extraction methods, and thallium can be extracted from plant biomass using carboxylic acids. The crystalline accumulation mirrors mechanisms seen in halophytes, plants that expel excess salt through leaf glands, suggesting that kale uses a similar strategy to manage toxic metal overload.³

Remediation and Recovery Together

One of the strongest arguments for plant-based metal extraction is that it simultaneously remediates degraded land and produces a recoverable resource. Conventional mining rehabilitation typically involves stripping and displacing contaminated topsoil at high financial and ecological cost. Phytomining inverts that logic by treating the contaminated site as a productive field, generating economic return while drawing down metal concentrations over successive growing seasons.^{2,4}

Phytoextraction is followed by a series of metallurgical processes applied to the harvested plant biomass. These include hydrometallurgy, pyrolysis, and pyrometallurgy, with refining pathways already being developed for nickel bio-ores that offer a template for thallium and other metals. Experts at the Sustainable Minerals Institute stated that non-conventional mining methods, such as phytomining, will become central to securing the metals needed for medical technologies and the renewable energy transition.^{1,3}

Enhancing What Nature Built

The natural accumulation rates of hyperaccumulator plants, while remarkable, can be further amplified through targeted interventions. Genetic engineering approaches that modulate the expression of metal transporter proteins allow plants to concentrate higher metal loads without succumbing to phytotoxicity, directly improving biomass yield and metal recovery per growing cycle.⁴

Soil amendments also play a role. Biochar, chelating agents, and microbial inoculants improve metal bioavailability in the rhizosphere, the zone of soil immediately surrounding the root system, making it easier for plants to absorb and translocate metals into harvestable shoot tissue. Combining selective breeding with microbial-assisted strategies provides a practical roadmap to make phytomining economically competitive with conventional extraction at sites where ore grades are otherwise too low to justify excavation.^{4,5}

Food Safety and the Dual-Use Dilemma

The same trait that makes *Brassica* crops attractive as phytomining agents also raises food safety concerns that demand clear management. Kale grown in soils containing between 0.1 and 124 µg of thallium per gram showed the highest bioconcentration factor among the tested vegetables, ranking it as the highest dietary health risk to humans in contaminated regions.

Regulatory thresholds vary considerably across jurisdictions: Germany sets a maximum permissible thallium level in food at 0.5 mg/kg, while the European Food Risk Assessment body has called for broader dietary intake evaluations.³

The solution lies in deliberate land-use separation. Plants grown for phytomining on dedicated contaminated sites, not in agricultural fields, pose no food chain risk. This separation is already standard practice in nickel phytomining projects, where crops are treated as an industrial input rather than a food product. Keeping the two use cases distinct allows the technology to advance without undermining public confidence in Brassica vegetables as food.^{1,3}

A Tool Whose Time Has Come

The convergence of rising critical mineral demand, post-mining land degradation, and advances in plant science has made phytomining a credible industrial strategy. The research published in [Metallomics](#) represents a pivotal step, moving the science from observational studies to mechanistic clarity. It shows precisely how thallium is stored, in what chemical form, and where in the plant it concentrates. That knowledge directly informs the downstream metallurgical processes needed to turn a kale harvest into a refined metal output.³

The path forward requires collaboration between plant biologists, geochemists, and metallurgists to develop crop-specific refining protocols and validate yields at the field scale. With thallium priced at thousands of dollars per kilogram and growing demand from the superconductor and semiconductor industries, the economic case for deploying leafy vegetables as sustainable mining tools is becoming difficult to overlook.^{2,3}

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Smart Photonic Packaging for Food Safety

Smart photonic packaging for the food industry integrates optical sensors and photonic components to monitor food condition and environmental factors, helping ensure safety and extend shelf life. UN statistics show that around 19% of food is wasted in domestic and commercial settings, while more than 3.1 billion people cannot afford a healthy diet.¹



Image Credit: ultramansk/Shutterstock.com

Experts are increasingly relying on optical technologies to drive a meaningful reduction in food waste while enabling real-time monitoring of food conditions. This approach supports better decision-making across the supply chain, with a strong focus on human health, safety, and commercial value.

What is Smart Photonic Packaging?

Three Major Types of Packaging Technology

There are three major types of packaging technologies employed globally to ensure food safety and preservation. Active food packaging extends the shelf-life of food products by releasing substances like antioxidants and anti-microbials from the packaging to interact with

the food and the environment.²

Intelligent food packaging continuously monitors the food products and the surrounding environmental parameters, ensuring food quality, minimizing food spoilage, and ensuring human safety.³

The most advanced type of packaging is the photonics-enabled or smart photonics packaging for the food industry. It involves the integration of optical sensing mechanisms and photonic components into packaging devices, enabling real-time food monitoring, chemical changes analysis, and multisensory smart monitoring of chemical changes and ecological parameters.

Integration of Optical and Photonic Components into the Packaging Material

The photonic packaging involves the integration of [optical sensors](#) within the packaging devices, allowing for high-speed signal and data transmission from the sensing platform, with low latency and high energy efficiency.⁴

The integration of smart optical sensing intelligent components, like sensors using [quantum dots](#) (QDs), and fluorophores can be done by directly embedding them into packaging films using printing or mixing them into the polymeric film during fabrication. These optical sensors allow for monitoring of oxygen levels, moisture levels, gas levels, and various contaminants.⁵

The detection mechanisms of these optical sensors integrated within modern photonic food packaging include fluorescence dye quenching, colorimetric detectors, and the utilization of Surface-enhanced [Raman spectroscopy](#) (SERS) substrates.

