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Food Safety

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Foreword

Welcome to the latest edition of our Food Safety eBook, where we explore the evolving landscape of food safety and testing. As concerns about contamination, regulatory oversight, and food integrity continue to grow, innovations in detection technologies and data analysis are driving significant change across the global food industry. This collection of articles highlights the most pressing challenges and the cutting-edge solutions helping to ensure what we eat is safer, cleaner, and more trustworthy than ever before.

Gain critical insight into per- and polyfluoroalkyl substances (PFAS), increasingly found in food products, in **Your Ultimate Guide to Robust PFAS Detection in Food.** This whitepaper outlines how advanced mass spectrometry techniques are delivering greater precision in identifying these persistent environmental contaminants.

Explore how regulatory frameworks are adapting in **Reforming Food Testing: What Changes to the FDA Mean for Safety and Industry Standards**, where we unpack the implications of recent updates to US policy and their potential global impact on food testing protocols. Sustainability and safety intersect in **How Can Food Safety be Improved by Renewable Energy?**, a look at how cleaner energy sources are supporting safer production methods and better environmental stewardship.

Discover analytical efficiencies in **How to Streamline Pesticide Analysis in Fruit Juice with Direct Injection LC-MS/MS**, a detailed guide to minimizing sample prep while maximizing data reliability.

Automation is also playing a crucial role. **Using AI to Detect Food Contaminants** reveals how machine learning is enhancing detection accuracy and reducing false positives, while **Robots Designed to Improve Food Safety** examines how robotics are transforming quality assurance practices on production lines.

In **The Science Behind Rapid MRM: Detecting Food Contaminants Faster than Ever**, learn how this technique accelerates contaminant detection without sacrificing accuracy. Also featured is **How Sensors Are Enhancing Food Safety and Reducing Waste**, showcasing real-time monitoring innovations, and **Are Machine Learning Models the Future of Food Safety?**, a forward-looking perspective on predictive analytics in food risk management.

As food systems become more complex, this eBook provides a timely snapshot of the science, technology, and regulation shaping the future of food safety. We hope it informs and inspires your work in this vital field.

Your ultimate guide to robust PFAS detection in food

This article shows a >2x improvement in robustness when analyzing PFAS food extracts on the SCIEX 7500+ system. At the conclusion of the trial, which included approximately 6400 food matrix injections, the majority of PFAS compounds (10 out of 13) retained >70% of their initial sensitivity.

The presence of interfering co-extractables in food matrices complicates residue analysis, potentially resulting in instrument contamination and system downtime.

The robustness of the SCIEX 7500+ and SCIEX 7500 systems was assessed in an accelerated manner using an aggressive sample preparation technique and missing the diverter valve.

The SCIEX 7500+ system includes innovative Mass Guard technology, which improves instrument robustness while retaining optimal sensitivity for longer.[1]

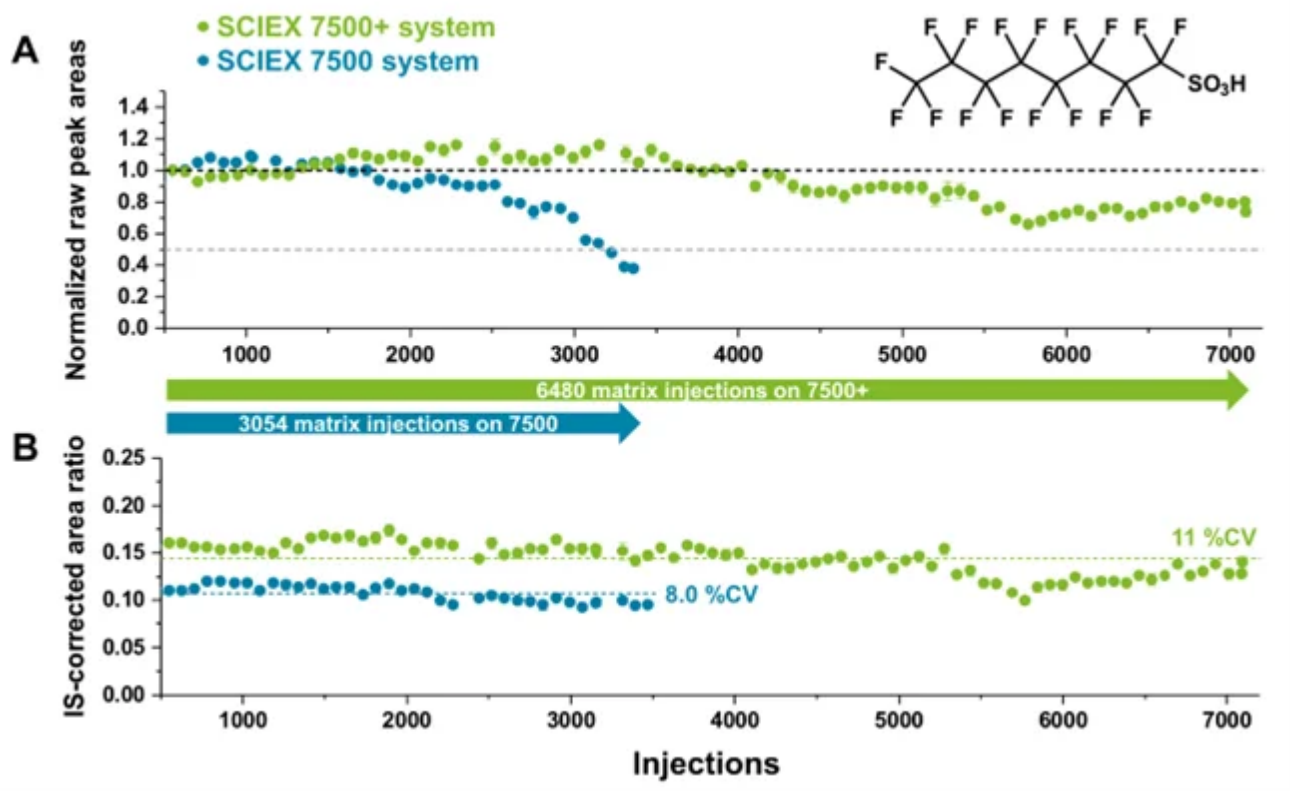

Figure 1. Raw peak areas normalized to initial response (A) and internal standard (IS)-corrected peak area ratios (B) for perfluorooctane sulfonate (PFOS) in solvent quality control (QC) samples on the SCIEX 7500 (blue) and on the SCIEX 7500+ (green) systems. *Each datapoint represents the mean with standard error bars. In panel A, the dotted lines represent the 100 % and 50 % raw peak areas relative to the initial response. Robustness was compared*

based on the total number of injections before the instrument sensitivity declined to 50 % of the maxima. In panel B, the dotted lines represent the overall mean and %CV for each experiment. Food extracts were injected between each solvent QC datapoint. Image Credit: SCIEX

Key benefits of high-throughput PFAS analysis in food using the SCIEX 7500+ system

- **Enhanced robustness from Mass Guard technology:** The SCIEX 7500+ system has improved hardware components to reduce contamination and maintain instrument uptime.
- **Exceptional instrument stability:** The SCIEX 7500+ system achieved >2x improvement in robustness, with over 6,400 injections of food matrices compared to over 3000 injections on the SCIEX 7500 system.
- **User-accessibility via an extractable DJet+ assembly:** Increased flexibility for user cleanup as needed.

Introduction

The complexity of the matrix makes high-throughput analysis of PFAS in food samples challenging. Instrument robustness is critical for ensuring good test performance with minimal downtime.

The SCIEX 7500+ system retains the high sensitivity of the SCIEX 7500 system while also providing increased resilience via Mass Guard technology.[1] This involves the addition of T Bar electrodes to the Q0 region, which actively filters out contaminated ions and produces a cleaner ion beam (**Figure 2**).

Visual analysis of the downstream ion optics demonstrates that the SCIEX 7500+ system has fewer pollution deposits than the SCIEX 7500 system on the IQ1 lens. Furthermore, the SCIEX 7500+ system improves customer access to the instrument's front-end DJet+ assembly, allowing for easier cleaning.[1]

The long-term robustness of the SCIEX 7500+ and SCIEX 7500 systems was tested under accelerated settings.

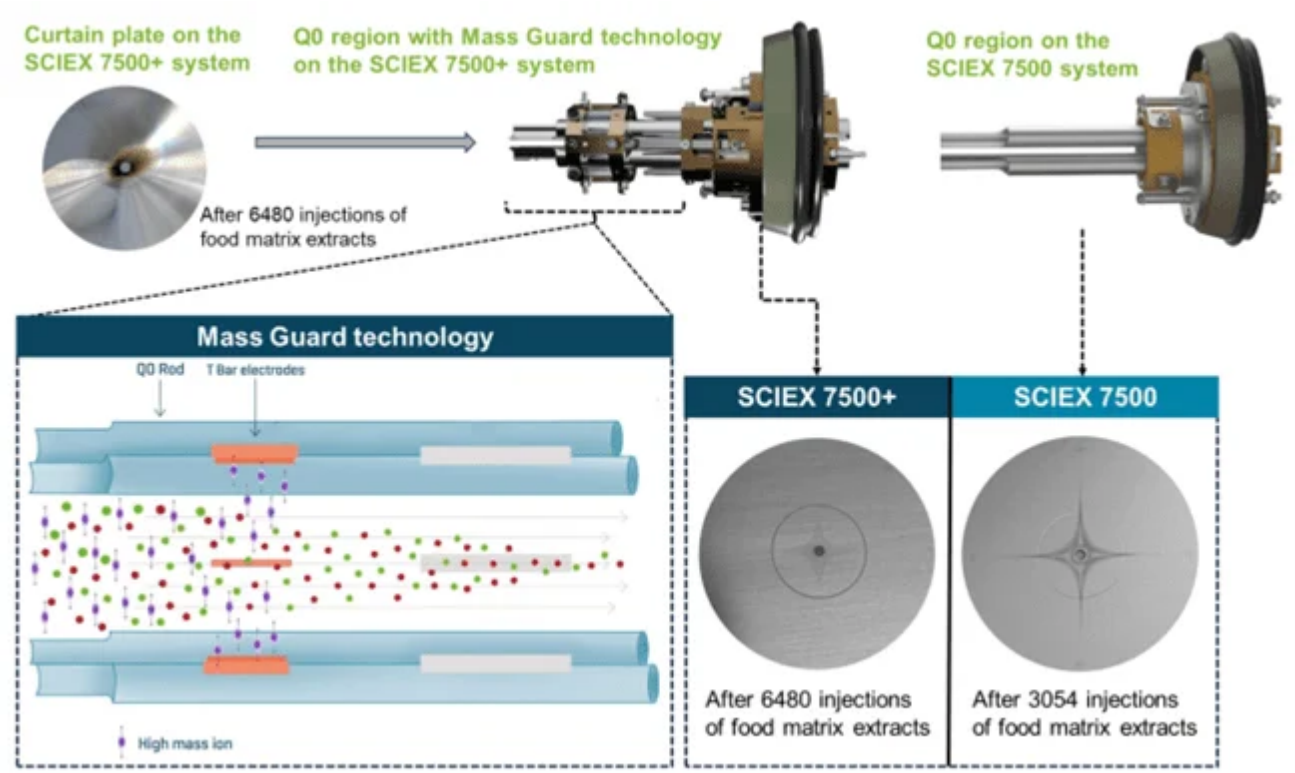

Figure 2. Hardware components of Mass Guard technology. *The added T Bar electrodes in the Q0 region of the SCIEX 7500+ system actively remove contaminating ions (purple symbols), resulting in a much cleaner sample plume (red and green symbols) entering the instrument. Visual comparison of the ion optics downstream of the T Bar electrodes showed less impact from matrix contamination despite significant residue deposited on the source curtain plate (top left), when compared against the same component on the SCIEX 7500 system without this protection, as shown on the bottom right. Image Credit: SCIEX*

Methods

To assess the robustness of both systems, the experimental regime was constructed to maximize the matrix load injected over successive weeks, which included:

- A diverse range of food matrices
- More matrix interferences were found in the extracts due to a modified sample preparation method compared to standard optimized methods.
- Short duration allows for more consecutive matrix injections between solvent QCs (**Figure 3**).
- Acquire continuously without using a diverter valve or doing any maintenance on the mass spectrometer.

Samples and reagents: Wellington Laboratories provided native and mass-labeled PFAS standards for preparing quality control (QC) samples in solvents and matrix post-spikes in food

extracts. Salmon fillets, avocado, five-spice powder, and rabbit feed were bought from local supermarkets.

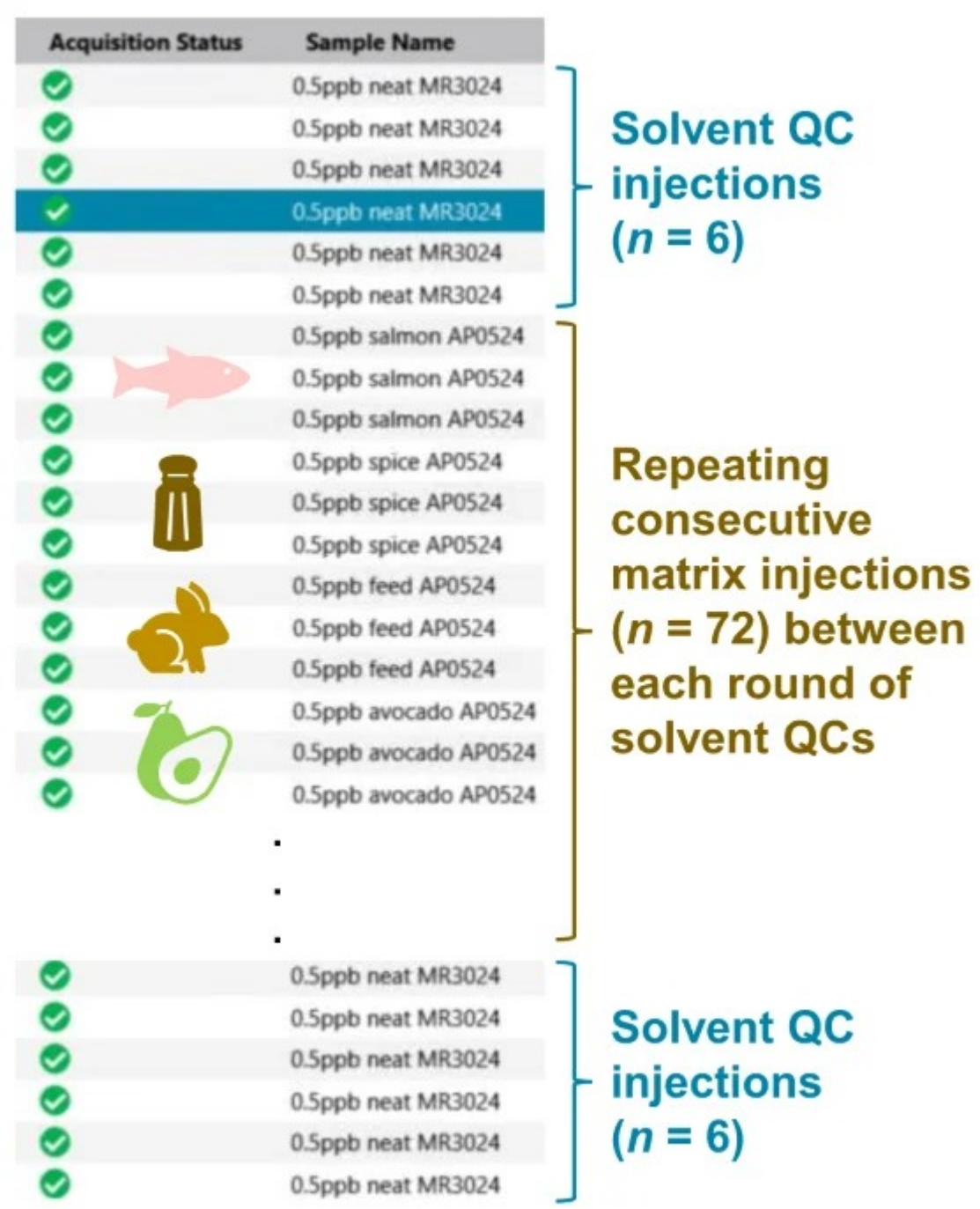

Figure 3. Injection sequence on both systems. *Robustness was evaluated by consecutive injections of food matrix extracts that were bracketed by solvent QC replicates at a frequency ratio of 12:1 matrix:solvent, i.e. 72 matrix injections for every 6 solvent QC replicates. Image Credit: SCIEX*

Sample preparation: To prepare the samples for extraction, a food processor was used to homogenize the salmon fillet and avocado (~50 g each), and a mortar and pestle was used to

grind the rabbit feed (50 g).

The food samples were extracted using a QuEChERS method designed for PFAS measurement in food, but the final solid-phase extraction (SPE) step was skipped to maximize impurities in the final matrix extracts.[2]

In a 50 mL centrifuge tube, 5 g of homogenized salmon or avocado (or 2 g of feed or spice powder) was mixed with water. This was 5 mL for salmon/avocado or 15 mL for feed/spice powder. This was then followed by extraction with 12 mL of acetonitrile and 150 µL of formic acid.

After adding a QuEChERS packet (6000 mg $MgSO_4$, 1.5 g NaCl; Phenomenex P/N AH0-9044), the sample was vortexed and agitated for 5 minutes at 1500 rpm.

After 5 minutes of centrifugation at 10000 rcf, the supernatant was transferred to a 15 mL dispersive (dSPE) tube (900 mg $MgSO_4$, 150 mg PSA, 45 mg GCB; Phenomenex P/N KS0-9510). After shaking and centrifuging the dSPE tube, the supernatant was evaporated until dry and reconstituted in 10 mL of methanol.

This final methanolic extract was divided into equal 1 mL aliquots with a solvent ratio of 80:20 (v/v) methanol/water.

Solvent QC samples were created by spiking a mixture of native and mass-labeled PFAS standards with the same solvent composition as the food matrix extracts. As shown in Figure 3, the instrument's resilience was assessed by monitoring the solvent QCs between large blocks of successive matrix injections.