[Download the PDF of this page here](#)

Optical Sensing Technologies Enabling Food Safety Monitoring

Fluorescence-Based Spoilage Detection

The degradation of food leads to changes in pH levels due to microbial activity and protein degradation. The pH-responsive fluorescence-based packaging systems have become critical in recent years to ensure food freshness and safety. Fluorescent materials with excellent biocompatibility and lower toxicity are the most promising materials for pH-responsive sensing packaging platforms.

At present, most systems rely on either visible color-change detection or fluorescence-based sensing. More recently, researchers have developed dual-mode sensing packaging films that combine fluorescein isothiocyanate (FITC) with anthocyanins extracted from dragon fruit peel. These films leverage both FITC fluorescence and the visible color-change properties of the anthocyanins, creating a complementary sensing approach.

The result is a packaging solution that has proven effective for both meat and fruit-based products, enabling non-destructive, real-time monitoring of food quality.⁷

The real-time monitoring of biogenic amines like histamines by fluorescent sensors makes them a good choice for integration with food packaging. Research studies have demonstrated their efficiency as sensor-based hydrogels, smart photo-responsive labels for industrial use, and logic devices enabling real-time monitoring of biogenic amines, for the indication of food spoilage.⁸

Raman and SERS-Based Packaging Sensors

Raman spectroscopy is becoming crucial for applications in food quality monitoring and safety analysis. Food components inherently have weak Raman scatterer constituents, rarely interfering with Raman signals. Furthermore, deep penetration of food samples during Raman spectroscopy allows for inelastic scattering, revealing critical information about food molecules.⁹

In particular, Surface-Enhanced Raman Scattering (SERS)-based sensors have proven highly effective for detecting food contaminants. These simultaneous detection strategies are generally classified into two approaches: label-free and labeled methods.

SERS-based sensing relies on substrates composed of noble metal nanoparticles, which amplify the Raman signal of target food analytes. This signal enhancement enables the detection of contaminants at extremely low, trace-level concentrations, making SERS a powerful tool for food safety monitoring.¹⁰

While SERS-based packaging sensors are quite reliable, the cost of developing reliable substrates is quite high. Experts are working hard to develop reusable and low-cost substrates with analyte enrichment features to facilitate food quality analysis in complex environments.¹¹

Time-Temperature Indicators (TTIs) Using Optical Readouts

Precise temperature regulation is critical for preserving food quality and ensuring adherence to quality standards. Time-Temperature Indicators (TTIs) are a critical technology for contact-

based thermal sensing, easily attached to modern food packaging, monitoring real-time changes. They are critical for comprehensive temperature traceability, ensuring cold chain integrity, allowing for uninterrupted, thermally-regulated supply-chain process optimized for storage and transportation of food products.¹²

The temperature fluctuations in perishable food products lead to irreversible changes in color. The integration of photonic TTIs allows for the provision of visual information, allowing consumers to judge the quality of food.¹³

Industry Drivers Behind Smart Photonic Packaging Adoption

The demand for smart photonic packaging in the food industry has increased significantly due to different factors. Firstly, the food safety regulations and standards are becoming stricter to ensure a decline in food-related diseases. The U.S. Food and Drug Administration has implemented the FDA Food Safety Modernization Act (FSMA), which is a transformative safety system focusing on preventing foodborne illness, rather than reacting to it.¹⁴

There has also been a sharp rise in demand for preservative-free, fresh food products, making an intelligent packaging system essential for monitoring environmental parameters. Furthermore, cold logistics and supply chain systems are also being optimized for reducing the amount of food waste generated before reaching the consumers. In this regard, photonic packaging is crucial for ensuring the safe storage and transportation of perishable goods.

The European Union is funding a project titled FoodPackLab 2, in which companies and organizations from 5 different countries are focusing on the development of smart, photonic packaging for food items.¹⁵ Photonic Biosystems has also been developing optical intelligent sensing systems for food packaging, with their intelligent non-invasive optical sensing platforms for food packaging enabling real-time measurements.¹⁶ These examples highlight the commercial importance of photonic smart packaging systems for achieving Sustainable Development Goals (SDGs), by ensuring less food spoilage.

Manufacturing and Integration Challenges

While photonic smart packaging is a game-changer for the food industry, the manufacturing, printing, and integration costs for photonic components and nano-sensors are limiting their widespread usage in industrial settings.¹⁷ Studies have also revealed that optical components and photonic packaging materials degrade with varying temperatures and time. These factors significantly affect the shelf life of the photonic packaging, with companies working to improve the shelf life of sensors.

To tackle these challenges, the focus has been shifted towards other technologies, such as printable smart photonic packaging with longer shelf life and lower manufacturing costs.¹⁸ Another crucial technology is the Roll-to-Roll (R2R) processing, allowing for industrial-scale fabrication of large-area photonic devices on flexible substrates, making them perfect for food packaging and safety monitoring.¹⁹

How Smart Photonic Packaging Reduces Food Waste?

The components within the photonic smart packaging allow for optical analysis of food products to predict a dynamic expiration date based on real-time quality of food items and environmental parameters. If the condition of fruit or meat-based products is deteriorating rapidly, photonic smart packaging sends alerts to the consumer, even if the printed expiration date is much further away.

Future Developments

Many developments are being made in the field of photonic smart packaging, where Optical Phased Array (OPA) components are being integrated within photonic smart packaging. These optical systems have much lower power consumption while providing high-speed monitoring capabilities for food products.²⁰ Multi-phase and multi-modal photonic sensing platforms are being tested and integrated with traditional packaging systems to enable high-quality smart monitoring systems optimized for food products. Modern manufacturing techniques like nanoimprint lithography (NIL) allow for the manufacturing of complex optical structures for photonic smart packaging, allowing for cheaper large-scale fabrication of smart food packaging.

The implementation of smart photonic packaging in the food industry is proving to be revolutionary, paving the way for next-gen food monitoring systems. The integration of digital systems like AI models and Convolutional Neural Networks (CNNs) has improved monitoring capabilities while reducing power consumption. The future holds great promise for smart photonic packaging, with large-scale industrial implementation looking possible in the next 15-20 years.

[Explore how spectroscopy helps with food safety here](#)

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Thermal Processing in the Food & Beverage Industry



Thermal analysis is essential in the **food and beverage sector**, supporting quality control, safety testing, and product development. Laboratory ovens and furnaces enable precise temperature control for applications such as **moisture determination, ash analysis, and sample preparation**.

Moisture content is a key quality parameter affecting shelf life and product stability. Laboratory drying ovens are commonly used for **loss on drying (LOD)** methods, providing uniform heating and controlled airflow to ensure accurate and repeatable results.

For **ash and mineral content determination**, high temperature furnaces are used to combust organic material, leaving inorganic residues for analysis. These systems offer stable high temperature performance and programmable control, supporting standardized food testing methods.

Beyond routine analysis, thermal equipment is widely used in **research and development**, including ingredient stability studies, packaging evaluation, and process optimization.

Reliable thermal processing solutions help laboratories maintain consistent product quality, regulatory compliance, and innovation across the food industry.

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Inside Food & Beverages: Engineering Quality Through Particle Analytics

In food and beverage manufacturing, product quality is shaped by more than the ingredients on the label. The way a product looks, feels, tastes, pours, dissolves, or remains stable over time is often influenced by particle behavior at a much smaller scale.



Image Credit: New Africa/Shutterstock.com

Particle size, shape, surface charge, and stability can all affect texture, mouthfeel, appearance, shelf life, and processing performance. This article explores how particle characterization helps manufacturers better understand those relationships and then use such insights to improve quality, consistency, and formulation outcomes across the product lifecycle.

The article is structured around three main sections, each focused on a different part of the food and beverage landscape, but all connected by the same central idea: better measurement leads to better product understanding.

The first section, **Engineering Texture and Functionality in Solid Foods**, looks at how particle

properties influence solid products such as coffee, chocolate, and sugar. These examples show how closely product performance is tied to the size and shape of individual particles.

In coffee, grind size distribution has a direct impact on extraction, flavor balance, aroma release, and brew consistency. Even relatively small differences in particle distribution can change the final drinking experience. The article highlights how the [CAMSIZER X2+](#) can be used to analyze coffee powders quickly and accurately, particularly in cases where traditional sieve methods struggle with oily or agglomeration-prone materials.

Chocolate provides another clear example of the importance of particle control. Texture in chocolate is defined at the micrometer level, and particles above a certain size can create an unwanted gritty sensation. To help address this, the article discusses the [SYNC](#) analyzer, which combines Laser Diffraction with Dynamic Image Analysis to measure particle size while also giving visual confirmation of coarse particles.

This allows manufacturers to look beyond a single average number and better understand the fractions that can influence smoothness and mouthfeel. Sugar, meanwhile, is presented as a case where more advanced image-based techniques can improve on traditional sieve analysis by offering greater reproducibility as well as additional insight into particle shape, agglomerates, and potential contamination.

Together, these examples show that texture and functionality depend not just on what a product contains, but on how its particles are distributed and how they behave.

The second section, **From Ingredients to Beverages: Controlling Stability and Performance**, shifts the focus to liquid systems, where stability is often one of the biggest formulation and quality challenges. Using examples including green tea, milk powders, beer, and CBD beverages, the article shows how particle interactions can be used to detect and predict instability earlier than traditional methods allow.

In green tea, subtle colloidal changes can eventually lead to haze, sedimentation, or reduced visual appeal. The article shows how STABINO ZETA can be used alongside particle size analysis to provide faster insight into colloidal stability, helping manufacturers assess destabilization risk before obvious failure occurs.

In milk powders, the challenge is not only long-term stability but also rehydration. The article explains how TURBISCAN technology can monitor rehydration in real time, giving manufacturers a clearer view of how powders disperse and how stable the resulting system remains.

Beer stability is also discussed, with charge titration presented as a quicker and more sensitive alternative to traditional forcing tests for identifying early colloidal changes linked to haze formation. In CBD beverages, where nanoemulsion quality is closely tied to droplet size and surface charge, the article describes how NANOTRAC FLEX, STABINO ZETA, and TURBISCAN can be used together to support formulation development, process control, and shelf-life evaluation.

Across these applications, the message is consistent: earlier visibility into particle behavior makes it easier to control stability and reduce formulation risk.

The third section, **Accelerating Innovation in Formulation and Additives**, looks at how particle characterization can also support development work, not just quality control. The article uses examples including plant proteins and beverage emulsions to show how analytical tools can help manufacturers move from trial and error to a more informed, data-driven approach.

With plant proteins, understanding how ingredients disperse and dissolve is essential, as these behaviors affect texture, stability, and process performance. The article highlights TURBISCAN DNS as a tool for monitoring solubility and dispersion in real time, making it easier to compare ingredients such as pea and soy and understand their practical differences under processing conditions.

In beverage emulsions, the focus is on weighting agents and the role they play in improving stability and appearance. By monitoring creaming, opacity changes, and ring formation, manufacturers can compare traditional and natural alternatives more effectively and optimise formulations with greater confidence.

This section reinforces the wider value of particle characterization as a development tool that helps improve speed, consistency, and decision-making.

Across all three sections, the article highlights a few key ideas. One is that particle behavior has a direct effect on product performance, whether the goal is smooth texture, controlled extraction, better dispersion, improved rehydration, or longer shelf life.

Another is that combining multiple analytical techniques gives a far more complete picture than relying on a single measurement alone. By bringing together technologies such as Dynamic Image Analysis, Laser Diffraction, Dynamic Light Scattering, Zeta Potential, and Stability Analysis, manufacturers can gain deeper and more actionable insight into how products behave.