Chromatography: The ExionLC AC system was used for chromatographic separation, using a Luna Omega PS C18 analytical column (100 x 3.0 mm, 3 µm, Phenomenex P/N 00D4758-Y0) and a delay column (50 x 3.0 mm, 5 µm, Phenomenex P/N 00B-4753-Y0).

The SecurityGuard ULTRA UPLC Fully Porous PS C18 cartridge (Phenomenex part number AJ0-9508) was utilized. A flow rate of 0.8 mL/min, injection volume of 10 µL, and column temperature of 40 °C were utilized. Table 1 shows the LC gradient used.

Table 1. LC gradient. Source: SCIEX

Time (min)	Mobile phase A (%)	Mobile phase B (%)
0.00	90	10
0.25	90	10
0.50	45	55
1.50	10	90
3.50	10	90
3.60	90	10
5.00	90	10

Mobile phase A: Water with 10mM ammonium acetate
Mobile phase B: Methanol with 10mM ammonium acetate

Mass spectrometry: Analysis was carried out utilizing scheduled multiple reaction monitoring (sMRM). Table 2 displays the source and gas characteristics used in both systems. MRM settings were optimized for the target PFAS.

Table 2. Source and gas parameters. Source: SCIEX

Parameter	Value
Polarity	Negative
Ion source gas 1*	40 psi (7500+), 50 psi (7500)
Ion source gas 2	70 psi
Curtain gas	50 psi
Source temperature	400°C
Ion spray voltage	-2000 V
CAD gas	12

* GS1 was optimized to achieve equivalent sensitivity between both systems.

Data processing: Data collection and processing were carried out using SCIEX OS software, version 3.4.0. The SCIEX OS software included built-in automatic checks to monitor instrument contamination for quick and easy troubleshooting.

Comparison of robustness performance between the SCIEX 7500+ system and SCIEX 7500 system

The foods selected for matrix injections (salmon, spice powder, avocado, and rabbit feed) reflect the variety of food samples evaluated by normal testing facilities. Rabbit feed was used as a surrogate for silage, which is known to contain significant amounts of interference.

After more than 3000 injections on the SCIEX 7500 system, preliminary trials employing the entire US FDA extraction and clean-up procedure[2] revealed no significant sensitivity decline for any target analyte.

The final SPE clean-up was eliminated to enhance the matrix interference burden on the system. However, these alterations represent demanding conditions, and the optimal extraction and clean-up process should be used for routine food analysis.

Figure 1A demonstrates the robustness performance using the uncorrected raw peak areas observed. Following the initial 500 matrix injections, solvent quality control monitoring commenced. The raw peak regions were normalized to the initial stabilized response, as indicated by the 100% black dotted line in Figure 1A.

To compare robustness, the total number of injections required until the instrument's sensitivity dropped to 50 % of its initial response was used. Both devices displayed excellent robustness, as shown by Figure 1A for perfluorooctane sulfonate (PFOS).

On the SCIEX 7500 system, the raw peak areas of PFOS remained steady for ~2500 injections before decreasing to 50 % after >3000 injections. More remarkably, the SCIEX 7500+ system outperformed this injection count by more than two times, with PFOS sensitivity remaining consistent at 80 % after more than 7000 injections.

Similar robustness trends were found for the other target PFAS (Figure 4). At about 3400 injections, 11 of the 13 PFAS examined preserved more than 90 % of their initial sensitivity on the SCIEX 7500+ system, while the majority of the analytes had decreased to less than 50 % on the SCIEX 7500 system.

This sensitivity performance remained good on the SCIEX 7500+ system after 7000 injections, with most analytes still responding at 70% of their initial value.

Figure 4 shows a visual comparison of the SCIEX 7500+ system's better resilience to the SCIEX 7500 system for four different representative PFAS: PFHxA, PFOA, PFHxS, and PFDS.

Isotope-labeled internal standards (IS) are widely employed in PFAS food analysis. However, because the native and internal standards respond similarly to the assay environment, IS-corrected peak regions can disguise an instrument's true performance.

For example, the percentage CVs of the IS-corrected area ratios of PFOS were 8 % for more than 3300 injections on the SCIEX 7500 system and 11 % for more than 7000 injections on the SCIEX 7500+ system (Figure 1B).

This consistency indicates that the instrument's performance remained steady throughout the experiment, despite the severe conditions, such as the high matrix load fed continually to the ion source without the protection of a diverter valve or any interim maintenance.

As a result, uncorrected raw peak areas provide a more accurate indication of instrument performance over time and can alert the user when maintenance is required.

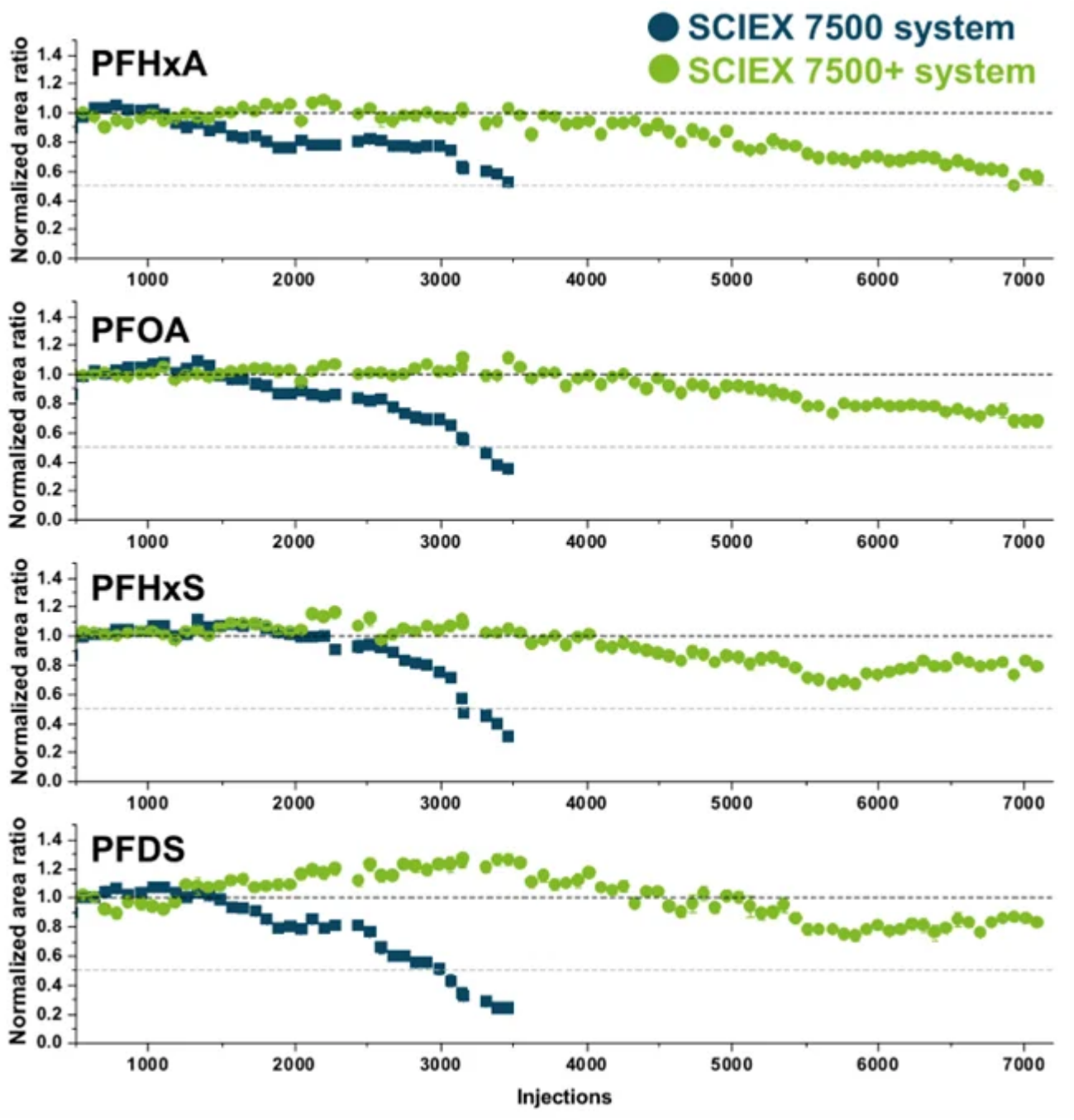

Figure 4. Comparison of robustness trends observed for perfluorohexanoic acid (PFHxA), perfluorooctanoic acid (PFOA), perfluorohexane sulfonate (PFHxS) and perfluorodecane sulfonate (PFDS) in solvent QC samples injected on the SCIEX 7500 system (blue) and SCIEX 7500+ system (green) throughout the experiment. *Each datapoint represents the average of replicate injections with its associated standard error bars. The black and grey dotted lines represent the initial stable analyte response at 100 % and 50 % of that initial response, respectively. Image Credit: SCIEX*

Enhanced software tools for system performance tracking

System suitability tests (SSTs) using QC samples are essential for guaranteeing data correctness and repeatability in long-term experiments. Intermittent infusion-based checks can also offer real-time information about the instrument's functioning across acquisition batches.

SCIEX OS software includes an automatic procedure that allows the user to monitor detector performance and system charging without manual intervention (Figure 5).

Any suboptimal performance determined by the SSTs and contamination tests would necessitate instrument maintenance. The replaceable DJet+ assembly on the SCIEX 7500+ system enhances front-end serviceability by giving the user greater control over maintenance scheduling and system uptime.

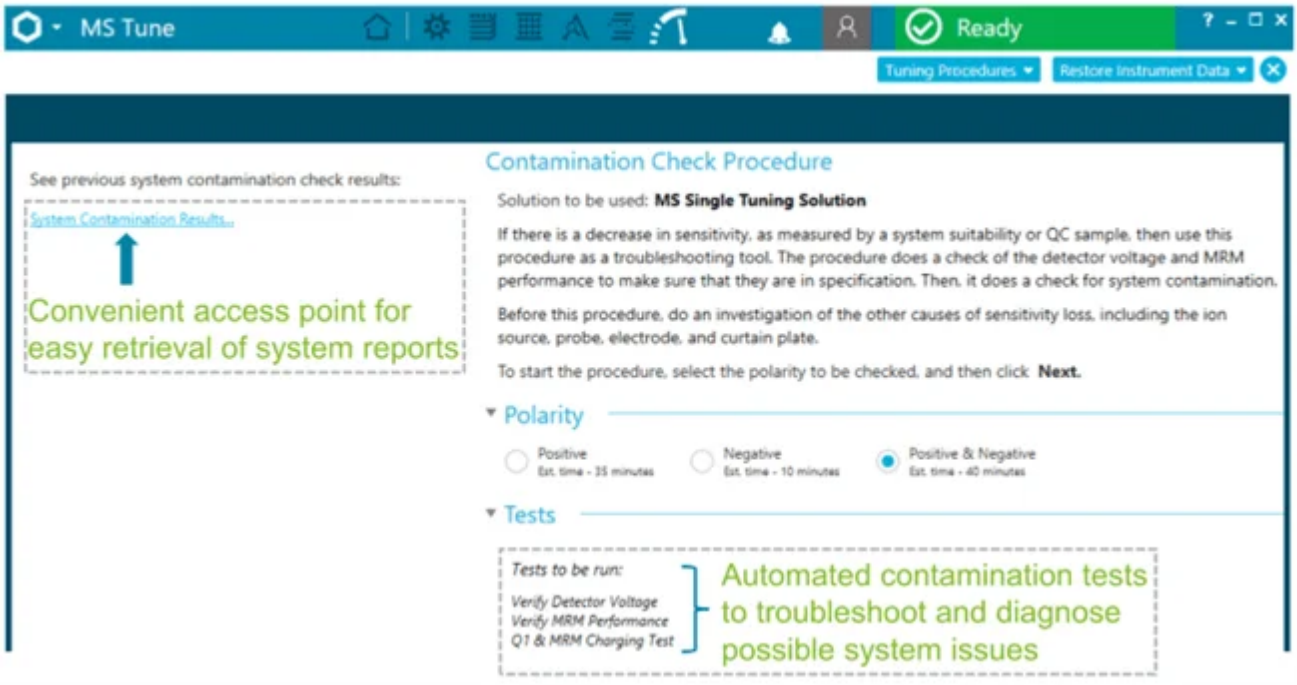

Figure 5. Built-in contamination check procedures in SCIEX OS software for easy

troubleshooting. *The MS Tune module in SCIEX OS software provides an automated contamination check procedure that allows the user to troubleshoot and monitor instrument performance during sensitivity loss. At the end of the procedure, the software generates a summary report of the instrument health based on the tests ran. Image Credit: SCIEX*

Conclusion

Mass Guard technology actively removed contaminating ions in complicated matrices, conferring outstanding robustness to the SCIEX 7500+ system.

The SCIEX 7500+ system maintained quantitative performance after over 7000 injections of food extracts and solvent QC samples, with most PFAS analytes retaining more than 70 % of the initial peak area sensitivity.

SCIEX OS software enhancements for system performance tracking and the extractable DJet+ assembly provide enhanced flexibility for user-initiated system maintenance and uptime management.

Building on the renowned sensitivity of the SCIEX 7500 system, the SCIEX 7500+ system delivers exceptional data stability to provide a robust and high-performance platform for PFAS analysis in food.

References and further reading

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Acknowledgments

This article was produced using materials originally authored by Holly Lee[1], Ian Moore[1], Craig M. Butt[2], and Elliott Jones.[2]

[1] *SCIEX, Canada*
[2] *SCIEX, USA*

About SCIEX

The mission of SCIEX is to deliver solutions for the precision detection and quantitation of molecules, empowering our customers to protect and advance the wellness and safety of all.

SCIEX has led the field of mass spectrometry for 50 years. From the moment we launched the first ever commercially successful triple quad in 1981, we have developed groundbreaking technologies and solutions that ensure global food safety today.

Today, as part of the Danaher family of global life science and technology innovators, we continue to pioneer robust solutions in mass spectrometry and capillary electrophoresis. But we don't just develop products. It is what we do together with our customers that sets them apart. That's why thousands of food experts around the world choose SCIEX to get the answers they can trust and keep running - day in and day out with consistent performance.

We proudly stand behind our tagline: The Power of Precision.

Reforming Food Testing: What Changes To The FDA Mean For Safety And Industry Standards

The U.S. food safety system is undergoing substantial reform following the introduction of new policies by the Food and Drug Administration (FDA) between late 2024 and mid-2025. These changes affect several areas, including microbial testing, chemical contaminant control, additives, and product labeling, and aim to modernize oversight, integrate new tools, and improve transparency.

Image credit: Fox_Ana/Shutterstock.com

The FDA, part of the U.S. Department of Health and Human Services (HHS), is responsible for the safety and security of the U.S. food supply, cosmetics, dietary supplements, and medical devices, protecting public health.

The latest changes have several implications for the food industry, from adopting new technologies to meeting stricter reporting expectations while ensuring safety and consumer trust.

Microbial Safety Testing and Traceability

Microbial contamination is among the most immediate threats to food safety. The FDA has introduced measures through the Food Safety Modernization Act (FSMA) to prevent foodborne illnesses. Several rules have been finalized to implement FSMA and ensure specific actions are taken to avoid contamination across the animal and human food supply chain.

One of the most significant changes is the food traceability rule, which requires manufacturers, processors, packers, and food distributors to maintain detailed records of key tracking events, from harvesting to packing and shipping.[1] Although the complete traceability requirements for high-risk foods may not take effect until 2028, companies are already under pressure to strengthen microbial prevention strategies and supply chain documentation.

Alongside regulatory requirements, technological advances are changing the landscape of microbial testing, such as whole genome sequencing (WGS), which is increasingly applied in industry for routine monitoring and source tracking.[2] Emerging tools such as biosensors and volatile compound detectors offer real-time contamination detection, while machine learning models trained on genomic and environmental data are beginning to predict microbial risks before they become systemic. These innovations indicate a shift from reactive detection to preventive controls.

Chemical Contaminants and Residues Transparency and Screening

Chemical residues, whether arising from environmental contamination, agricultural practices, or processing, remain a crucial regulatory challenge. In March 2025, the FDA and HHS introduced the Chemical Contaminants Transparency Tool, an online database of contaminant levels that evaluates potential health risks of contaminants in human foods.[3]

The tool makes regulatory benchmarks easier to access by consolidating tolerances, action levels, and advisory thresholds for heavy metals, mycotoxins, and industrial chemicals. It is a compliance resource for manufacturers and a public accountability mechanism, as the increased visibility may encourage companies to strengthen monitoring beyond regulatory minimums.

In parallel, the FDA released the Expanded Decision Tree for food chemical toxicity screening, which incorporates endpoints for developmental, neurotoxic, and endocrine effects, and applies modern dietary exposure models.[4] This tool allows a more structured process for

regulators in prioritizing chemical evaluations, while industry benefits from the ability to pre-screen potential additives before formal submission. The decision tree reflects the FDA's trend towards predictive toxicology and less reliance on animal testing.

Withdrawal Standards of Identity

Another important reform is the decision to revoke 52 outdated standards of identity. These rules used to prescribe precise compositions for foods such as canned fruits, macaroni products, and juices. While they helped define consistency, many predated modern protections around ingredient safety, labeling, nutrition claims, and good manufacturing practices.[5]

Removing these standards intends to eliminate unnecessary regulatory burdens and encourage product innovation. Manufacturers now have greater freedom to reformulate products, explore plant-based alternatives, or reduce sugar without conflicting with outdated requirements.

This flexibility also brings new responsibility, since consumer protection depends more heavily on accurate labeling and effective enforcement against misleading claims without prescriptive standards. For example, increased vigilance is needed to prevent misbranding and food fraud, which have been persistent challenges in categories such as olive oil and honey. Regulators will need to rely on post-market surveillance rather than pre-defined compositional rules.

Stringent Requirements on Additives and Colorants

In 2025, the FDA issued updated guidance emphasizing stricter compliance for synthetic dyes while indicating a preference for natural alternatives. This followed growing scientific evidence linking certain artificial dyes to hyperactivity and behavioral concerns in children, such as a recent systematic review highlighting neurobehavioral effects of synthetic food colorants.[6] This aligns with growing consumer demand for clean-label products and heightened concerns over the safety of specific artificial colors.