Most importantly, the article shows that earlier insight leads to better outcomes, helping teams reduce variability, improve consistency, and accelerate development.

Read the full article to explore each application in more detail



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Why Active Food Packaging Materials are Essential for Changing Food Safety Requirements

[Foodborne Illness and the Limits of Conventional Packaging](#)

[Active Packaging as a Materials-Engineered Concept](#)

[Types of Active Packaging Materials](#)

[Recent Research and Development](#)

[Design and Regulatory Considerations](#)

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Deterioration of packaged food is a huge issue for global suppliers. It is a major contributor to the spread of foodborne illnesses, which, according to the WHO, affect one in 10 people worldwide each year. Conventional food packaging tries to prevent deterioration through passive barrier performance, but this is only effective within defined operating conditions.



Image Credit: i viewfinder/Shutterstock.com

Addressing modern food safety requirements may take a different paradigm: active food packaging materials.

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Foodborne Illness and the Limits of Conventional Packaging

Foodborne illness is caused by contamination with pathogenic microorganisms and chemical hazards like heavy metals. Exposed consumers may suffer from acute gastrointestinal disease or more serious outcomes like chronic neurological, carcinogenic, and immunological effects.

According to World Health Organization assessments, foodborne illness results in an estimated 420,000 deaths annually, with disproportionate impacts on vulnerable populations, including pregnant women, children, and immunocompromised individuals.

Producers naturally risk substantial economic losses as a result of product contamination.

Food deteriorates through four dominant mechanisms: oxidation, moisture imbalance, microbial activity, and chemical instability. Oxidative and moisture-driven processes progressively degrade nutritional and sensory quality, while chemical instability accelerates the formation of undesirable or potentially harmful by-products during storage. Microbial activity presents the most direct safety threat, as pathogen growth can occur despite refrigeration, particularly when environmental conditions fluctuate during distribution.

Conventional packaging typically uses polymer films and multilayer laminates to limit oxygen and water vapor transmission, slowing deterioration rather than actively suppressing it. However, it provides no adaptive response to temperature excursions, variable respiration rates, or residual reactive species present at sealing, so deterioration progresses once barrier limits are exceeded.

This gap underscores the need for packaging that goes beyond passive containment, incorporating materials that can actively regulate oxygen, moisture, and microbial activity. Such active systems are essential for maintaining product stability and extending shelf life under variable storage and distribution conditions.¹

Active Packaging as a Materials-Engineered Concept

Active packaging integrates reactive functionality into the package structure. This means

preservation is achieved through controlled interaction with the product and its surrounding atmosphere rather than solely through barrier resistance.

The defining feature of this concept is the materials' ability to absorb or release specific chemical species under controlled conditions, embedding preservation functionality directly at the material level, even when the package appears physically identical to conventional systems.

These materials are designed and engineered based on their specific mode of interaction, such as scavenging reactive species, releasing functional compounds in a controlled manner, or employing immobilized surface activity to inhibit microbial growth without migration.

Effectiveness depends on factors like reaction kinetics, mass transport, and interfacial stability, directly connecting preservation performance to material composition, loading, and compatibility with the packaging substrate.^{1,2}

Types of Active Packaging Materials



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Oxygen Scavenging Materials

Oxygen scavengers are one of the most established active packaging technologies. They target oxidative spoilage in products such as high-fat snacks, nuts, meat, dairy items, and fresh produce.

Common approaches include:

- Iron-based scavengers:
 - Use oxidation of elemental iron in the presence of moisture to form stable iron oxides
 - Historically supplied as sachets or pads inside packages
 - Increasingly integrated into film structures to provide more uniform scavenging and remove ingestion risks
- Enzymatic scavengers:
 - Rely on enzymatic systems such as glucose oxidase, often combined with catalase
 - Convert glucose to gluconic acid while consuming oxygen and decomposing the hydrogen peroxide produced
 - Suitable for iron-sensitive products where metal migration or discoloration is a concern
- Nanocomposite scavengers:
 - Incorporate zero-valent iron nanoparticles onto high-surface-area supports, such as kaolinite or bentonite clays
 - Offer enhanced activity under both humid and relatively dry conditions
 - Applicable to dry foods such as coffee, bakery products, and dried meats
 - Deployment is guided by regulatory bodies, such as EFSA to ensure safe use³

Moisture-Regulating Materials

Water activity (a_w) is a critical parameter for microbial stability, enzymatic reactions, and texture. Moisture-active packaging components are engineered to manage local water activity and condensate.

Examples include:

- Desiccants and absorbent pads:
 - Remove excess moisture from headspace or exudate from fresh meat, fish, and poultry
- Superabsorbent films and layers:

- Based on cross-linked polyacrylates, carboxymethyl cellulose, or other hydrophilic networks
- Take up and retain significant amounts of water as a gel, stabilizing the micro-environment around the product
- By maintaining water activity below approximately 0.85, these materials can inhibit the growth of most foodborne pathogens and extend shelf life in high-moisture applications such as fresh produce and ready-to-cook meat products³

Antimicrobial Materials

Antimicrobial packaging is designed to reduce or prevent the growth of spoilage and pathogenic microorganisms on the food surface. Two main strategies are implemented:

- Controlled-release antimicrobials:
 - Protein-based bacteriocins, such as nisin and natamycin, are incorporated into films or coatings
 - Target species include *Listeria monocytogenes* and *Staphylococcus aureus*
 - Formulations are tuned to meet regulatory migration limits while maintaining antimicrobial efficacy
- Contact-active inorganic systems:
 - Use materials such as silver-loaded zeolites dispersed in polyolefins or polyamides
 - Provide long-term antimicrobial activity on the packaging material's surface
 - Designed to minimize leaching into the food matrix, helping to maintain safety and compliance over the product life cycle

These systems can be particularly valuable for ready-to-eat foods, minimally processed products, and applications where post-processing contamination is a concern.^{4,5}

Antioxidant and Chemical Stabilization Materials

Antioxidant-releasing packaging complements oxygen scavengers by directly intercepting radical and non-radical species that drive oxidation.

Common functional additives include:

- Natural extracts (e.g., rosemary):
 - Demonstrated to inhibit hydroperoxide formation in lipid-rich foods such as processed meats

- Tocopherols and ascorbic acid:
 - Interrupt radical chain reactions and quench singlet oxygen
 - Can enhance the performance of other antioxidants present in the product

These compounds may be delivered to the food surface or act within the vapor phase, offering targeted protection in high-fat foods, nuts, and snacks where oxidative rancidity is a major quality issue.⁶

Sensors play a key role in food safety: [Read about it here.](#)

Recent Research and Development

Fresh Inset's MCPBag for Longer-Lasting Pears

[Fresh Inset](#)'s MCPBag is an active packaging solution that extends the shelf life of pears by gradually releasing 1-MCP to inhibit ethylene, slowing ripening and softening.

Trials by IDC Patagonia showed pears in MCPBag produced 60% less ethylene and remained firm and colorful, achieving a shelf life four to eight days longer than standard bags.

The system works without specialized infrastructure, offering growers and retailers a scalable solution that could reduce global fruit and vegetable waste by up to 9.46 million tons annually.⁷

Stretchable Antimicrobial Active Packaging for Real-time Monitoring and Preservation

Recently, [Korean researchers](#) designed the stretchable, antimicrobial NSSAW wrapper, an active packaging solution that combines preservation with real-time monitoring.

The wrapper incorporates a curcumin-TPU matrix that inhibits 99.99% of *Staphylococcus aureus* and 99.9% of *Escherichia coli*, along with a nanostructured SERS sensor that enables non-destructive detection of nutrients, pesticides, and spoilage markers.

This dual-function active packaging supports continuous freshness tracking, shelf-life extension, and quality management across cold chain logistics, retail, and consumer applications.⁸

Design and Regulatory Considerations

Designing active packaging materials takes an integrated, system-level approach that combines multiple functional components without compromising mechanical, optical, or barrier properties.

Performance depends not only on the individual activity of each component but also on its interactions, which must be characterized to ensure compatibility and predictable behavior under storage and distribution conditions. For instance, moisture-activated oxygen scavengers may require minimum headspace humidity levels that conflict with the product's desired water activity, necessitating careful balancing of component functions within the package architecture.

Active compounds must also comply with approved migration limits established by regulatory frameworks, including European Union Regulations No. 10/2011 and 450/2009 and U.S. FDA guidelines, to ensure consumer safety and prevent harmful exposure from packaging materials.

The global active and intelligent packaging market is **projected** to grow from 14.9 billion USD in 2025 to 41.4 billion USD by 2035. However, this can only be achieved through characterization, predictive modeling, and adherence to regulatory standards, ensuring that active packaging meets its functional goals without compromising consumer safety while also supporting scalable manufacturing and consistent performance across commercial production.^{3,9}

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Scientists Use Algae to Convert Food Waste Into Sustainable Ingredients

Researchers at King Abdullah University of Science and Technology (KAUST) have discovered something new about a very old organism and used it to transform waste from a chocolate factory into C-phycoerythrin, a valuable red pigment that is estimated to have a global market value of over US\$275 million by 2030.

The study, published in *Trends in Biotechnology*, outlines how *Galdieria yellowstonensis*, an ancient strain of red algae, can eat the sugars found in chocolate-processing waste to grow into a protein-rich biomass containing C-phycoerythrin, which is used in food, cosmetics, and pharmaceutical products. Adding to the findings was the unexpected discovery that high levels of carbon dioxide promote *Galdieria* growth. Normally, carbon dioxide is a waste produced by microbes eating sugar.

KAUST Associate Professor Kyle Laursen and lead author of the study said: *"Our work studying the metabolism of algae is uncovering new ways to turn waste into valuable products sustainably. Chocolate production, for example, generates waste when process lines start and stop. We realized this waste could be a useful food for Galdieria."*

Phycocyanin from *Galdieria*, of which C-phycoerythrin is one type, was recently deemed food-safe by the U.S. FDA and is suitable for beverages and other food applications. However, compared to conventional methods for phycocyanin, which use cyanobacteria, the KAUST method using *Galdieria* can significantly reduce costs and increase yields because the hot and highly acidic environment in which *Galdieria* thrive can reduce the presence of other microbes.

Additionally, the recycling of factory waste into feed for microorganisms like algae to produce valuable products helps local industry contribute to a circular economy. This is especially relevant for food producers, who are facing increasing pressures in relation to production costs, waste management, and [climate change](#).

Mars Corporate Affairs Director-Middle East and Africa Obai Rahim: *"At Mars, we are committed to fostering innovation and sustainability through meaningful partnerships with leading academic institutions like KAUST. We are pleased that our chocolate samples could support this collaborative research, and we were delighted to welcome the KAUST team to our KAEC facility."*

"This project reflects our dedication to advancing science and developing sustainable solutions, especially those that leverage local resources and expertise. The exploration of blue phycocyanin

production from Galdieria grown on food waste aligns with our vision for a more sustainable future and our ongoing efforts to reduce food waste and promote circular economic practices.

"Mars values the opportunity to engage with local industry and academia, and we look forward to continuing our collaboration with KAUST to drive impactful research and innovation in the region."

For their experiments, Lauresen and his research team collected waste from a chocolate factory in Saudi Arabia.