For manufacturers, transitioning to natural colorants presents technical and economic challenges, including stability issues under heat and light and higher sourcing costs. Reliance on synthetic dyes will face growing scrutiny in both safety and market acceptance. High-profile examples, such as the FDA's review of Red No. 3 in confectionery products, illustrate how regulatory action and consumer pressure converge. Companies that adapt early may gain an advantage in consumer trust and regulatory compliance.

Global Supply Chains and Oversight

The global nature of food supply chains means that U.S. food safety depends as much on international oversight as domestic enforcement. To strengthen accountability abroad, the FDA expanded its use of unannounced inspections at foreign manufacturing facilities in late 2024, covering food and other regulated products intended for the U.S. market.[7]

This development places added responsibility on importers, who must ensure that suppliers maintain robust preventive controls, testing protocols, and documentation. The change closes long-standing regulatory gaps and reassures consumers that imported products meet the same safety standards as domestic goods.

Recall and Consumer Protection

The FDA has also updated recall guidance to improve coordination and speed of consumer notifications, emphasizing digital platforms and retailer communication. Faster, more transparent recalls are critical to minimizing public health impacts, particularly in outbreaks involving pathogens such as *Salmonella* or undeclared allergens. These reforms strengthen the consumer protection framework alongside the technical standards described above.

Conclusion

The changes recently introduced by the FDA represent a move toward a food safety system that is more transparent, science-driven, and adaptive. Advances in microbial testing are shifting the focus from reactive detection to predictive measures, whereas new tools are strengthening chemical risk assessments while increasing accountability.

The phasing out outdated identity standards gives manufacturers more flexibility and greater responsibility for accurate labeling. Tighter controls over additives and expanded inspections abroad signal a regulatory environment that prioritizes innovation and consumer protection. Combined with recall modernization efforts, the reforms show an integrated approach to prevention, transparency, and rapid response.

Companies that adapt early to these reforms will be best placed to build resilience, protect public health, and maintain consumer trust in a rapidly evolving regulatory landscape.

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Microplastics in Drinking Water: Should We Be Worried?

Microplastics have become an increasingly significant environmental and public health issue in recent years. Once primarily associated with marine pollution, these tiny particles are now commonly detected in freshwater sources and bottled and tap water. Their pervasive distribution, combined with the chemicals and biofilms they can transport, has heightened concerns about their potential effects on human health. As drinking water represents a major route of exposure, awareness and apprehension regarding microplastics continue to rise worldwide.[1–4]

Image Credit: PawelKacperek/Shutterstock.com

What are Microplastics?

Plastics are extensively used across industries due to their affordability, chemical stability, durability, and water resistance. Global plastic production has risen to 368 million tons annually, with projections reaching 33 billion tons by 2050. Yet, only 9% of plastic waste is recycled, and 79% is discharged into the environment. The discarded plastic waste accumulated over land, stagnant water bodies, and wastewater effluent/sludge eventually enters rivers.[1,2]

Environmental exposure degrades plastics into numerous tiny plastic fragments/particles, such as microplastics/microscopic fragments of plastic waste with particles less than 5 mm in size, and even nanoplastics with less than 1 µm in size. Microplastics differ in composition, density, shape, and size.[1,2]

Annual microplastic emissions are estimated at 10–40 million tons and could double by 2040. Microplastics are classified as primary microplastics, which are produced in less than 5 mm sizes for use in cosmetics and textiles, and secondary microplastics, which are formed by environmental breakdown.[3,4]

How Do Microplastics Get into Water?

Microplastics in surface water, groundwater, and wastewater have raised serious concerns about the potential contamination of drinking water. Microplastics enter drinking-water sources through various pathways, with surface run-off and wastewater effluent, both treated and untreated, being the primary contributors. These pathways include rain-induced run-off, treated and untreated sewage discharge, industrial effluents, degraded plastic waste, and atmospheric deposition.[1,4]

Primary microplastics, used in products like medicines and cosmetics, often enter domestic wastewater after use. Most wastewater treatment plants are not designed for complete microplastic removal. Hence, a large amount ends up in the effluent discharged into freshwater bodies and becomes part of the fresh/drinking water supply chain.[4]

The rise in microplastic levels in the Chicago River has been linked to effluents from adjacent wastewater treatment facilities. Components of water treatment and distribution systems—often made of plastic materials like polyethylene and polyvinyl chloride can degrade and lead to microplastic contamination.[4]

While primary microplastics contribute around 15–31% of total microplastics in drinking water, almost 69–81% are secondary microplastics. These originate from the breakdown of larger plastic/macroplastic waste in landfills and open dumps. Leachate from these sites carries microplastics that seep along with the water and contaminate surface and groundwater systems.[4]

Hence, microplastics are present in surface-derived drinking water and also in groundwater, although in smaller concentrations. Drinking water contains fragment and fiber-shaped microplastics, with polyethylene terephthalate, polyethylene, polyvinylchloride, and polypropylene being the most common polymer types in it.[4]

What are the Dangers of Microplastics?

Microplastic ingestion in humans primarily occurs through contaminated drinking water. Once ingested, some particles get excreted through bile, urine, or faeces due to their resistance to degradation. The microplastic elimination rate depends on size, shape, polymer type, and associated chemicals. However, microplastics can bioaccumulate in secondary organs after translocating from the gut with chronic/cumulative exposure, causing tissue obstruction due to their persistence in the body.[4]

This bioaccumulation raises significant public health concerns as microplastics are now prevalent in various environmental matrices and drinking water.

In the gastrointestinal system, microplastics trigger inflammatory responses, disrupt cellular functions, increase gut permeability, and alter microbial composition and metabolism. Their surface protein corona may facilitate their passage through the gastrointestinal tract.

A small portion of these particles may enter the bloodstream through the gastrointestinal wall and circulate to various organs and tissues, a process supported by *in vivo* studies.[2]

Recent findings reveal microplastic presence in human blood, placenta, breast milk, and lungs. Microplastic exposure causes adverse effects like oxidative stress, genotoxicity, inflammation, necrosis, and apoptosis, which may lead to tissue damage, fibrosis, or malignancy.[2]

Animal studies have displayed that polystyrene microplastics accumulate in the kidney, lungs, and intestine, leading to oxidative stress, altered lipid and energy metabolism, and neurotoxicity. Circulating microplastics have also been associated with pulmonary hypertension and vascular dysfunction, underscoring the potential for systemic health effects.[2,4]

Challenges in Removing Microplastics

The removal of microplastics from drinking water remains a major challenge due to constrained technical parameters and unclear removal mechanisms.

Detection of very small particles (<10 µm) and those in low concentrations, whether spherical or fragmented, is particularly difficult with current methodologies. Sample contamination during collection and laboratory processing further complicates accurate analysis.

A key issue is the lack of standardized analytical methods for sampling, identifying, and quantifying microplastics in drinking water. There is no consensus on the sample size, units of

measurement, or pretreatment procedures needed to eliminate interference from non-plastic substances like salts. Existing quality assurance and control methods also require review and updates to ensure accurate and consistent microplastic assessments.[2,3]

Video Credit: Tap Score/YouTube.com

Latest Research in Microplastic Removal

Conventional treatment methods are effective to some extent in removing microplastics due to their physical similarity to suspended particulates. Among these, coagulation-precipitation is the most crucial process, with removal efficiencies reported between 17% and 71%.

One study showed coagulation-sedimentation reduced microplastics from 6614 to 3472 microplastics/L (40.5–54.5% efficiency). Another found air flotation removed up to 83% of microplastics.[2] Advanced treatment technologies, such as membrane separation, effectively remove microplastics from water.

A study showed that ultrafiltration and reverse osmosis reduced microplastic levels from 2.2 microplastics/L to 0.28 microplastics/L and 0.21 microplastics/L, respectively. While promising for drinking water purification, further research must consider economic feasibility and membrane contamination risks.[2]

A paper recently published in the *Polish Journal of Environmental Studies* proposed practical quality assurance and quality control (QA/QC) techniques to improve the accuracy of microplastic analysis. It addressed the lack of standardized/efficient QA/QC measures for sampling and analysis, which has hindered consistent environmental research on microplastics.

The study highlighted that microplastic research remains in its early stages, with varied and sometimes controversial methods used for sampling and laboratory analysis.

By comparing different approaches, the authors introduced a set of QA/QC measures to enhance the reliability and precision of analytical data for microplastics.[2]

Do Reusable Water Bottles Contain Microplastics?

Water stored in reusable plastic water bottles is not free from microplastic contamination. A study in the *Journal of Hazardous Materials* investigated chemical migration into water stored in reusable plastic bottles—new, used, and dishwasher-washed—over 24 hours.

Using liquid chromatography–high-resolution mass spectrometry, researchers identified over 3,500 compounds related to dishwashing, with 430 persisting even after flushing. More than 400 plastic-related compounds were detected, including oligomers from biodegradable polyester (polycaprolactone) and aromatic amines, possibly introduced as slip agents or antioxidants.[5]

Many of these chemicals had not previously been reported in bottled water. Used bottles release primarily plasticizers, antioxidants, and photoinitiators, the latter raising concern for potential endocrine-disrupting effects.

Overall, dishwashing significantly increased the leaching of plastic-related compounds, and subsequent flushing only halved their intensity, highlighting possible health risks associated with repeated use of plastic bottles.[5]

Continued Research in Microplastics in Drinking Water Needed

The widespread presence of microplastics in drinking water, originating from environmental pollution and everyday plastic use, poses significant health and environmental concerns.

Despite some removal by conventional and advanced treatment methods, the lack of standardized detection and analysis techniques hampers effective mitigation. Continued research and stricter quality control are essential to safeguard public health and ensure cleaner drinking water.

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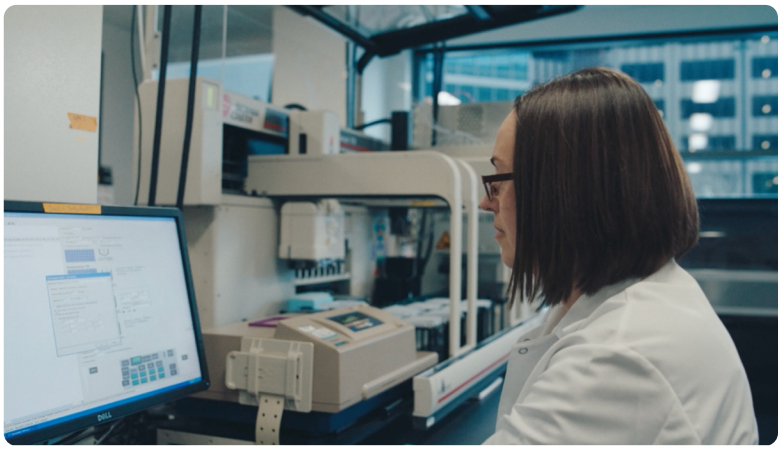

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How to streamline pesticide analysis in fruit juice with direct injection LC–MS/MS

This article presents a comparative study to evaluate the sensitivity performance of the SCIEX 7500+ system for quantifying pesticides in orange juice.

Food and beverage samples are well-known for their complexity and contribute to matrix effects via co-extractables. In addition, these matrices are known to cause instrument contamination.

The SCIEX 7500+ system with Mass Guard technology[1] was created to improve instrument robustness while retaining the sensitivity of the SCIEX 7500 system.

A quantitative approach for evaluating more than 200 pesticides in orange juice proved method transferability and equal sensitivity from the SCIEX 7500 to the more robust SCIEX 7500+ systems (Figure 1).

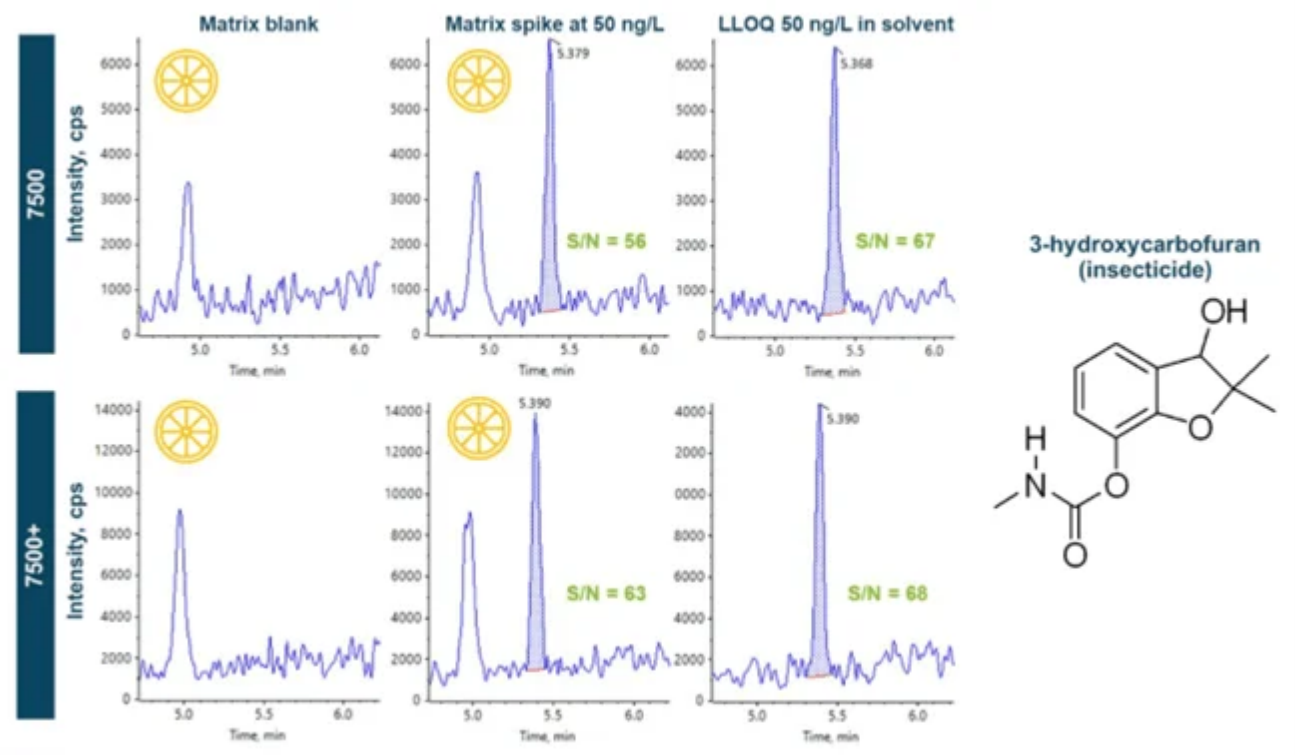


Figure 1. Seamless method transfer to the SCIEX 7500+ system while retaining equivalent sensitivity performance on the SCIEX 7500 system. *Representative extracted ion chromatograms (XICs) of 3-hydroxycarbofuran in the blank orange juice (left panels), orange juice post-spiked (middle panels) at the same concentration as the in-vial lower limit of quantitation (LLOQ) of 50 ng/L in solvent (right panels), are shown on the SCIEX 7500 system (top) and the SCIEX 7500+ system (bottom). The sensitivity of both instruments enabled the use of solvent-*

based calibration and a small injection volume of 1 µL, which, in turn, reduced the matrix effects to <10 % as demonstrated by the similar peak areas between the post-spiked matrix and solvent standard. Image Credit: SCIEX

Key benefits of pesticides quantitation on the SCIEX 7500+ system

- **Easy method transfer and comparable quantitative performance:** Both the SCIEX 7500 and SCIEX 7500+ systems achieved equivalent lower limits of quantitation (LLOQ) values (mid ppt to high ppb) using the identical instrument and compound parameters.
- **Rapid sample preparation and low matrix load:** The sensitivity of both systems allowed for quick dilution and 1 µL injection volumes, reducing matrix effects and the requirement for substantial sample cleanup.
- **User accessibility to front-end cleaning:** Routine maintenance, including self-directed removal and cleaning of the DJet+ assembly, contributes to the robustness of the SCIEX 7500+ system.

Introduction

The analysis of pesticides in food and beverage matrices is critical for food safety. The European Commission has established maximum residual limits (MRLs) for pesticide residues in food and animal feed.

As a result, much effort is dedicated into quantitative investigation of these molecules. High-performance liquid chromatography-mass spectrometry (LC-MS/MS) is a potent analytical technology used for pesticide residue monitoring in food due to its excellent sensitivity and specificity.

Detection of pesticide residues is difficult due to pesticide chemistry and occurrence diversity, as well as the complexity of food matrices. Given that many pesticides have EU MRLs in the sub-to-low parts per billion (ppb) range[2], equipment resilience is critical for preserving assay sensitivity and analytical productivity.

The SCIEX 7500+ system incorporates Mass Guard technology[1] to enhance robustness while preserving the high sensitivity of the SCIEX 7500 system. These dedicated hardware components reduce instrument contamination and improve access to the front-end DJet+ assembly, making cleaning easier and more efficient.[3]

The SCIEX 7500 and SCIEX 7500+ systems had comparable sensitivity (S/N within ±20%) and

similar LLOQ values (mid-ppt to high-ppb) for the pesticides studied.

In both systems, more than 90% of the pesticides had LLOQs lower than the universal default MRL of 0.01 mg/kg, which is given for most pesticides.[3]

Methods

The same LC conditions and MS parameters were applied to both the SCIEX 7500+ and SCIEX 7500 systems. The same samples were used for analysis across both platforms.

Samples and reagents: The iDQuant standards kit[4], which contains over 200 pesticides, was utilized to create solvent calibration standards and matrix spikes in orange juice. A series of mixed stock standard solutions (1-1000 ng/mL) was produced in acetonitrile and kept at -20 °C until analysis.

An aqueous-based calibration curve (10-50,000 ng/L) was created in MilliQ water for LC-MS/MS analysis. Orange juice was purchased from a nearby supermarket and refrigerated at -20 °C until analysis.

Sample preparation: After thawing, a typical 50 mL aliquot of orange juice was centrifuged at 4000 rpm for 5 minutes to settle the pulp. A 1 mL aliquot of supernatant was diluted with 9 mL of water and filtered through a 0.45 µm syringe filter (VWR International) for matrix post-spikes.