The researchers plan to further develop their process by assessing the scalability and technical capacity of Galdieria production processes on locally available wastes, helping more businesses in Saudi Arabia make the critical shift towards a circular carbon economy.

Source:

[King Abdullah University of Science and Technology \(KAUST\)](#)

From Food to Reliable Analysis: The Underestimated Power of Sample Preparation

Reliable food analysis begins long before the final measurement is made. However advanced the analytical method may be, the result still depends on whether the sample being tested is representative and sufficiently homogeneous.



Image Credit: DK Gestaltung/Shutterstock.com

In food analysis, this is not always simple. Products vary widely in moisture, fat content, texture, structure, and composition, so sample preparation is more than a routine first step. It is a major factor in determining whether results are accurate, reproducible, and useful.

This article explores why sample preparation matters so much in food analysis, the challenges posed by different food matrices, and how the right grinding, homogenization, and sieving approaches can improve reliability throughout the workflow.

The first main section, **Challenges Posed by Different Food Matrices**, shows that there is no one-size-fits-all preparation method for food samples. Dry, granular, and crystalline materials such as grains, sugar, and salt are among the easiest to process, but they still require controlled grinding to reach the desired particle size without changing the material itself.

For these types of samples, the article highlights rotor and centrifugal mills such as the [ZM 300](#) and SR 300, which are designed to deliver reproducible results for dry and brittle products.

More difficult are oily, moist, and sticky foods such as chocolate, cheese, meat, and baked goods. These materials can smear or clump during grinding, making even particle reduction

harder to achieve. For these matrices, the article points to knife mills such as the [GRINDOMIX GM 200](#) and GM 300, which are suited to fast and intensive homogenization.

Foods with high water content, including fruits, vegetables, soups, and sauces, create a different challenge: moisture may help break the sample down, but it can also lead to sticking or poor movement inside the grinding chamber.

Fibrous and tough materials such as dried herbs, plant matter, and freeze-dried fish require a more targeted cutting approach, and the article highlights the SM 100, SM 300, and SM 50 for these applications. Together, these examples show that food matrices behave very differently, and preparation methods need to be matched to the sample rather than applied as a standard process.

The next section, **Cryogenic Sample Preparation as a Special Case**, focuses on samples that are especially soft, sticky, fatty, or temperature sensitive. In these cases, conventional grinding can create heat, cause smearing, or lead to the loss of volatile components, all of which can affect the sample before analysis even begins.

Cryogenic grinding addresses this by cooling the material with dry ice or liquid nitrogen so it becomes brittle and easier to pulverize. The article presents this as an important option for high-fat and delicate food products where preserving sample integrity is critical.

Instruments such as the CryoMill and MM 500 control are highlighted as solutions specifically designed for this type of preparation, helping laboratories process challenging materials while reducing the risk of unwanted changes during grinding.

The section on **Equipment Designs and Mill Types in Food Analysis** broadens the discussion by showing how different technologies suit different sample types. Knife mills are ideal for soft, fatty, and moist samples. Rotor and centrifugal mills are better suited to dry, brittle, and granular materials.

Cutting mills are recommended for fibrous and tough products, while ball mills are used when finer or ultrafine grinding is required. The article shows that successful sample preparation is not just about making particles smaller. It is about choosing the right equipment for the matrix, the target fineness, the sample volume, and the analytical method that follows.

Another important section is **Reproducibility and Quality Assurance**, which sits at the heart of the full article. Reproducibility is essential in food analysis, especially where results need to be compared across users, laboratories, or production batches.

The article uses fat analysis as an example to show how much difference proper homogenization can make. Coarsely ground sausage samples showed much greater variation in measured fat content than finely homogenized samples, where the standard deviation was dramatically lower.

This illustrates one of the article's key messages: effective sample preparation does not just prepare a sample for analysis, it directly improves the reliability of the result. The article also notes that accessories such as cyclone systems can support cooling, sample discharge, and dust reduction, helping improve consistency in routine laboratory work.

The final main section, **The Importance of Sieving in Quality and Production Control**, looks beyond grinding and homogenization to particle classification. Sieving plays an important role in determining particle size distribution, monitoring processes, checking batch consistency, and detecting oversized particles or agglomerates.

Because particle size affects properties such as solubility, flowability, sensory quality, and extraction behavior, it remains a critical parameter in many food products. The article highlights air jet sieving as especially useful for fine, light, or agglomeration-prone powders where conventional mechanical sieving can struggle. The AS 200 jet pro is presented as an all-in-one system combining air jet sieving, integrated weighing, and software-supported evaluation to help standardize particle analysis and improve reproducibility.

Overall, the article shows that sample preparation is not just a preliminary stage in food analysis, but one of its most important foundations. By adapting methods to different food matrices, selecting suitable equipment, and focusing on reproducibility at every step, laboratories can generate results that are far more accurate, consistent, and meaningful.

[Read the full article for more detail here](#)



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New DNA Tests Expose Spice Fraud Across Popular Herbs and Spices

A Europe-wide validation study shows that DNA-based qPCR methods can reliably detect and quantify adulterants in some of the world's most widely used spices and herbs, strengthening the fight against food fraud.



Study: [Interlaboratory validation of thirteen qPCR methods to quantify adulterants in culinary spices and herbs](#). Image Credit: alexkoral / Shutterstock

In a recent study published in the journal ***European Food Research and Technology***, researchers at the European Commission, Joint Research Centre (JRC), Geel, Belgium, interlaboratory-validated 13 real-time deoxyribonucleic acid (DNA)-based quantitative polymerase chain reaction (qPCR) methods, selected from a previously in-house validated set of 30 methods, to detect and quantify key adulterants in six spices and herbs widely used in the daily diet.

These included paprika/chili, saffron, turmeric, oregano, black pepper, and cumin. They strengthened the evaluation with an interlaboratory comparison (ILC) involving 25 laboratories overall, with each method tested by 15 Europe-based laboratories.

The assays showed strong analytical performance, with repeatability ranging from 4% to 25%, reproducibility generally from 6% to 25% (one exception at 28.5%), and trueness bias between –11% and 27%.

The results support their potential inclusion in international technical standards and use in official control laboratories, supporting food authenticity and consumer protection.

Spice Adulteration and qPCR Authentication Background

Culinary spices and herbs are high-value commodities vulnerable to fraud through adulteration, substitution, and contamination with heavy metals, synthetic dyes, or cheaper plant materials.

These practices compromise authenticity and raise concerns for consumer health and trust. European Union (EU) monitoring systems, including the Coordinated Control Plan (EUCCP) and Rapid Alert System for Food and Feed (RASFF), highlight the need for robust authentication tools.

In response, the European Commission has promoted reliable, standards-aligned analytical methods. Although DNA-based approaches show promise, they have not yet undergone full interlaboratory validation for herbs and spices, leaving a key gap in standardized testing in routine food authentication.

Interlaboratory qPCR Validation Study Design

In this study, researchers interlaboratory-validated 13 qPCR methods that had previously met in-house validation criteria for detecting the five most common adulterants in spices and herbs, including paprika/chili, saffron, turmeric, oregano, black pepper, and cumin. Methods meeting predefined criteria were then advanced to an ILC involving 25 participating laboratories overall.

The team selected laboratories based on technical capacity, requiring experience with 96-well format qPCR systems and at least annual instrument calibration. Interested laboratories first completed a questionnaire assessing their technical expertise, analytical capability, and ability to manage the required sample workload within the timeframe.

Each selected laboratory received standardized DNA templates prepared centrally by the Joint Research Center–Geel (JRC–GEEL), ensuring uniformity across all analyses. These included

five calibration samples with known mixing ratios, five blinded test samples with unknown adulterant concentrations, no-template controls (NTCs), primers, and qPCR master mix. Participants reported cycle threshold (Cq) values using a standardized reporting template within one month.

To generate the reference materials, the researchers prepared binary plant mixtures gravimetrically, followed by cetyltrimethylammonium bromide (CTAB)-based DNA extraction, semi-automated purification, and fluorometric quantification. They evaluated a range of adulterant-matrix combinations, such as maize in paprika, safflower in saffron, and rice in black pepper.

Before distribution, the researchers determined limits of detection (LOD) and limits of quantification (LOQ) in-house using serial dilutions and repeated qPCR runs across multiple days. Measurement uncertainties were then assessed from the interlaboratory performance data.

For the ILC, they analyzed the samples over two consecutive days under repeatability conditions to assess method performance. Key validation parameters included reproducibility, repeatability, and trueness.

qPCR Performance Across Participating Laboratories

Of the 48 laboratories that responded to the questionnaire, 25 were selected based on technical capability, instrument calibration status, experience in food fraud detection, and capacity to use multiple methods.

Each method was tested by 15 laboratories, with the full ILC conducted across two participation periods. The 13 qPCR methods demonstrated strong and consistent analytical performance across laboratories. Relative standard deviation of repeatability (RSDr) ranged from 4.0% to 25%, while relative reproducibility (RSDR) was generally between 6.0% and 25%, with one exception at 28.5% for paprika mixed with sunflower-derived press cake. Trueness bias remained within -11% to 27% across all methods, supporting overall analytical reliability.

Importantly, RSDr stayed below 25% across all tested binary mixtures, even at the lowest levels of adulteration (0.5–2.0 g per 100 g depending on the spice matrix). This met and, in many cases, exceeded the minimum performance requirements for genetically modified organisms (GMOs) and food testing. A lack of systematic trend between concentration levels and RSDr indicated stable performance across the full analytical range.

Reproducibility was also robust, with all but one value remaining below the 25% threshold. The exception was observed in paprika mixed with 1.0 g per 100 g sunflower-derived press cake (28.5%). However, this RSDR value remained below the acceptable limit of 35%, confirming overall interlaboratory consistency.

Trueness assessment further supported method reliability. In-house evaluations showed bias below 25% across all concentrations, a finding largely confirmed by the ILC results. Only one case marginally exceeded this threshold in oregano with 5.0 g per 100 g goosefoot (27%).

Implications for Official Spice Testing

The interlaboratory comparison confirms that the 13 qPCR methods are robust, reliable, and suitable for routine use in official food control laboratories. They consistently met international validation criteria and showed strong performance in detecting and quantifying adulterants in commonly used spices. However, they should be applied within a broader analytical framework rather than as standalone tools.

The authors also noted that DNA extraction and purification were not part of the ILC, and that biological variability in plant materials can affect DNA-based quantification. These methods can complement screening approaches like next-generation sequencing and digital PCR, as well as chemical and traceability-based investigations.

Moving forward, digital PCR and integrated weight-of-evidence strategies offer promising pathways to further strengthen food fraud detection.

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Journal reference:

- Behr, M., Pellegrin, C., Garlant, L. et al. (2026). Interlaboratory validation of thirteen qPCR methods to quantify adulterants in culinary spices and herbs. *European Food Research and Technology*, 252, 168. **DOI:** 10.1007/s00217-025-05028-x, <https://link.springer.com/article/10.1007/s00217-025-05028-x>

Nanocomposite Sensor Improves Heavy Metal Detection in Milk

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Nanocomposite sensor using MgO and ZnO enables sensitive detection of lead and cadmium in milk. This sensor improves food safety through rapid, selective, and cost-effective electrochemical analysis.