The final spiking quantities in the extract ranged from 50 to 5000 ng/L, which corresponds to 5 to 500 ng/L based on a 10x dilution during sample preparation. The final extracts were put straight into the LC-MS/MS analysis.

Chromatography: Chromatographic separation was done on a Shimadzu Prominence LC20 system with a Phenomenex Kinetex Biphenyl column (2.1 x 50 mm, 2.6 µm, 100 A, P/N 00B-4622-AN). A flow rate of 0.4 mL/min, injection volume of 1 µL, and column temperature of 40 °C were utilized. Table 1 shows the LC gradient used.

Table 1. LC gradient. Source: SCIEX

Time (min)	Mobile phase A (%)	Mobile phase B (%)
0.00	100	0
1.00	100	0
15.00	0	100
18.00	0	100
18.05	100	0
20.00	100	0

Mobile phase A: 90:10 (v/v) water:methanol with 5mM ammonium formate
Mobile phase B: 90:10 (v/v) methanol:water with 5mM ammonium formate

Mass spectrometry: Analysis was carried out utilizing scheduled multiple reaction monitoring (sMRM) with polarity switching on both systems. Table 2 displays the source and gas characteristics used in both systems.

Table 2. Source and gas parameters. Source: SCIEX

Parameter	Value
Polarity	Positive and negative
Ion source gas 1	40 psi
Ion source gas 2	70 psi
Curtain gas	40 psi
Source temperature	300°C
Ion spray voltage	1800 V (+), -2000 V (-)
CAD gas	9

The analyte panel had 410 positive and 48 negative transitions that were monitored with a 5 ms pause and 15 ms settling time. Optimized MRM transitions were employed.

Figure 2 shows the sMRM summary plot of retention times (RTs), allowing the user to visually determine if the cycle time or dwell durations required adjustment based on the MRM concurrency.

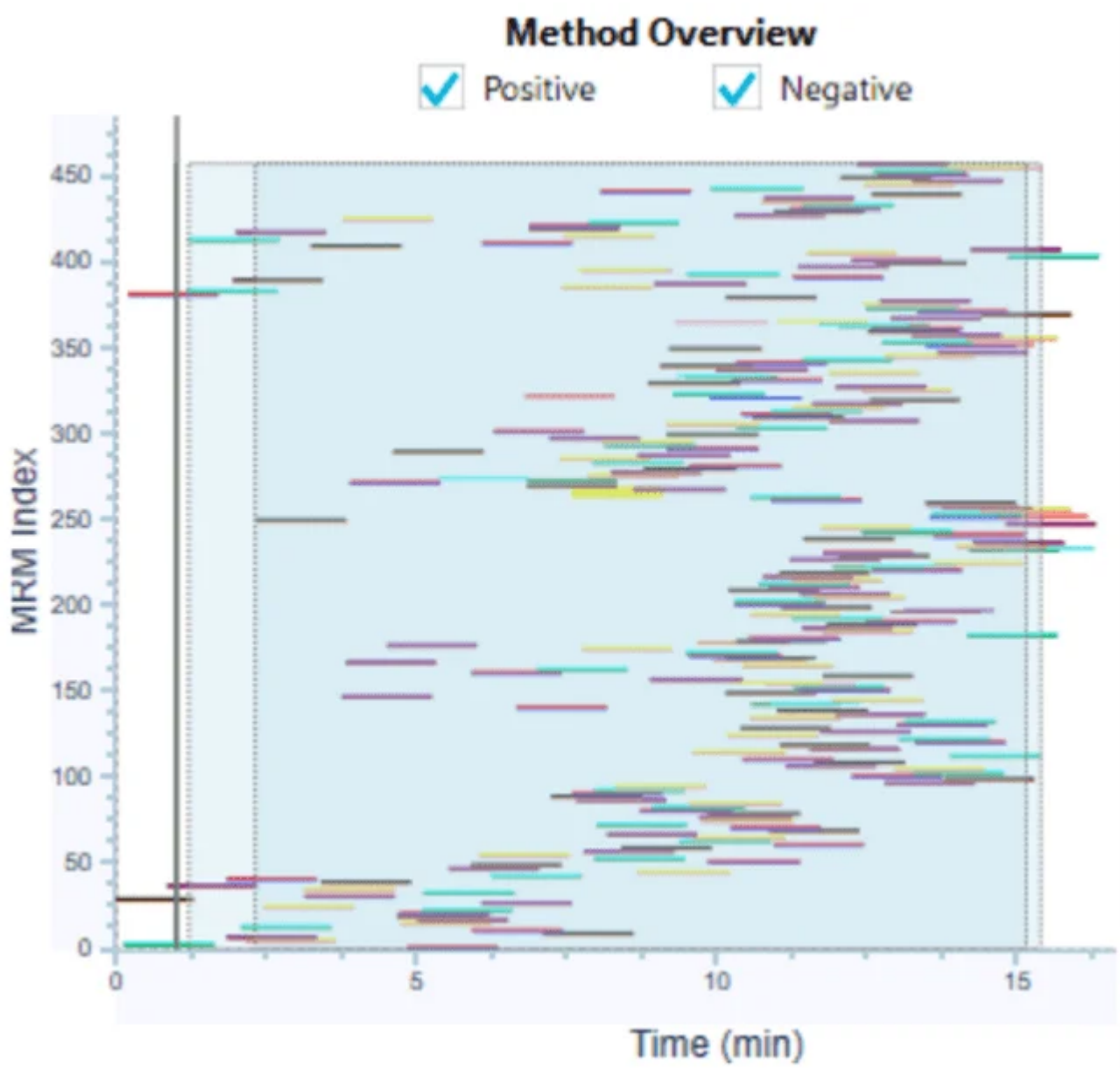


Figure 2. sMRM summary plot of the RT distribution of analytes. *The coloured bars represent the individual RT window of each MRM transition monitored in the method. Image Credit: SCIEX*

Data processing: Data collection and processing were carried out using SCIEX OS software versions 3.3.1 and 3.4.0. Peaks were automatically merged using the MQ4 algorithm, and quantification was done with a weighting of 1/x.

Quantitative performance of the SCIEX 7500+ system and 7500 system

On the SCIEX 7500 and SCIEX 7500+ systems, the target pesticides panel was measured using a solvent-based calibration curve that covered at least 3 orders of magnitude and had r^2 values greater than 0.99 for the majority of analytes.

To demonstrate the ease of method transfer and to produce a normalized instrument comparison, the identical instrument and compound parameter settings were used on both systems, and all experiments were performed using the same HPLC system.

The converter tool in SCIEX OS software enabled a seamless transfer of method settings, ensuring that the same acquisition methods were employed on both platforms (Figure 3).

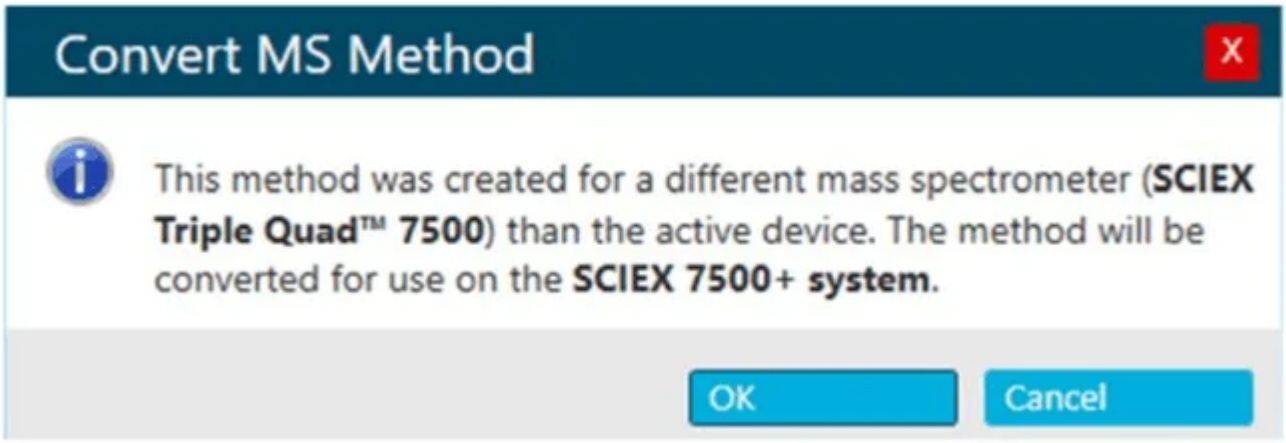
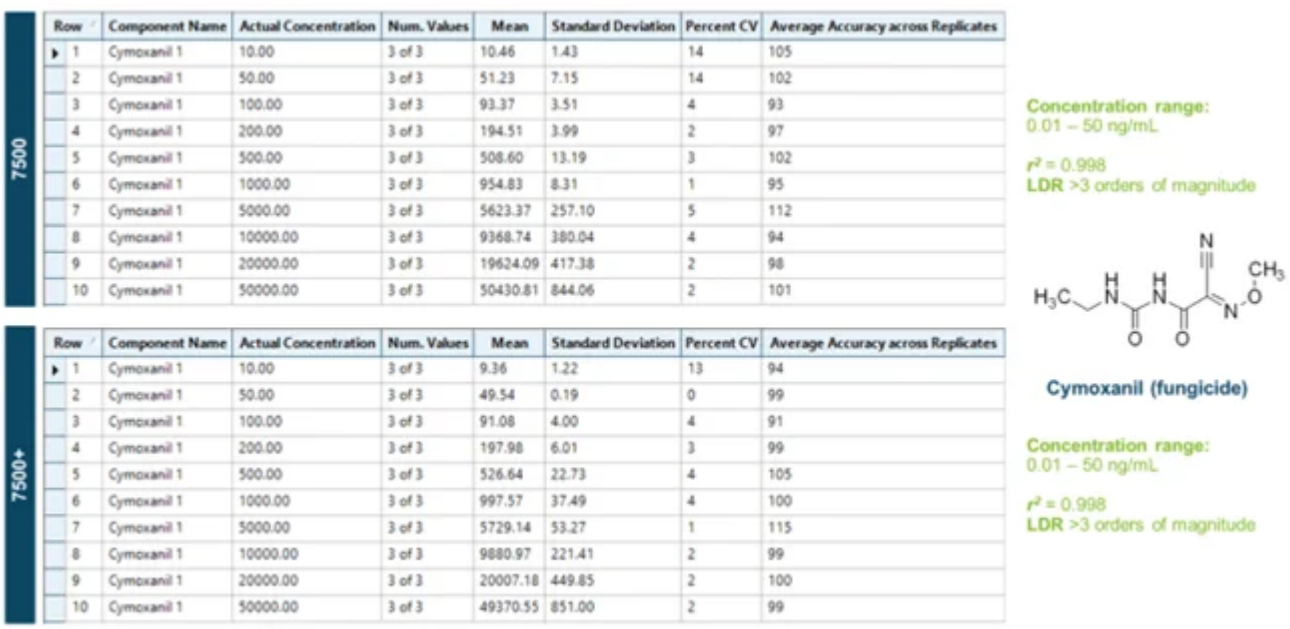


Figure 3. Method conversion in SCIEX OS software. *Method conversion between different LC-MS/MS systems is enabled for all instrument models supported by the software. Image Credit: SCIEX*

Figure 4 illustrates the sensitivity of both systems by directly comparing the quantitative results for a representative example pesticide, cymoxanil. The statistics windows generated by SCIEX OS software display the mean concentration, standard deviation, precision (%CV), and average accuracy (%) determined from triple injections of the solvent-based calibration curve on the two systems.

The linear performance of each system, as measured by the r^2 value and linear dynamic range (LDR), is shown on the right side of the statistics panel. For cymoxanil, both systems obtained an accuracy range of 91-115 % and precision of <15 % CV, with an r^2 value of 0.998.

Most analytes had acceptable accuracies within ±30 % and %CV <25 % at the LLOQs, whereas accuracies within ±20 % and %CV <15 % were frequently reached at all other calibration levels.



7500

Row	Component Name	Actual Concentration	Num. Values	Mean	Standard Deviation	Percent CV	Average Accuracy across Replicates
1	Cymoxanil 1	10.00	3 of 3	10.46	1.43	14	105
2	Cymoxanil 1	50.00	3 of 3	51.23	7.15	14	102
3	Cymoxanil 1	100.00	3 of 3	93.37	3.51	4	93
4	Cymoxanil 1	200.00	3 of 3	194.51	3.99	2	97
5	Cymoxanil 1	500.00	3 of 3	508.60	13.19	3	102
6	Cymoxanil 1	1000.00	3 of 3	954.83	8.31	1	95
7	Cymoxanil 1	5000.00	3 of 3	5623.37	257.10	5	112
8	Cymoxanil 1	10000.00	3 of 3	9368.74	380.04	4	94
9	Cymoxanil 1	20000.00	3 of 3	19624.09	417.38	2	98
10	Cymoxanil 1	50000.00	3 of 3	50430.81	844.06	2	101

Concentration range:
0.01 – 50 ng/mL

r^2 = 0.998
LDR >3 orders of magnitude

7500+

Row	Component Name	Actual Concentration	Num. Values	Mean	Standard Deviation	Percent CV	Average Accuracy across Replicates
1	Cymoxanil 1	10.00	3 of 3	9.36	1.22	13	94
2	Cymoxanil 1	50.00	3 of 3	49.54	0.19	0	99
3	Cymoxanil 1	100.00	3 of 3	91.08	4.00	4	91
4	Cymoxanil 1	200.00	3 of 3	197.98	6.01	3	99
5	Cymoxanil 1	500.00	3 of 3	526.64	22.73	4	105
6	Cymoxanil 1	1000.00	3 of 3	997.57	37.49	4	100
7	Cymoxanil 1	5000.00	3 of 3	5729.14	53.27	1	115
8	Cymoxanil 1	10000.00	3 of 3	9880.97	221.41	2	99
9	Cymoxanil 1	20000.00	3 of 3	20007.18	449.85	2	100
10	Cymoxanil 1	50000.00	3 of 3	49370.55	851.00	2	99

Cymoxanil (fungicide)

Concentration range:
0.01 – 50 ng/mL

r^2 = 0.998
LDR >3 orders of magnitude

Figure 4. Comparison of the quantitative performance of an example fungicide, cymoxanil between the SCIEX 7500 system (top) and SCIEX 7500+ system (bottom). *Mean accuracy and precision (%CV) were calculated from triplicate injections of each concentration across the solvent-based calibration curve, as shown by the statistics panes in the Analytics module of SCIEX OS software. Image Credit: SCIEX*

Figures 5A and B show pesticide measurements in the solvent and orange juice matrix. Figure 5A shows sample XICs of an example herbicide, diuron, in the solvent blank, solvent standards at the LLOQ of 10 ng/L and 100 ng/L, and orange juice post-spiked at 100 ng/L acquired in positive ion mode using the two systems.

Except for the solvent blank, which displays no apparent peak for diuron, all peaks exhibited S/N values greater than 10, indicating that they exceeded the instrumental LOQs for this compound. Figure 5B shows another sample set of XICs for the pesticide fipronil, obtained in negative ion mode.

As with the diuron data, the S/N ratio values are >10 for all concentrations examined, and the results were consistent across both instruments. In addition, Figures 5A and B show similar peak regions for the 100 ng/L solvent standard and the orange juice matrix post-spiked at the same concentration.

The matrix effects of diuron and fipronil on both systems were <10 %, as calculated by dividing the peak areas in the post-spiked matrix by the solvent standard.

The sensitivity of the SCIEX 7500 and SCIEX 7500+ systems allowed for rapid sample preparation and 1 µL injections, which helped reduce matrix effects and simplified

quantification through solvent-based calibration.

The insets of figure 6 show another measure of instrument equivalency: the distribution of normalized S/N ratios for 205 pesticides (500 ng/L) detected on the two systems. Each pesticide was measured in triplicate on both equipment, and the S/N ratio was computed using SCIEX OS software.

These values were then normalized by dividing the S/N value computed using the SCIEX 7500+ system by the S/N value obtained using the SCIEX 7500 system. A value of 1.0 represents equal S/N values for each instrument.

The majority of pesticides have S/N ratios within 20 % of each other, as shown by the green lines representing the mean ± 20 %.

The insets of Figure 6 displays a histogram of the same distribution, with the green shaded area indicating the ±20 % range. These data reveal that the results obtained with both equipment have identical S/N ratios, supporting the conclusion that both methods have equal sensitivity for measuring pesticides.