Study: An electrochemical sensor based on MgO/ZnO nanocomposite modified carbon paste electrode for toxic heavy metal ions in milk. Image Credit: Iryna Inshyna/Shutterstock

In a recent article published in the journal [*Scientific Reports*](#), researchers presented the development of an electrochemical sensor based on a magnesium oxide (MgO) and zinc oxide (ZnO) nanocomposite-modified carbon paste electrode (CPE) designed for detecting toxic heavy metal ions in milk.

Milk Contamination Challenge

Given the widespread consumption of milk and its vulnerability to environmental contamination, ensuring milk safety by monitoring trace heavy metals like lead (Pb^{2+}) and cadmium (Cd^{2+}) is essential. The proposed sensor aims to provide a sensitive, selective, and rapid approach to detect these contaminants, addressing limitations of conventional analytical techniques.

Milk acts as a critical dietary source but is increasingly susceptible to contamination by toxic heavy metals such as Pb^{2+} and Cd^{2+} . These metals pose serious health risks due to their persistence, bioaccumulation, and interference with biological processes. Traditional detection methods such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS) provide high accuracy but are costly, require complex instrumentation, and require laborious sample preparation, limiting their practicality for field use.

Nanocomposite Design & Electrode Fabrication

The MgO and ZnO nanoparticles were synthesized separately via precipitation and alkali precipitation, followed by hydrothermal treatment to obtain the MgO/ZnO nanocomposite. The particles were characterized structurally and morphologically using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), UV-visible spectroscopy (UV-Vis), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX), confirming successful synthesis and appropriate elemental composition.

To fabricate the sensor, the MgO/ZnO nanocomposite was integrated into a carbon paste matrix, forming the modified electrode. Electrochemical performance was evaluated using cyclic voltammetry (CV) with potassium ferrocyanide as a redox probe, assessing parameters such as reversibility and electroactive surface area, compared with electrodes modified only with ZnO or MgO. Optimization experiments fine-tuned variables including solution pH, deposition potential, metal ion concentration, and deposition time to maximize sensor response.

Heavy metal detection was conducted using anodic stripping voltammetry (ASV), whereby target metal ions first accumulated on the electrode surface, followed by electrochemical reduction and stripping to produce measurable current peaks. Real samples of cow milk from local farms and a university dairy were collected and analyzed using the sensor via a standard addition method to account for matrix effects. Validation of results was performed against conventional flame atomic absorption spectroscopy (FAAS).

Electrochemical Performance & Real Sample Analysis

The structural analyses demonstrated that the MgO/ZnO nanocomposite possessed a porous architecture and high surface area suitable for electrochemical applications. The formation of p–n heterojunctions between MgO and ZnO enhanced electron transfer by facilitating charge redistribution at the interface, as supported by EDX elemental analysis, which showed successful incorporation of ZnO into the MgO matrix.

Electrochemical characterization via cyclic voltammetry indicated that the MgO/ZnO modified electrode displayed higher peak currents and better reversibility than single-metal oxide modified electrodes, confirming increased electroactive surface area and improved charge transfer kinetics. The sensor showed enhanced sensitivity attributable to the synergistic effect of the nanocomposite, which provides abundant adsorption sites and facilitates rapid electron transfer.

The detection mechanism involves selective adsorption of Pb^{2+} and Cd^{2+} ions onto the MgO/ZnO surface through electrostatic attraction and complexation with oxygen-containing functional groups. During ASV, the adsorbed metal ions are reduced to their metallic forms, with stripping peaks corresponding to individual metals, allowing for simultaneous detection. The sensor exhibited well-defined anodic peaks with excellent reproducibility in voltammograms.

Analytical performance revealed a linear response for Pb^{2+} and Cd^{2+} ions in the concentration range of 100–8000 $\mu\text{g/L}$, with detection limits of 0.142 $\mu\text{g/L}$ for Pb^{2+} and 0.45 $\mu\text{g L}^{-1}$ for Cd^{2+} . Sensitivities of 0.710 $\mu\text{A}\cdot\mu\text{g}^{-1}\text{L}^{-1}$ for Pb^{2+} and 0.787 $\mu\text{A}\cdot\mu\text{g}^{-1}\cdot\text{L}^{-1}$ for Cd^{2+} were reported. Comparative studies showed that this sensor outperforms many previously reported electrodes, highlighting its practical utility.

The sensor demonstrated excellent selectivity by effectively discriminating Pb^{2+} and Cd^{2+} ions over common interfering ions such as Cu^{2+} , Zn^{2+} , Co^{2+} , and Fe^{3+} . Furthermore, the electrode maintained stability, retaining over 95% of its initial response after three weeks of storage. Repeatability tests showed low relative standard deviations (2.7% for repeatability and 1.98% for reproducibility), underscoring the consistent fabrication and robust electron transfer properties.

Sensor Potential & Future Directions

This work successfully demonstrates the synthesis and utilization of a MgO/ZnO

nanocomposite-modified carbon paste electrode as an efficient electrochemical sensor for detecting toxic heavy metal ions in milk. The nanocomposite imparts enhanced electrochemical properties, including increased surface area, improved electron transfer, and selective adsorption, all of which contribute to superior sensitivity, stability, and specificity.

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The study underscores the potential to further develop MgO/ZnO/CPE platforms into portable, miniaturized devices for on-site food safety and environmental monitoring. Overall, this electrochemical sensor holds promise for broad applications in public health protection and environmental surveillance, providing a cost-effective and reliable tool for trace heavy metal detection.

Journal Reference

Kebede M.T., Tsegaye A.A., et al. (2026). An electrochemical sensor based on MgO/ZnO nanocomposite modified carbon paste electrode for toxic heavy metal ions in milk. *Scientific Reports*. DOI: 10.1038/s41598-026-49835-y, <https://www.nature.com/articles/s41598-026-49835-y>