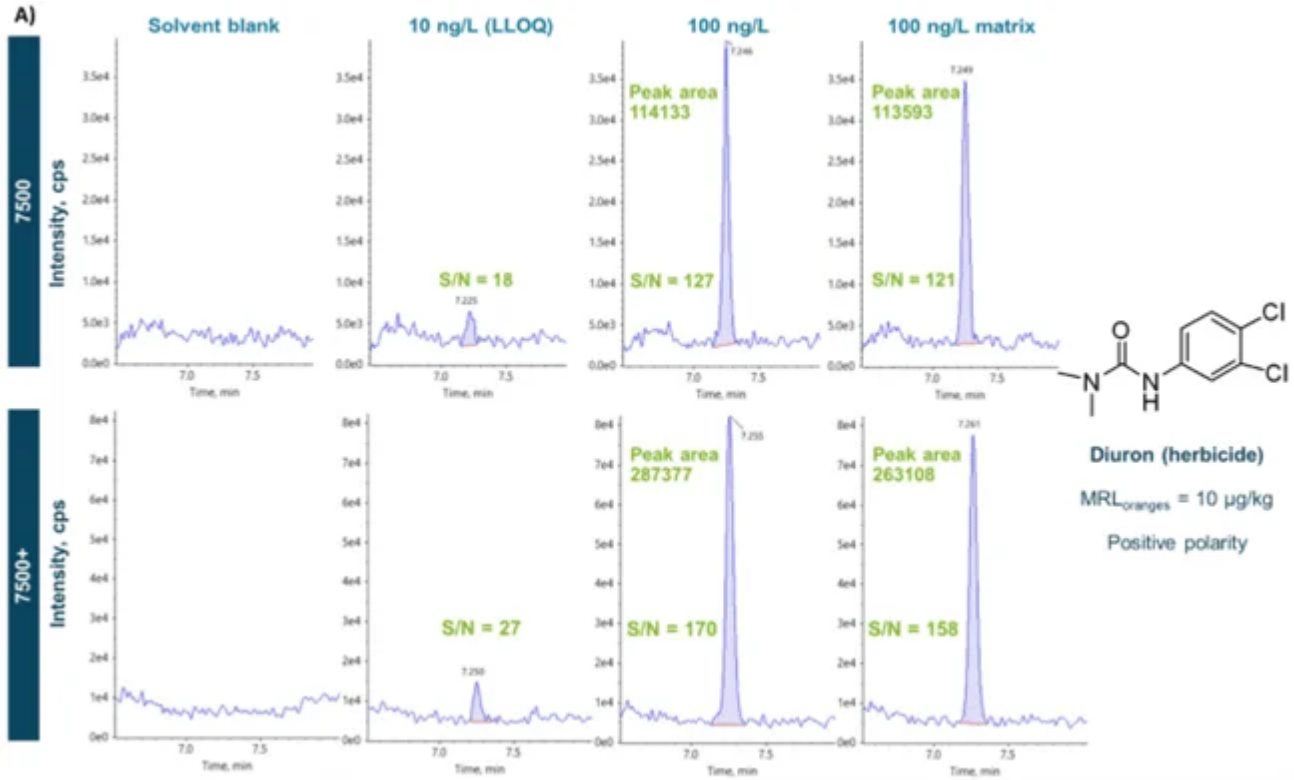


Figure 5a. Representative XICs of an example herbicide, diuron, in the solvent blank, in solvent standards at the LLOQ of 10 ng/L and 100 ng/L and in orange juice post-spiked at 100 ng/L acquired in positive polarity using the SCIEX 7500 system (top) and SCIEX 7500+ system (bottom). *Image Credit: SCIEX*

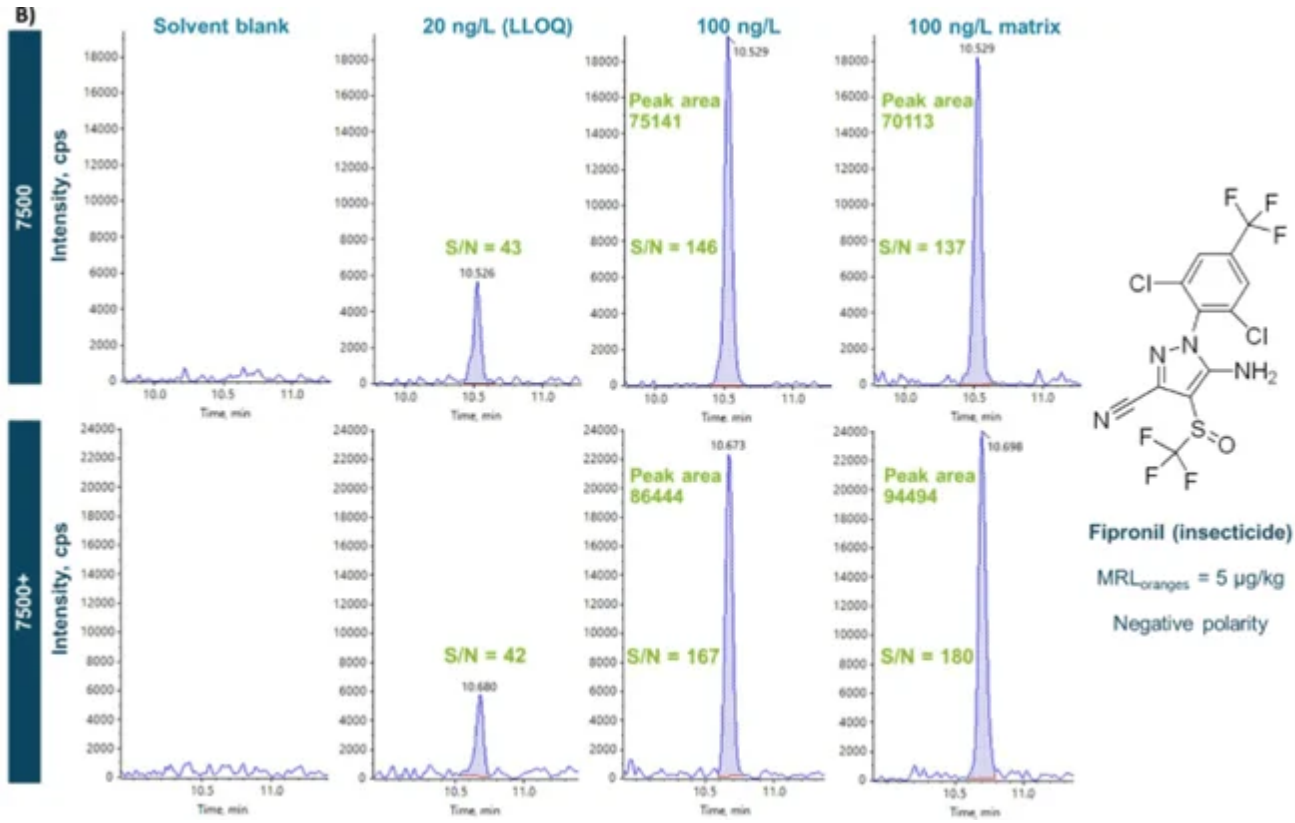


Figure 5b. Representative XICs of an example insecticide, fipronil, in the solvent blank, in solvent standards at the LLOQ of 20 ng/L and 100 ng/L and in orange juice post-spiked at 100 ng/L acquired in negative polarity using the SCIEX 7500 system (top) and SCIEX 7500+ system (bottom). *Image Credit: SCIEX*

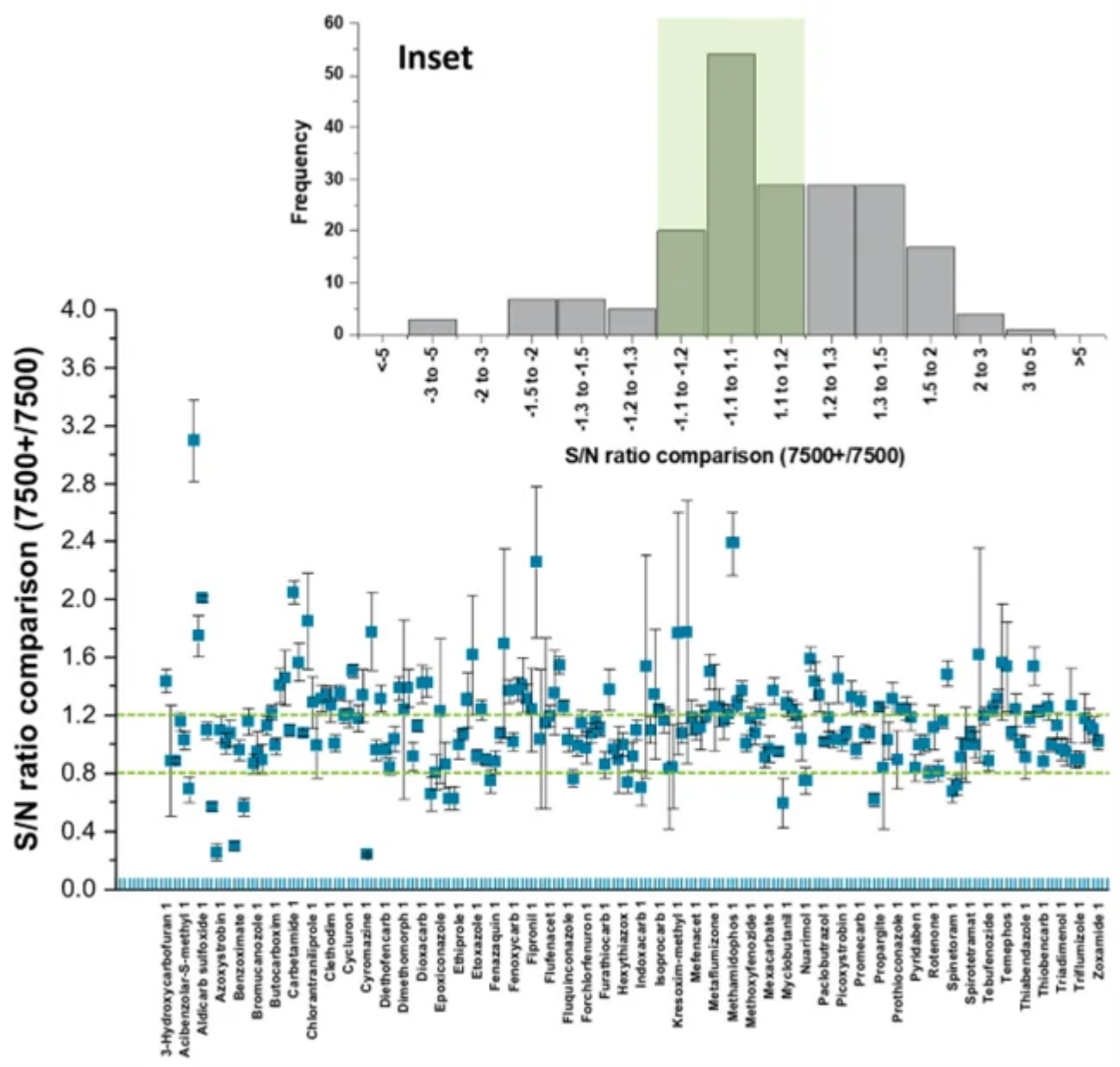


Figure 6. Comparison of signal-to-noise (S/N) ratios for 205 pesticides (a subset of the total panel) between the SCIEX 7500+ system and SCIEX 7500 system. *Each data point represents the average S/N and its associated standard error calculated from triplicate injections of a 500 ng/L mixed pesticides standard in solvent. The green dotted lines highlight the compounds with S/N within ±20 % between both systems.* ***Inset: Frequency distribution of S/N comparison between the SCIEX 7500+ system and SCIEX 7500 system.*** *Most of the pesticides demonstrated a S/N ratio difference in the range of -1.2 to 1.5 between the SCIEX 7500+ and SCIEX 7500 systems. Image Credit: SCIEX*

Figures 4-6 provide representative examples from the broad pesticide cohort examined.

Figure 7 (below) provides a visual representation of the whole sample set of analytes by overlaying the distribution of LOQ values from data collected on the SCIEX 7500 system (top,

blue) and the SCIEX 7500+ system (bottom, green).

The LOQ values span from low ppt to high ppb, and the distributions are nearly identical for both instruments.

More than 90 % of pesticides evaluated on both systems exhibited LOQ values below the average MRL value of 10 µg/kg for most pesticides in the raw orange commodity, as indicated by the vertical red dotted line in Figure 7.

The sensitivity of the SCIEX 7500 and SCIEX 7500+ systems allowed for the quick quantification of more than 200 pesticides in orange juice via direct injection without the need for substantial sample preparation.

The dilute-and-shoot strategy reduced matrix load in both systems, reducing matrix effects and allowing for quantification using solvent-based standards.

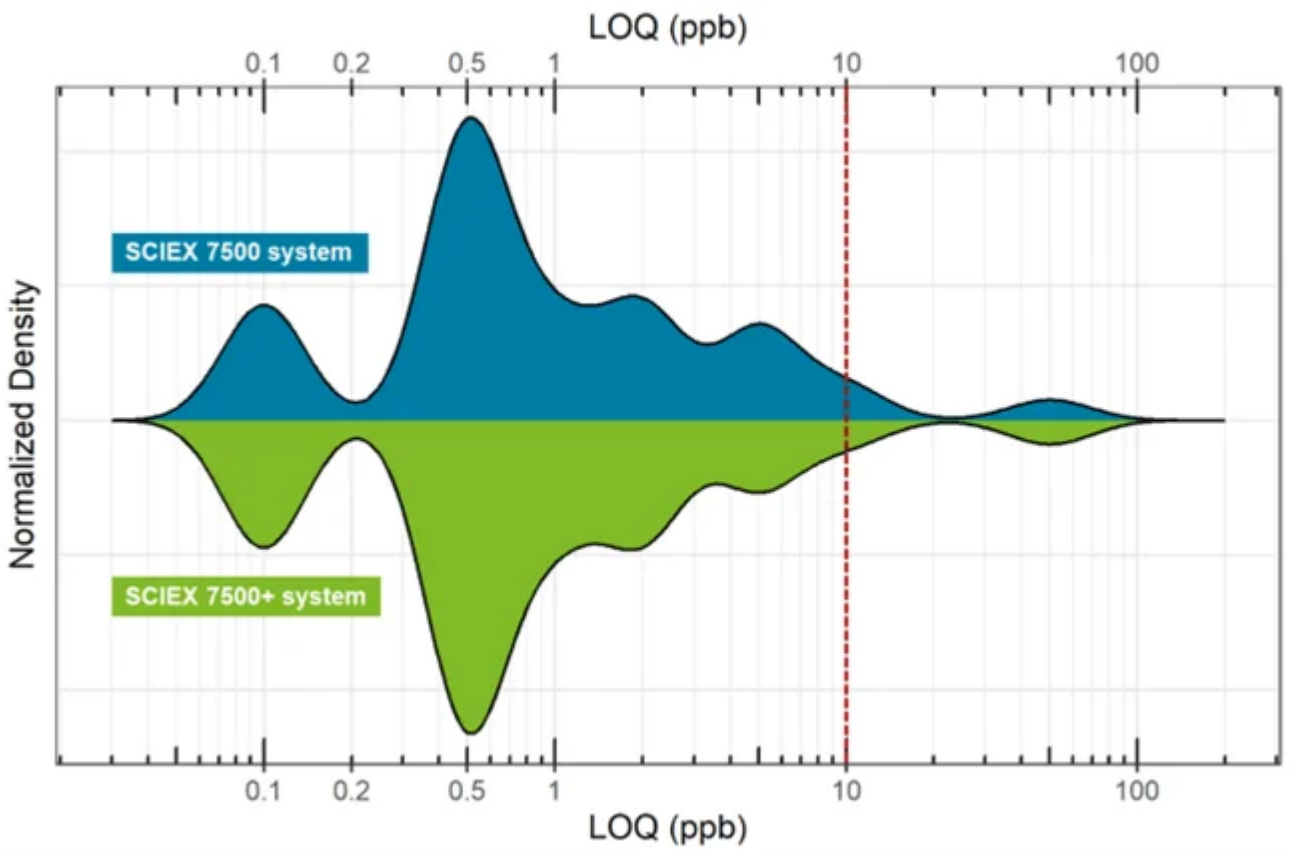


Figure 7. Overlaid comparison of the LOQ distribution achieved on the SCIEX 7500 system (top, blue) and the SCIEX 7500+ system (bottom, green). *The in-vial LOQs ranged from 0.01 to 5 ng/mL based on the lowest calibration level meeting the acceptance criteria of accuracy (±30 %) and precision (%CV <20 %). Expressed on a per mass basis using the orange juice density of 1.038 g/mL and a 10x dilution of the juice during sample preparation, the LOQs were converted to be in the range of 0.1 to 50 µg/kg (ppb). In both systems, >90 % of the pesticides demonstrated LOQs*

below the typical MRL of 10 µg/kg (red dotted line) specified for most pesticides. Image Credit: SCIEX

Conclusion

- The SCIEX 7500+ system achieved equivalent or lower LOQ values for 90% of pesticides measured as compared to the SCIEX 7500 system.
- The S/N calculations for pesticides were similar, if slightly higher, on the SCIEX 7500+ system as compared to the SCIEX 7500 system.
- User access to the DJet+ assembly allows for convenient front-end cleaning and system uptime for routine analysis.

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Acknowledgments

This article was produced using materials originally authored by Holly Lee[1], Michael Deng[1], Craig M. Butt[2], Paul R.S. Baker[2], and Craig M. Butt[2]

[1] *SCIEX, Canada*
[2] *SCIEX, USA*

About SCIEX

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SCIEX has led the field of mass spectrometry for 50 years. From the moment we launched the first ever commercially successful triple quad in 1981, we have developed groundbreaking technologies and solutions that ensure global food safety today.

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The Future of Multiplex Nanosensors in Food Safety

In a recent review article published in *Small*, researchers emphasized the critical need for rapid, cost-effective, and highly specific nanosensors-based detection methods to ensure food safety in an increasingly complex global food supply chain.

Image Credit: KYTan/Shutterstock.com

Background

The review outlines recent technical advances that make multiplex detection more practical and powerful. By integrating nanomaterials with bioreceptors such as aptamers, antibodies, and molecularly imprinted polymers, researchers are enabling simultaneous detection of a wide range of contaminants, from heavy metals and pesticides to bacteria and toxins.

These nanosensors often incorporate innovative signal readouts—optical, electrochemical, or colorimetric—that support real-time or near-real-time detection.

The review also highlights the crucial role of computational tools, particularly machine learning, in interpreting complex sensor data. These algorithms can recognize signal patterns, identify contamination fingerprints, and boost detection specificity, helping to translate raw data into actionable insights. This kind of integration is key to bridging the gap between lab-based research and practical, field-ready food safety solutions.

Recent Developments in Multiplex Nanosensors

Several recent studies featured in the review demonstrate how nanosensor design is evolving. One prominent approach involves using nanostructured materials, such as magnetic nanoparticles, quantum dots, and plasmonic nanostructures, to build highly sensitive and selective detection platforms. These materials can be functionalized with specific recognition elements to target multiple contaminants at once, often achieving strong signal-to-noise ratios.

Some researchers are developing nanosensor arrays inspired by electronic noses and tongues, capable of identifying multiple chemical residues or microbial contaminants with minimal sample preparation. One standout example is a paper-based dye array system paired with machine learning algorithms, which can detect viable pathogens like E. coli directly in food samples, cutting detection time from days to just a few hours.

The review also covers advancements in optical sensing techniques, including surface plasmon resonance (SPR), fluorescence, and colorimetric assays. These offer multiplexed detection that is either visually intuitive or instrument-readable. For instance, fluorescent nanoparticle-based biosensors have been developed to detect multiple heavy metals in parallel, providing rapid and easy-to-interpret results.

On the electrochemical side, nanosensors capable of measuring a variety of toxins or pesticides have shown impressive selectivity, even in complex sample environments. Advanced data analytics, such as pattern recognition and neural networks, are increasingly

used to handle the large datasets these sensors generate. These tools improve detection accuracy and support the identification of both known and emerging contaminants.

Another major focus is the integration of nanosensors with digital infrastructure, such as the Internet of Things (IoT) and blockchain. This connectivity enables real-time data transmission and traceability throughout the food supply chain, from production to consumption. The review describes several prototypes that combine nanosensors with IoT platforms to send immediate alerts about contamination events, allowing for quicker responses and reduced risk.

Some multifunctional sensors are now being developed to assess not only safety indicators like contamination but also food quality metrics such as freshness and nutritional content. These capabilities are especially relevant in building a more transparent, consumer-focused food system.

Discussion

While the field has seen impressive progress, the review notes several challenges that still need to be addressed before widespread adoption is feasible. These include variability in nanomaterial synthesis, instability of biological recognition elements, and the potential for signal interference in complex food matrices.

The authors emphasize that sophisticated data processing, especially through machine learning, is essential for making sense of increasingly complex sensor outputs and ensuring reliability across diverse conditions.

There's also growing interest in decentralized monitoring systems, powered by IoT-connected nanosensors. These systems could dramatically shorten detection times, improve transparency, and enable smarter food safety management throughout the supply chain. Still, the authors point to the need for standardized testing protocols, clearer regulatory pathways, and scalable manufacturing solutions to support commercialization.

Importantly, multifunctional sensors—those that can detect contaminants while also assessing quality and nutritional indicators—are seen as key tools for promoting sustainability and consumer trust.

Journal Reference

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Automation in Nutritional Testing: How Technology is Improving Accuracy, Efficiency, and Compliance

The food industry is under pressure to do more, and do it better. From food safety and labeling to traceability and compliance, there's a growing need for smarter, faster ways to get things done. Nutritional content testing, a critical part of quality control and product labeling, is one area where automation is starting to make a big difference.

Image Credit: Paula Cobleigh/Shutterstock.com

Manual testing methods are slow and prone to error. But now, with tools powered by Artificial Intelligence (AI), robotics, and connected software, labs can test for nutrients, allergens, and contaminants with more speed and consistency.

Let's look into how automation is really reshaping food testing - from the tech behind it to real-world use cases.

Key Technologies Behind the Shift

Automation isn't about replacing lab staff - it's about making routine processes faster, more accurate, and easier to scale. A mix of advanced tools is making all of that possible.

AI and Machine Learning (ML)

AI and ML arguably form the backbone of modern automated nutrient analysis.

AI models are getting really good at analyzing food data. Convolutional Neural Networks (CNNs), for instance, can classify food images, spot contaminants, and estimate serving sizes. Pre-trained models like ResNet or EfficientNet, trained on food-specific datasets, are already being used to recognize different cuisines or flag issues in low-sodium labeling.

Transfer learning helps these systems adapt to niche tasks - like detecting spoilage or verifying label claims. Reinforcement learning fine-tunes the testing process by adjusting conditions (like reagent amounts or incubation times) based on what's happening in real time.[1,2]

Spectroscopy and Hyperspectral Imaging

For quick, non-destructive testing, NIR (near-infrared) and hyperspectral imaging tools are increasingly being used to measure things like moisture, fat, and protein levels.

A good example is PerkinElmer's in-line NIR systems in dairy processing. They continuously monitor product quality without slowing down the line. Hyperspectral cameras, combined with machine learning, can also detect nutrient shortfalls in crops or spot allergens in finished goods. These systems are fast, reliable, and more accurate than manual testing and are especially useful for plant-based foods where maintaining consistent protein levels is vital for gaining consumer trust.[1,3]

Chromatography and Mass Spectrometry

Nutrient and contaminant testing is also getting faster thanks to automated chromatography and mass spectrometry setups. Liquid chromatography (LC) and mass spectrometry (MS) systems now use robotic sample prep to limit human handling and reduce contamination risks.

These methods are used to find pesticide residues in grains or verify omega-3 levels in drinks - helping food producers stay compliant with the United States Food and Drug Administration (FDA) and European Union (EU) regulations. They also help confirm clean-label claims, like "no artificial preservatives."[1,4]

Robotics and Lab Management Software

Many tasks in food testing labs are repetitive, time-consuming, and sensitive to human error. Robotics and automation software are now handling these processes more efficiently. Robotic arms are used to perform routine tasks like pipetting, diluting samples, and adjusting pH levels with high precision.

These systems are often integrated with Laboratory Information Management Systems (LIMS), which organize testing schedules, track samples throughout the process, and generate audit-ready reports. This setup not only speeds up workflows but also helps labs catch issues early. For example, if histamine levels in seafood samples are too high, the system can flag the issue before products leave the facility.[3,4] This kind of integration helps labs handle large volumes of tests without compromising precision.

Where Automation is Being Used

Automation in nutritional testing isn't limited to one corner of the food system. It's touching nearly every point in the supply chain - from how ingredients are analyzed in labs to how crops are monitored in the field. As these technologies mature, they're not just speeding things up - they're shifting how decisions are made, how risk is managed, and how value is created.

1. Smarter Nutrient Analysis

AI-powered platforms are changing how nutrition data is interpreted. These systems go beyond static label creation - they pull from multiple data streams (like imaging, chromatography, and historical batch data) to identify patterns, anomalies, and even potential regulatory red flags.

In high-throughput environments, this means teams can flag inconsistencies before a product reaches packaging. In smaller operations, it means faster turnaround without sacrificing accuracy.[5,6]

The consumer side is evolving too. Personalized nutrition platforms, like Spoon Guru, now use small language models to scan ingredient data and tailor food recommendations to specific health needs. This bridges lab testing and end-user dietary compliance - something that used to exist in two entirely separate spheres. In early studies, these tools have significantly improved adherence to dietary plans, showing the potential for AI to drive not just efficiency but health outcomes.[5,6]

2. Allergen Detection and Batch Traceability

Automated allergen detection is solving a long-standing industry challenge in terms of being able to identify contamination in real-time without disrupting production flow. Traditional batch testing required pulling samples and waiting on lab results. Today's hyperspectral imaging systems and machine vision can scan product lines continuously, detecting allergens like peanuts or gluten based on spectral signatures or trace particles.

What's particularly notable is how these tools intersect with traceability tech like blockchain. Once an anomaly is detected, it can be tied to a specific batch, location, or ingredient shipment. This provides a level of forensic traceability that not only helps with recall management but can also inform supplier relationships and contract terms.[3,5]

This isn't just about safety - it's about accountability and data transparency, which are becoming competitive differentiators in food manufacturing.

3. Precision Agriculture

Upstream, automation is transforming the way nutrients are managed in agriculture. Drones, satellites, and AI models are being used to assess plant health and soil composition, identifying nutrient imbalances that aren't visible to the naked eye.

Instead of applying fertilizer evenly across a field, farmers can now target specific sections that are low in nitrogen or potassium. That improves yield quality and reduces excess runoff - an environmental issue that's increasingly under regulatory scrutiny.

What's interesting here is the link between farm-level data and food processing outcomes. As traceability expands, the ability to connect soil nutrient levels to end-product composition (e.g., protein levels in plant-based foods) becomes more realistic. This could redefine quality assurance standards and open up new ways of certifying food origin and nutritional integrity.[1]

4. Real-Time Quality Control

In processing facilities, automation is allowing for a shift from reactive to proactive quality control. With sensors embedded in production lines, changes in nutrient content - like moisture loss during drying or fat content during frying - can be monitored continuously.

Instead of running tests after the batch is complete, adjustments happen in real time. This not only prevents waste and ensures consistency, but it also opens the door for iterative product development. Teams can test minor changes in formulation or cooking parameters with immediate feedback, shortening R&D cycles and reducing the risk of quality failures.[7]

It's a quiet shift, but an important one, as labs are no longer just quality checkpoints - they're becoming strategic inputs into innovation and product differentiation.

5. Smarter Supply Chains

Automation is also improving how food moves through the system, especially in areas that have historically struggled with visibility and timing. Robotic process automation (RPA) and predictive inventory systems are now being used to balance stock levels, anticipate demand surges, and trigger restocks before shortages occur.

In cold chain environments, autonomous vehicles and smart sensors are ensuring that perishable goods are stored and shipped under optimal conditions. Real-time temperature tracking isn't new - but what's changing is how that data is now connected directly to QA systems, flagging shipments that may have been compromised before they even reach the

loading dock.

The result is a supply chain that's not just more efficient, but also more responsive and self-correcting. This reduces waste, cuts operational risk, and helps companies meet increasingly strict sustainability targets.[8]

Real-World Case Studies

The impact of automation isn't hypothetical - it's already happening:

- **BioSystems Y15**: By automating lactose testing, a dairy producer cut testing time by 70 %, reducing label errors and avoiding penalties. This also freed up staff to focus on higher-level QC tasks.[9]

- **PerkinElmer NIR**: A cereal company used NIR tools to monitor protein and fiber content in real time. This reduced ingredient waste by 15 % and helped maintain consistency for health-conscious consumers.[10]

- **Food Lab, Inc.**: Using AI-driven labeling software, Food Lab produces FDA-compliant nutrition labels in less than 24 hours. This has streamlined client timelines and improved accuracy in allergen and calorie declarations.[11]

What connects all of these examples isn't just automation - it's integration. The value comes from connecting data sources, automating decisions, and closing the loop between testing, production, and labeling.

Challenges and What's Next

Automation's progress hasn't been without roadblocks. One of the biggest challenges is dataset diversity. Many AI models have been trained on limited food types - mostly Western, highly structured products. Mixed dishes, regional ingredients, or variable formats (like stews or sauces) often fall outside their effective range.

Small and mid-sized labs also face financial and staffing barriers. Equipment costs can be high, and training personnel to manage and maintain these systems takes time. Legacy infrastructure also adds complexity, especially when trying to retrofit older systems with modern tools.

There's also the issue of regulatory fragmentation. Nutritional claims that pass in one country

might not in another. For example, what qualifies as "low fat" can differ by up to 20 % between the U.S. and EU.[1,2,6] That complicates automation workflows built around fixed compliance rules.

Looking ahead, several trends could ease these barriers. Portable NIR devices and app-based soil testing are already making advanced analysis more accessible to small producers. Predictive models are being used to forecast nutrient degradation, helping teams set dynamic expiration dates tied to temperature and humidity conditions.

Quantum computing may eventually play a role, especially in reducing the processing time of complex spectral data. But in the near term, collaboration will matter more - between AI engineers, nutrition scientists, and policy experts - to build more inclusive, adaptable systems that work across food types, regions, and testing environments.[1,3,5]

Final Take

Automation in nutritional testing is no longer about optimizing isolated tasks. It's becoming a connective layer across the entire food system - linking the farm to the lab to the consumer. Whether it's improving nutrient precision, detecting allergens, or keeping supply chains aligned, the shift toward smarter, more integrated systems is already underway.

As these tools continue to evolve and scale, they're not just helping food companies work faster, they're helping them work smarter, with better data and more confidence in every decision.

Want to Learn More?

If you're looking to build on these ideas or explore related topics, here are a few areas worth digging into next:

- **AI-Based Analysis in Food Safety Strategies**
- **The Role of AI and Robotics in Beverage Quality Control**
- **How Can Blockchain Technology Make Supply Chains More Sustainable?**
- **A Guide to Fertilizer Quality and Nutrient Analysis**
- **Digital solutions to reduce the food waste in stores**

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The science behind rapid MRM: detecting food contaminants faster than ever

This article describes the analysis of an LC-MS/MS method for over 600 pesticides and mycotoxins in a single injection using a rapid MRM acquisition rate approach on the SCIEX 7500+ system.

Good data quality was demonstrated with an MRM acquisition rate as low as 3 ms (1 ms dwell time and 2 ms pause time) while preserving instrument sensitivity, accuracy, and precision. In the solvent-based calibration standards, the majority of the analytes (89%) had limits of quantification (LOQ) of 1 ng/mL.

Figure 1 displays extracted ion chromatograms (XICs) for three pesticides at 1 µg/kg in soybean extract, indicating high sensitivity even at trace levels.

The SCIEX 7500+ system includes the new Mass Guard technology, which is intended to boost instrument robustness while maintaining optimal sensitivity, as well as the user-accessible DJet+ assembly, which provides cleaning flexibility[1].

Overlaid XICs of 3 compounds at 1 µg/kg, acquired with a 1 ms dwell, 2 ms pause and 5 ms settling time in soybean extract. The images show overlaid quantifier and qualifier transitions for fenoprop, azoxystrobin and saflufenacil with ion ratio lines highlighting where the qualifier peak should sit to be within ±30 % ion ratio tolerance

Figure 1. Overlaid XICs of 3 compounds at 1 µg/kg, acquired with a 1 ms dwell, 2 ms pause and 5 ms settling time in soybean extract. *The images show overlaid quantifier and qualifier transitions for fenoprop, azoxystrobin and saflufenacil with ion ratio lines highlighting where the qualifier peak should sit to be within ±30 % ion ratio tolerance. Image Credit: SCIEX*

Key benefits of the SCIEX 7500+ system for large panel contaminant analysis

- **Fast MRM scan rate:** A fast MRM scan rate of 3 ms (dwell and pause time) without compromising analytical performance. This allows for more compounds to be analyzed in a single injection while maintaining ion ratio stability.
- **Continued high-end performance:** Pesticides with an in-vial solvent LOQ of 1 ng/mL and injection volume of 1 µL demonstrated consistent high-end performance, resulting in decreased matrix effects.

- **Positive and negative polarity switching:** High-end performance was maintained with 5 ms settling time for both positive and negative polarity switching.
- **Enhanced robustness and usability:** Mass Guard technology extends instrument robustness and a DJet+ assembly to provide greater flexibility for user cleaning as necessary.

Introduction

Detecting pesticides in food is crucial for human health. The European Union (EU) regulates the presence of pesticides and mycotoxins in plant and animal-derived foods based on the maximum limits stated in regulations 396/2005 and 2023/915.[2-3]

These chemicals are commonly studied in food matrices with LC-MS/MS. However, assessing large analyte panels can be challenging depending on instrument speed - insufficient speed makes it difficult to monitor numerous concurrent chemicals while maintaining data quality.

In this technical note, the improved MRM acquisition rate of the SCIEX 7500+ system - as low as 3 ms per MRM - was utilized to evaluate 560 pesticides and 43 mycotoxins, resulting in 1,462 MRM transitions in a single injection. To keep things simple, only the pesticide results will be presented in this article.

The new Mass Guard technology enhances the system's robustness, while the DJet+ assembly allows for quicker and more routine user cleaning, minimizing the need for service interventions and enhancing instrument uptime.

Methods

Standard preparation: Individual analyte stock solutions were produced at 1 mg/mL in organic solvent. Spiking solutions were created by volumetrically diluting stock solutions with methanol or acetonitrile.

Spiked sample preparation: Representative samples from several categories were selected, including foods with high oil content (avocado), low oil content (soybean), and challenging or unique commodities (tea).

The matrices examined were lemon, mango, avocado, tea, and soybean. The samples were spiked at various concentrations (1, 3, 10, and 30 ppb) and extracted with the QuEChERS CEN technique.[4] For cleanup, a Normec Groen Agro Control internal technique was used.

Chromatography: Separation was done using an ExionLC AD system from SCIEX and a Phenomenex Kinetex™ C18 (2.1 x 100 mm, 2.6 µm, 100 A) column (P/N: 00D-4462-AN).

A 28-minute gradient (including equilibration time) was utilized, with 0.1 % formic acid and 2 mM ammonium acetate in water for mobile phase A and 0.1 % formic acid and 2 mM ammonium acetate in methanol for mobile phase B (Table 1). The column temperature was kept at 50 °C with a flow rate of 0.3 mL/min and an injection volume of 1 µL.

Table 1. Chromatographic gradient for the analysis of pesticides and mycotoxins in food extracts using the SCIEX 7500+ system. Source: SCIEX

Time (min)	Mobile phase A (%)	Mobile phase B (%)
0.0	95	5
0.5	95	5
23.0	0	100
25.0	0	100
25.1	95	5
28.0	95	5

Mass spectrometry: Mass spectrometry data was collected using the SCIEX 7500+ system. The optimized source and gas parameters are shown in Table 2. The 560 pesticides and 43 mycotoxins were each subjected to optimized compound-specific MRM settings, resulting in 1,462 MRM transitions in a single injection.

Data processing: Data collection and analysis were done using SCIEX OS software 3.4.0.

Table 2. Source and gas parameters for the analysis of pesticides and mycotoxins in food extracts using the SCIEX 7500+ system. Source: SCIEX

Fast MRM acquisition rate while maintaining sensitivity

When analyzing over 600 pesticides and mycotoxins in a single injection, instrument speed is critical to data quality - the instrument must have short cycle times and enough data points

across the chromatographic peak.

The SCIEX 7500+ system can achieve dwell periods of less than 1 ms, pause times of less than 2 ms, and a settling time of 5 ms.

The practical ramifications of these fast rates include that each MRM transition requires only a 3 ms MRM acquisition rate, which, when paired with the Scheduled MRM algorithm, allows for the analysis of very large compound panels in a single injection.

To assess the MRM acquisition speed of the SCIEX 7500+ system, four alternative acquisition rates were used:

- Treatment 1: 2 ms dwell, 3 ms pause, and 15 ms settling
- Treatment 2: 2 ms dwell, 3 ms pause, and 5 ms settling
- Treatment 3: 1 ms dwell, 2 ms pause, and 5 ms settling
- Treatment 4: 1 ms dwell, 1 ms pause, and 5 ms settling

Across the entire range of pesticide analytes, the sensitivity of the SCIEX 7500+ system remained unaltered until the fastest acquisition rate (treatment 4) was utilized.

Figure 2 shows a comparison of the various rates, with butoxycarboxim as an example. The 1 ms dwell, 1 ms pause, and 5 ms settling time circumstances (treatment 4) resulted in a small (14 %) reduction in area count.

For this reason, future trials used the 1 ms dwell, 2 ms pause, and 5 ms settling time conditions (treatment 3). However, the data provided by treatment 4 may still be acceptable if the benefits of speedier acquisition outweigh the modest drop in sensitivity.

Sensitivity performance as a function of total acquisition rate for butoxycarboxim. The line graph (top) shows the peak area percent, normalized to the highest peak area, for butoxycarboxim at the 4 different acquisition rates: 2 ms dwell, 3 ms pause and 15 ms settling time (treatment 1); 2 ms dwell, 3 ms pause and 5 ms settling time (treatment 2); 1 ms dwell, 2 ms pause and 5 ms settling time (treatment 3) and 1 ms dwell, 1 ms pause and 5 ms settling time (treatment 4). The y-axis of the line graph is normalized to the area count in treatment 1. The graph shows a minimal area count decrease at the fastest acquisition rate. This trend is also shown in the XICs (bottom)

Figure 2. Sensitivity performance as a function of total acquisition rate for butoxycarboxim. *The line graph (top) shows the peak area percent, normalized to the highest peak area, for*

butoxycarboxim at the 4 different acquisition rates: 2 ms dwell, 3 ms pause and 15 ms settling time (treatment 1); 2 ms dwell, 3 ms pause and 5 ms settling time (treatment 2); 1 ms dwell, 2 ms pause and 5 ms settling time (treatment 3) and 1 ms dwell, 1 ms pause and 5 ms settling time (treatment 4). The y-axis of the line graph is normalized to the area count in treatment 1. The graph shows a minimal area count decrease at the fastest acquisition rate. This trend is also shown in the XICs (bottom). Image Credit: SCIEX

Beyond instrument sensitivity, the MRM acquistion rate used in treatment 3 (1 ms dwell, 2 ms pause, and 5 ms settling time) demonstrated good data quality in terms of both precision and accuracy.

Figure 3 shows the precision (%CV) and accuracy over the solvent-based calibration curve (n=3) for three representative compounds: butoxycarboxim, methamidophos, and saflufenacil. The results indicate that the mean %CV was <10 % for all calibration standard levels in the three compounds, with a mean accuracy of 85 %–111 %.

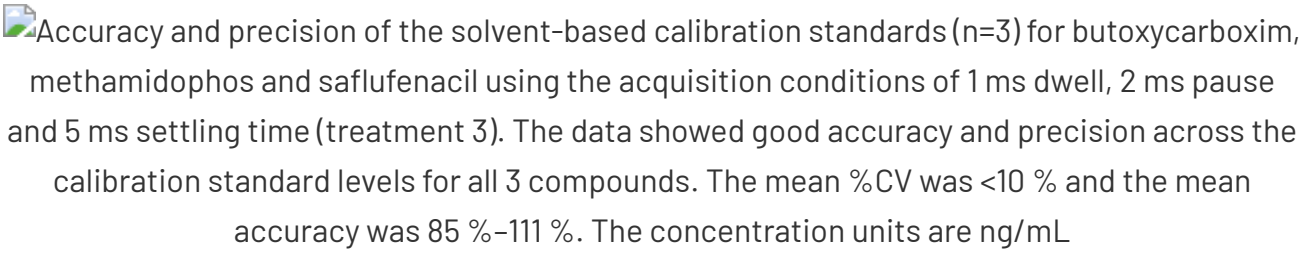

Figure 3. Accuracy and precision of the solvent-based calibration standards (n=3) for butoxycarboxim, methamidophos and saflufenacil using the acquisition conditions of 1 ms dwell, 2 ms pause and 5 ms settling time (treatment 3). *The data showed good accuracy and precision across the calibration standard levels for all 3 compounds. The mean %CV was <10 % and the mean accuracy was 85 %–111 %. The concentration units are ng/mL. Image Credit: SCIEX*

Finally, the MRM acquisition rate of 3 ms (dwell and pause time) allowed for more than 10 data points over the chromatographic peak, which is critical for reliable quantification.

Figure 4 shows XICs for three compounds: methamidophos, dimethoate, and triazophos, which were chosen based on their retention times covering the whole gradient. Despite the high level of analyte concurrency, the results contain sufficient data points.

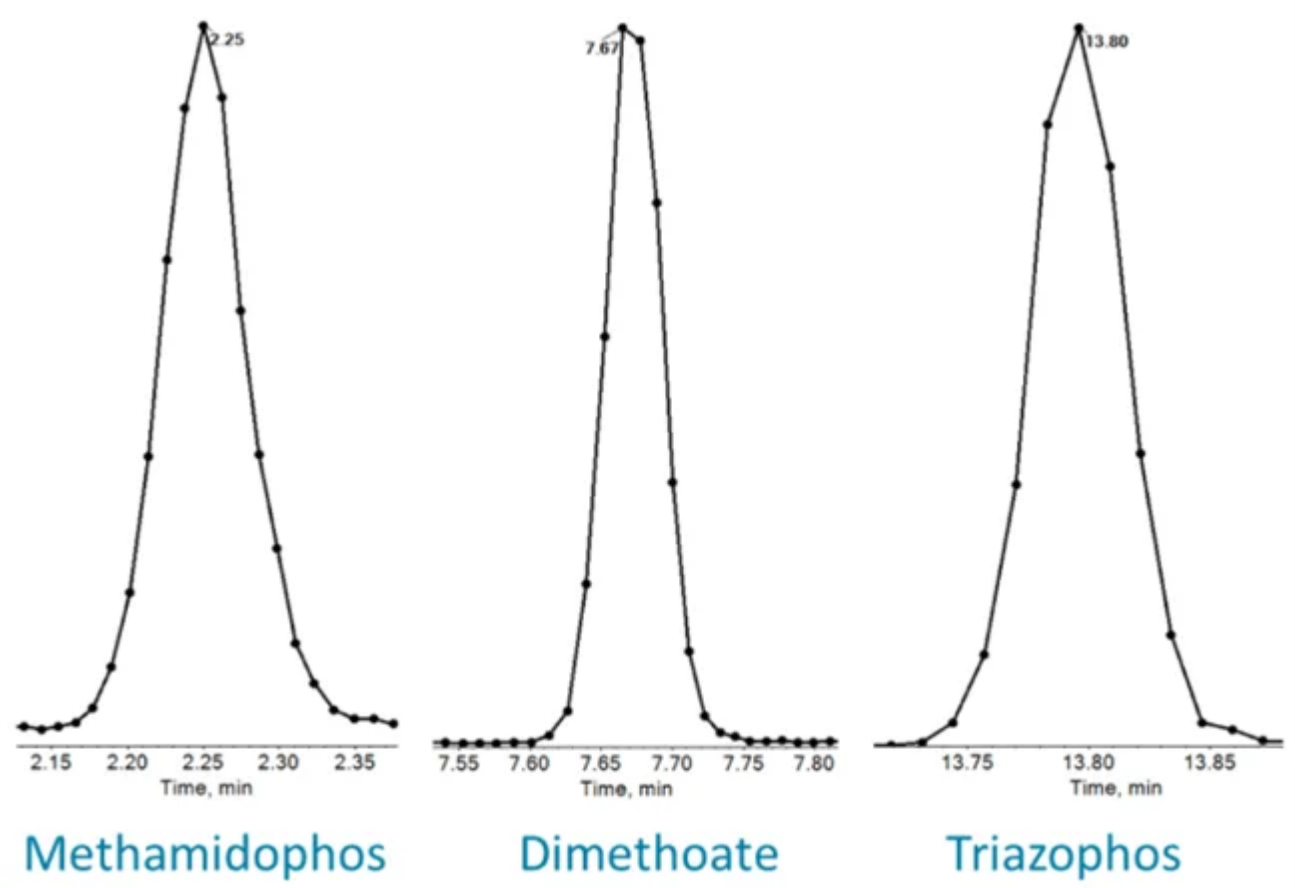

Figure 4. Data points across the chromatographic peak for 3 example compounds using fast MRM acquisition rate conditions. *The XICs demonstrate sufficient data points for good quantitation, even when using acquisition parameters of 1 ms dwell, 2 ms pause and 5 ms settling time (treatment 3). Image Credit: SCIEX*

Trace-level sensitivity

The fast MRM acquisition rate (1 ms dwell, 2 ms pause, and 5 ms settling time) also showed low ng/mL (ppb) LOQ values for pesticides in solvent-based standards.

Figure 5 shows the LOQ breakdown in calibration standards for the 560 insecticides. The majority (89 %) of pesticides had a LOQ of 1 ng/mL, the lowest concentration tested, with 97.9% and 99.5 % obtaining LOQs of 5 ng/mL and 10 ng/mL, respectively.

The SCIEX 7500+ system demonstrated exceptional sensitivity, achieving low LOQs with only 1 µL injection. Food extracts benefit from low injection volumes to reduce matrix effects, and reduced matrix loads can assist prolong optimal instrument performance, decreasing instrument downtime and service intervention.

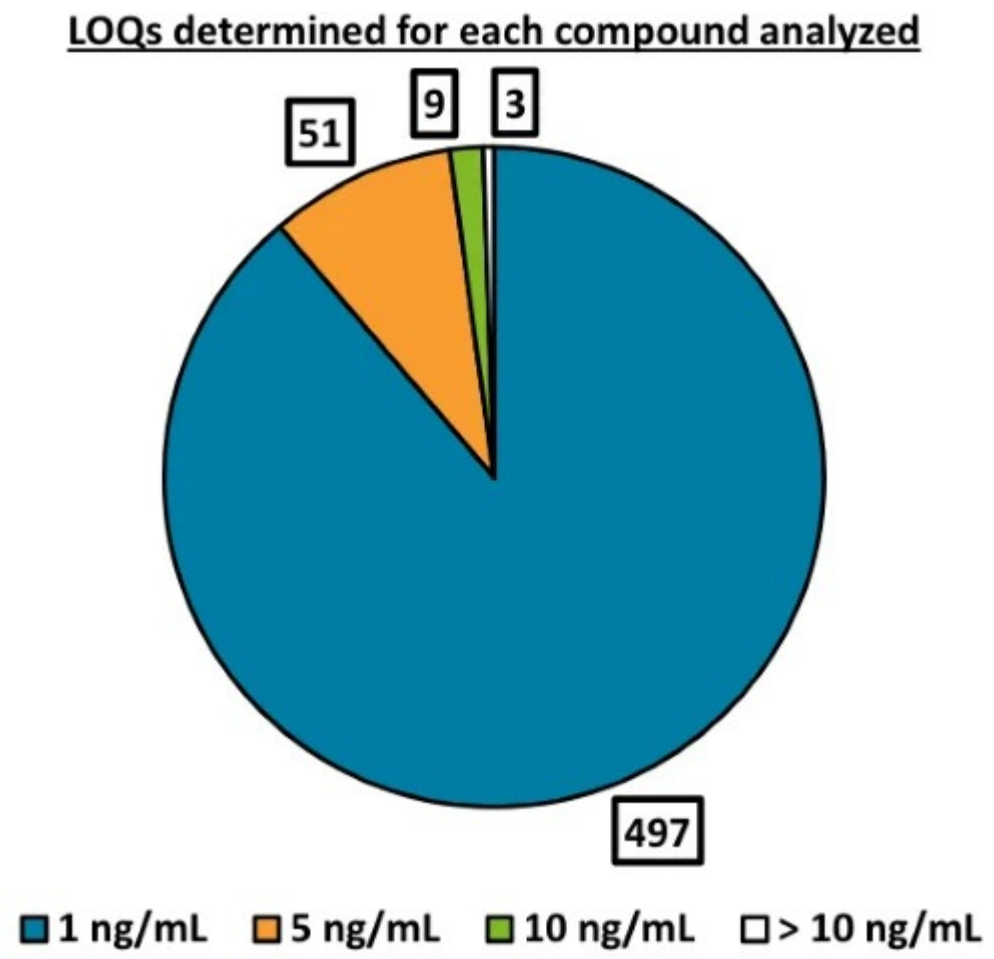

Figure 5. LOQs determined for 560 pesticide compounds analyzed within the mixed standard solution using the fast acquisition rate conditions of 1 ms dwell, 2 ms pause and 5 ms settling time. *The chart above shows that most compounds (497) achieved an LOQ of 1 ng/mL with 51 and 9 providing LOQs of 5 ng/mL and 10 ng/mL, respectively. Image Credit: SCIEX*

Figure 6 displays the superimposed XICs for 8 chemicals (4 in positive ion mode and 4 in negative ion mode) at the lowest concentration tested (1 ng/mL), demonstrating the system's sensitivity as well as the constant ion ratios observed.

Overlaid XICs of 8 different compounds (4 in positive ion mode and 4 in negative ion mode) at the lowest concentration analyzed (1 ng/mL) using the fast MRM acquisition conditions. The 3 XICs above show overlaid quantifier and qualifier transitions and ion ratio lines with a tolerance of 70 %–130 %

Figure 6. Overlaid XICs of 8 different compounds (4 in positive ion mode and 4 in negative ion mode) at the lowest concentration analyzed (1 ng/mL) using the fast MRM acquisition conditions. *The 3 XICs above show overlaid quantifier and qualifier transitions and ion ratio lines with a tolerance of 70 %–130 %. Image Credit: SCIEX*

SCIEX 7500+ system performance in spiked samples

The rapid MRM acquisition rate approach (1 ms dwell, 2 ms pause, and 5 ms settling time) was tested in food matrix spikes (soybean, avocado, mango, lemon, and tea) at 1, 3, 10, and 30 µg/kg. Figure 7 shows carboxim (positive ion mode) and triclopyr (negative ion mode) at 1 µg/kg in all matrices.

This figure shows the sensitivity of the SCIEX 7500+ system and the utilization of two MRM transitions (qualifier and quantifier), with qualifier ion ratio tolerance lines ranging from 70 % to 130 %.

A retention time shift across the matrices was detected, with triclopyr exhibiting the greatest impact. Specifically, a portion of the triclopyr peak in the tea extract occurred outside of the retention time window.

Retention shifts can occur when studying complicated and diverse matrices, and the tea matrix data demonstrate a potential risk when completing acquisitions using the Scheduled MRM method with short retention time periods.

The fast acquisition rate of the SCIEX 7500+ system can mitigate this risk by allowing it to broaden the retention time window while maintaining relatively short cycle durations and adequate data points over the chromatographic peak.

Ultimately, this reduces the necessity for retention time management, as well as the frustration associated with sample reinjections to fix retention times.

The analysis used an external calibration curve (in solvent) to quantify all pesticide chemicals in the five matrices. Many of the target analytes showed acceptable recoveries in the 3 ppb spike (Figure 8).

The high sensitivity of the SCIEX 7500+ system enabled a 1 µL injection volume, decreased matrix effects, and maintained LOQs down to 1 µg/kg.


Overlaid XICs of carboxim and triclopyr at 1 µg/kg for all 5 matrices tested. The images show the sensitivity of the SCIEX 7500+ system along with overlaid quantifier and qualifier transitions with ion ratio lines depicting 70 %–130 % tolerances. The XICs illustrate the retention time shifting, which occasionally occurs when analyzing diverse and complex matrices. The potential risk of shifting outside of the retention time window can be mitigated by the fast acquisition rate of the SCIEX 7500+ system, which allows for increased retention time windows while maintaining sufficient data points across the chromatographic peak

Figure 7. Overlaid XICs of carboxim and triclopyr at 1 µg/kg for all 5 matrices tested. *The images show the sensitivity of the SCIEX 7500+ system along with overlaid quantifier and qualifier transitions with ion ratio lines depicting 70 %–130 % tolerances. The XICs illustrate the retention time shifting, which occasionally occurs when analyzing diverse and complex matrices. The potential risk of shifting outside of the retention time window can be mitigated by the fast acquisition rate of the SCIEX 7500+ system, which allows for increased retention time windows while maintaining sufficient data points across the chromatographic peak. Image Credit: SCIEX*

Streamlined data processing using SCIEX OS software

Processing large data sets can be difficult and time-consuming. SCIEX OS software allows for custom calculations, data flagging, and filtering, which streamlines the data review process and ultimately saves time.

Figure 8 shows an example of a "Counter" column that calculates the number of matrices that met the 80 %-120 % accuracy requirements in 3 µg/kg spikes for each target pesticide. The "Counter" column can then be filtered to reveal only analytes that meet the accuracy criteria for all food matrices.

Alternatively, when the "Counter" column is set to "4", the results table displays pesticides for which a matrix violates the accuracy criteria. This example uses a custom filter to color matrices with poor accuracies (<80 %) blue and those with high accuracy (>120 %) red.

These customized, user-built features in SCIEX OS software help reduce the data review time by immediately viewing all matrices in a single results table and highlighting compounds that passed or failed the performance criterion. Custom computations can be adjusted to any data source, and there are several functionality options available.[5]

Easy implementation of custom calculations in SCIEX OS software to aid data review. This table illustrates how custom calculations and flagging rules can be implemented in SCIEX OS software to visualize which compounds fall within 80 %–120 % accuracy. Here, the "Counter" column is used to filter the data to show how many compounds have passed the accuracy criteria, with 5 indicating all criteria are met and 0 indicating none were met. The last 3 compounds listed show that flagging rules were applied due to accuracy values falling outside of 80 %–120 %. For quick and easy visualization, custom flagging rules have been used to shade cells with values <80 % in blue and cells with values >120 % in red

Figure 8. Easy implementation of custom calculations in SCIEX OS software to aid data review. *This table illustrates how custom calculations and flagging rules can be implemented in SCIEX OS software to visualize which compounds fall within 80 %–120 % accuracy. Here, the "Counter" column is used to filter the data to show how many compounds have passed the accuracy criteria, with 5 indicating all criteria are met and 0 indicating none were met. The last 3 compounds listed show that flagging rules were applied due to accuracy values falling outside of 80 %–120 %. For quick and easy visualization, custom flagging rules have been used to shade cells with values <80 % in blue and cells with values >120 % in red. Image Credit: SCIEX*

Instrument performance during unscheduled analysis

In addition to applying the Scheduled MRM algorithm for analysis, an unscheduled method was evaluated to determine the number of unscheduled MRM transitions conceivable given the system's increased speed.

Over 830 MRM transitions were used with a 1 s cycle time, which corresponds to a 0.5 ms dwell duration and 0.7 ms pause period. All data were acquired in the positive ion mode exclusively. Figure 9 depicts all transitions overlaid with selected samples to highlight individual substances (100 ng/ml).

This shows that sub-ms dwell and pause times are possible while maintaining acceptable performance.

Over 830 MRM transitions, collected using a 1 s cycle time, overlaid along with 3 highlighted examples. The top image shows all MRM transitions overlaid, and the bottom images show 3 chosen compounds - methamidophos, dimethoate and triazophos - from the total number of transitions analyzed

Figure 9. Over 830 MRM transitions, collected using a 1 s cycle time, overlaid along with 3 highlighted examples. *The top image shows all MRM transitions overlaid, and the bottom images*

show 3 chosen compounds - methamidophos, dimethoate and triazophos - from the total number of transitions analyzed. Image Credit: SCIEX

Conclusion

- The fast MRM acquisition rate of the SCIEX 7500+ system allows for more compound analysis in a single injection, with dwell and pause times below 1 ms while maintaining data quality.
- The majority (89 %) of compounds provided an in-vial solvent LOQ value of 1 ng/mL, indicating high sensitivity is attainable with the SCIEX 7500+ system.
- Matrix samples provide spiked LOQ values down to 1 µg/kg with minimal matrix effects.
- Custom calculations and layouts in SCIEX OS software can be utilized to simplify data review and processing.

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Acknowledgments

This article was produced from materials originally authored by Jianru Stahl-Zeng[1], Hassan El Khallabi[2], Jack Steed[3], Carlos Bueno[4], and Ian Moore[5].

[1]*SCIEX, Germany*
[2]*Normec Groen Agro Control*

[3]*SCIEX, UK*
[4]*SCIEX, Spain*
[5]*SCIEX, Canada*

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About SCIEX

The SCIEX mission is to deliver solutions for the precision detection and quantitation of molecules, empowering our customers to protect and advance the wellness and safety of all.

SCIEX has led the field of mass spectrometry for 50 years. From the moment we launched the first ever commercially successful triple quad in 1981, we have developed groundbreaking technologies and solutions that ensure global food safety today.

Today, as part of the Danaher family of global life science and technology innovators, we continue to pioneer robust solutions in mass spectrometry and capillary electrophoresis. But we don't just develop products. It is what we do together with our customers that sets them apart. That's why thousands of food experts around the world choose SCIEX to get the answers they can trust and keep running - day in and day out with consistent performance.

We proudly stand behind our tagline: The Power of Precision.

How Sensors Detect Food Adulteration and Mislabeling

Food fraud is getting easier, but the tools to catch it are getting smarter. From AI-powered sensors to smart packaging, technology is reshaping how adulteration and mislabeling are detected.

Image Credit: ultramansk/Shutterstock.com

Across global supply chains, food adulteration and mislabeling continue to erode consumer trust, compromise safety, and challenge regulatory oversight. Whether it's substituting premium olive oil with cheaper blends or passing off farmed fish as wild-caught, such practices not only deceive consumers but can pose serious health risks.

Now, an array of advanced sensors are giving regulators and producers a fighting chance. As these technologies mature, the ability to verify authenticity and detect fraud is shifting from the lab bench to the supermarket shelf. Whether mimicking human senses or drawing on machine learning, food fraud is on the way out.

The Scale of the Problem

Food adulteration is the intentional altering of a product, whether by adding, substituting, or

removing ingredients, that compromises its quality. Producers usually do these things to boost profits. Mislabelling is another issue, and it can compromise the product's identity, origin, or composition.

What makes the problem more acute today is the complexity of modern supply chains. A product might change hands dozens of times between origin and point-of-sale. The more steps, the greater the opportunity for deception, and the harder it becomes to trace.[1,2,3]

This is where sensors step in. Researchers and manufacturers are increasingly reliant on sensor technology to identify fraud, contamination, and substitution in products. Sensors can offer precise and nondestructive ways to do this, and some are even portable enough for use.

Different Sensors Have Different Advantages

Spectroscopic Sensors

Spectroscopic sensors reveal what's inside a product without destroying it. They use the properties of electromagnetic waves interacting with food, including infrared (IR), near-infrared (NIR), Raman, and ultraviolet-visible (UV-Vis) spectroscopy.[2,4]

They analyze molecular vibrations, scattering, and absorption to identify potential adulterants and verify the authenticity of food products.

For example, Raman spectroscopy can distinguish between authentic and adulterated honey, oils, or milk by detecting unique molecular fingerprints. Similarly, Fourier-transform infrared spectroscopy (FTIR) and NIR have been proven to be especially useful in detecting adulterants in fat-rich foods, coffee, and flour.[2,4]

Chromatographic Sensors

When the fraud is subtler, we need more sensitive techniques. Chromatographic sensors combine the separation of sample components with detection using optical or electrical signals.

Liquid chromatography coupled with mass spectrometry (LC-MS) and gas chromatography-mass spectrometry (GC-MS) are effective techniques for identifying adulterants within complex matrices like spices, oils, and meat products. These platforms are known for their high sensitivity and specificity, detecting both intentional mislabeling and small traces of adulteration, which helps maintain the integrity and quality of food products.[2]

Electronic Noses and Tongues

Inspired by biology, electronic noses (e-noses) mimic human senses to detect volatile compounds that give food its aroma. Similarly inspired, electronic tongues (e-tongues)

function by measuring the electrical signals generated when food components interact with electrodes. The sensor arrays provide complex data, which is analyzed with machine learning tools to identify patterns corresponding to specific adulterants or authentic profiles.

These tools can identify spoiled fish, watered-down milk, or off-spec fruit juice. Their strength lies not in pinpointing a single chemical, but in recognizing familiar profiles that correspond to authentic or tampered foods.[1,6]

Biosensors

Biosensors go a step further into biological mimicking, using enzymes, antibodies, or even nucleic acids as recognition elements, combined with electronic or optical detectors. They are used to spot pathogens, allergens, or toxins, and also to verify species identity through DNA-based assays.

Portable biosensors integrated with microfluidic chips allow rapid on-site testing, ideal for detecting food adulteration on the spot. Some biosensors have even been designed for direct integration into food packaging, providing continuous monitoring during transportation and storage.[7]

Physical Sensors

Changes to basic physical characteristics, such as refractive index, density, or dielectric properties, can also indicate food fraud. For example, if cheap fillers are added to oils, their optical properties shift in measurable ways.

Physical sensors that can detect these changes can carry out rapid, high-throughput screening.[8]

Smarter, Connected, Real-Time Sensing

A wave of innovation is happening in sensors. Traditional sensors are being integrated with digital platforms, equipped with microcontrollers and cloud connectivity, and embedded into AI. These IoT (Internet of Things) sensors can process data locally, flag anomalies, and send real-time results across supply chains.[7,9]

When sensors are equipped with this tech, they can upload results to the cloud or blockchain systems, integrating analytical chemistry, data science, and communications for instantaneous results. Being able to do this is supporting suppliers with transparency and traceability.

Implementing Sensors Across Supply Chains

In-Plant and Point-of-Entry Testing.

Producers and regulators now use sensors at food processing plants, import/export locations, and storage facilities. Rapid screening tools based on spectroscopy or e-nose arrays allow the food industry to conduct high-throughput inspections of bulk goods with minimal disruption to logistics.

For example, Raman spectrometers allow customs food inspectors to quickly verify the authenticity of imported teas, ensuring compliance with safety and quality standards without causing significant delays.[10,11]

Retail and Consumer-Level Detection

Some devices are small enough to be used outside of factories and labs. One example is the *READ FWDx*, which customers or staff can use on the shop floor. These devices can simultaneously identify multiple contaminants or adulterants within minutes, making quality assurance and consumer protection more practical. Their design prioritizes accessibility, making it easier to assess product quality in everyday settings.[12,13]

Packaging Innovations

Advanced packaging technologies now allow sensors or biosensor labels to be embedded within containers. These smart packages monitor environmental conditions, spoilage, or tampering and can transmit data to cloud systems. Blockchain integration ensures data integrity and supports traceability all the way to consumers, who can access information via quick response (QR) codes or Radio-Frequency Identification (RFID) tags.[7]

Enhancing Detection Through AI

Sensors generate huge amounts of data. To rationalise such large information streams, machine learning has stepped up to interpret the complex output into something more easily processed. Algorithms can classify samples, identify deviations, and even predict adulteration risks.

Using iterative learning models, systems continue to improve their accuracy, adapting to new fraud strategies or emerging adulterants. Additionally, AI enables the integration and interpretation of results from multiple sensor types. A combined system can assess optical signals, biosensor responses, and VOC profiles, generating robust conclusions even in challenging testing scenarios.[5,9]

Addressing the Challenges of Sensor Deployment

As with all technological advances, these fraud-busting sensors have outstanding problem

areas. It is difficult for reliable, environmentally stable sensors to be produced that can monitor extremely diverse food matrices, and researchers are continuing to try to strike the perfect balance. As sensors move from the laboratory to real-world settings, scientists focus on minimizing false positives, reducing sensitivity to confounding variables, and improving portability.[7]

Sensor systems must also adapt to evolving criminal practices, handle various adulterants, and address data privacy concerns while managing large volumes of information.[7]

Recent Advances, What's Next?

However, sensor technology is entering a new phase of development. Optical and electrochemical biosensors are more sensitive and selective than ever, and portable spectroscopic devices are approaching market readiness. Blockchain-linked sensors combined with real-time analytics promise continuous, tamper-proof supply chain monitoring. Modern point-of-care devices can assess contamination risks in food and water in under ten minutes, supporting more frequent and broader screening.[7,12,13]

Research demonstrates that next-generation sensor systems, augmented by AI, offer improved accuracy and support autonomous decision-making. Industry and regulatory bodies are strategically investing in these tools not just for detection but for deterrence, promoting food integrity and accountability across markets.[5,10,11]

As food systems grow more complex, these tools offer something increasingly valuable: more confidence in what we eat.

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The Role of AI and Robotics in Beverage Quality Control

In the world of beverages, quality control isn't just a box to check—it's what ensures every sip meets safety, consistency, and taste expectations.

Image Credit: Cagkan Sayin/Shutterstock.com

These days, AI and robotics are stepping in to take quality assurance to the next level. From spotting contaminants faster to keeping flavors consistent and predicting equipment issues before they happen, these smart technologies are making beverage production smoother, more efficient, and less prone to human error.

This article explores how AI-driven systems and robotic automation are being employed across multiple stages of beverage manufacturing for quality control, from detecting contaminants to predictive maintenance of equipment.

Smarter Contaminant Detection with AI

Nobody wants unexpected ingredients in their drink. Traditional methods of detecting contaminants—like manual sampling or basic sensors—can be slow and can sometimes miss subtle impurities. That's where AI-powered sensors and machine learning (ML) offer an

alternative, providing faster and more accurate ways to spot chemical, microbial, or foreign substances.[1]

For example, researchers have combined radio-frequency identification (RFID) sensors with ML to detect contamination in beverages. By attaching low-cost RFID tags to containers and analyzing changes in electrical signals, the AI was able to distinguish between pure and contaminated drinks with about 90 % accuracy. The approach was demonstrated on products like soft drinks, alcohol, and milk formula, demonstrating how this real-time contamination monitoring can be applied throughout production.

Spectroscopic sensors with ML are also proving particularly valuable, particularly in catching adulterated beverages. A recent study used Fourier-transform infrared (FTIR) spectroscopy to detect fruit juice adulteration, achieving over 97 % accuracy.[2] Meanwhile, AI-driven computer vision systems scan thousands of bottles per hour, flagging defects or contaminants with over 99% accuracy—something human inspectors could never match.[1]

How AI and Robotics Are Making Production Faster and Smarter

Beyond identifying issues, AI and robotics are enhancing efficiency in beverage production lines. In an industry where tight profit margins and high demand make speed and precision essential, automation plays a crucial role. Currently, around 26% of food and beverage packaging lines have integrated robotics into their workflows, increasing productivity by 25% through higher speeds and reduced errors.[3]

Robots are also helping address labor shortages and improving workplace safety. Instead of spending hours on repetitive tasks, human workers can now focus on supervision and higher-level decision-making. Take *Westheimer Brewery*, for example—when demand surged during the COVID-19 pandemic, they automated their bottling line, which not only increased output but also made the job easier for employees, leading to better retention.[3,4]

This trend is set to continue as more breweries and beverage manufacturers adopt AI and robotics, driving further advancements in efficiency, safety, and quality control. Research and industry reports indicate that increased automation can lead to more consistent products, reduced operational costs, and improved workplace conditions. As these technologies evolve, they will play an even greater role in shaping the future of beverage production, ensuring manufacturers can meet growing consumer expectations while maintaining high industry standards.

AI-Powered Taste Testing

Quality control isn't just about avoiding defects—it's about ensuring every batch tastes just right. AI is helping here, too, through electronic sensory systems that analyze flavor and aroma with precision..[5]

Electronic tongues (e-tongues) are sophisticated electrochemical sensor systems designed to detect dissolved flavor compounds. By utilizing machine learning for pattern recognition, e-tongues can analyze beverage flavor profiles and identify variations, much like human tasters. They precisely measure bitterness, evaluate flavor maturation, and differentiate between brands.

Studies have shown that e-tongues can successfully distinguish different types and brands of orange juice. This capability not only strengthens quality control by ensuring consistency across batches but also minimizes reliance on human tasting, reducing subjectivity and enhancing efficiency in production.[5]

Similarly, electronic noses (e-noses) sniff out volatile compounds in beverages. Paired with ML, they can quickly identify off-odors and confirm that a drink's aroma profile matches the product specification. Unlike traditional chemical analyses, e-noses aren't affected by ethanol, making them especially useful when it comes to identifying spoilage indicators.

All in all, AI-driven sensory analysis enhances consistency beyond human capabilities, ensuring uniform flavor and aroma while maintaining brand standards and quality across batches.[5]

The Role of Robotics in Bottling, Labeling, and Packaging

In the final stages of beverage production, when it comes to getting beverages out the door, speed and precision are key, especially when it comes to bottling, labeling, and packaging. Robotics and AI have transformed these stages, bringing speed and precision to once labor-intensive tasks.

- **Bottle Handling and Filling:** Robots are used to load empty bottles onto filling lines and unload filled bottles, synchronizing seamlessly with high-speed fillers.[4]
- **Labeling and Inspection:** AI-guided robotic systems ensure that labels are applied accurately and consistently on each bottle or can. With real-time machine vision, these systems achieve over 90 % fewer labeling errors compared to manual methods, enabling 360° label application and swift inspection of label quality, far surpassing human capabilities.[4]
- **Packing and Palletizing:** End-of-line packaging is often handled by robotic arms that pack bottles into cartons and stack those cartons onto pallets. These robots can lift heavy cases and arrange them in stable pallet patterns rapidly. Collaborative robots in

large beverage facilities, like Coca-Cola's, have enhanced efficiency by up to 50 %. The robots work safely alongside humans, moving crates or shrink-wrapped bundles continuously, which speeds up the shipping process.[4]

Preventing Downtime with Predictive Maintenance

AI isn't just helping with product quality—it's also keeping production lines running smoothly. Predictive maintenance systems use AI to monitor equipment health in real-time, detecting early warning signs of wear and tear before they lead to costly breakdowns.[6]

For instance, increased vibration in a bottle filler might signal a failing bearing. Instead of waiting for a full-blown breakdown, AI-powered systems flag these issues early, allowing maintenance teams to step in before major problems occur. This not only prevents unplanned downtime but also ensures production stays on track, especially during peak demand seasons.[6]

Additionally, AI-driven maintenance analytics enhance the timing and efficiency of maintenance tasks, allowing companies to schedule interventions just before potential issues arise. This strategy extends equipment lifespan by replacing parts at the optimal moment, reducing unnecessary downtime.

For example, Swire Coca-Cola (a major Coca-Cola bottler) implemented an AI-based Manufacturing Information System, centralizing production and maintenance data to significantly cut fault diagnosis time and minimize downtime, demonstrating the effectiveness of predictive maintenance in beverage manufacturing.

> *With this type of system, we have simplified our processes, saving time and easing stress on the lab techs, drivers, and other plant personnel as well.*
>
> *Sarah Heald, Quality Supervisor, Coca-Cola Beverages*

In broad terms, predictive maintenance systems help beverage manufacturers:

- **Minimize Downtime:** Continuous monitoring and early fault detection lead to timely repairs, preventing the costly domino effect of line stoppages. Production schedules stay on track, even in high-demand seasons.[6]
- **Ensure Consistent Quality:** Equipment is kept in peak condition, which prevents quality fluctuations. Issues like variation in carbonation level or capping force (that could result in leaks) are caught and corrected proactively, ensuring each product meets quality specs.[6]
- **Optimize Maintenance Schedules:** AI analytics determines the optimal maintenance intervals based on real equipment conditions. Maintenance can be performed during planned off-hours or batch changeovers, aligning with production cycles to reduce impact. This also means better allocation of maintenance resources and lower long-term costs due to fewer emergency fixes.[6]

Conclusion

AI and robotics are no longer just buzzwords in the beverage industry—they're making a tangible impact on quality control, efficiency, and production. From spotting contaminants with near-perfect accuracy to ensuring every bottle tastes just right, these technologies are setting new standards in manufacturing. And with predictive maintenance keeping production lines running smoothly, the days of unexpected breakdowns and wasted resources are fading fast.

Looking ahead, AI and robotics will only continue to evolve, bringing even smarter, more precise solutions to beverage production. Companies that embrace these advancements won't just keep up with the competition—they'll set the bar for quality, sustainability, and efficiency. Whether it's reducing human error, improving consistency, or optimizing workflows, one thing is clear: AI and robotics are here to stay, and they're changing the way our favorite drinks are made—one innovation at a time.

Want to Learn More?

If this article has piqued your interest, there is plenty more to read. Why not check out some of the below topics?

- **Quality Assurance at Coca Cola with CO_2 Purity Monitoring**
- **Understanding Food and Beverage Aromas with Olfactometers**
- **Microfluidic Devices for Beverage Analysis**
- **Food & Beverage Analysis via Metrohm Ion Chromatography**

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