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Pesticide Regulations and Pesticide Analysis in Exports in Turkey



“Reducing pesticide use for environmental sustainability and raising awareness of farmers on alternative control methods; Safe Food for Consumers”

[SafeFoodTR]

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Raising awareness among farmers in Turkey regarding pesticide regulations and pesticide analyses in exports



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1. INTRODUCTION

The agricultural sector, a fundamental pillar of the global economy and human health, is under pressure to feed the world's rapidly growing population while simultaneously battling biological, environmental, and economic threats. Every year, millions of tons of crops are lost due to damaging organisms such as insects, rodents, fungi, and weeds. It is at this juncture that pesticides (agricultural chemicals) intervene, serving as one of the most critical chemical components of the modern food production chain by preventing these losses and maximizing agricultural yield.

This study aims to address this vital tool of agricultural control, pesticides, in all its dimensions. The definition, historical evolution, and chemical diversity of pesticides will be examined to clarify their role in agricultural practices. The historical progression from simple inorganic substances to today's selective, synthetic organic compounds will highlight how this development has transformed both the sector's efficacy and the risks it faces.

However, despite the benefits they offer, pesticide use is a constant subject of debate due to the potential risks it carries regarding food safety, environmental pollution, and public health. To ensure consumer confidence and overcome barriers in international trade, the accurate and reliable detection of pesticide residues (MRLs - Maximum Residue Limits) in products has become mandatory. Therefore, the focus of this study will be on the current analytical methods used to detect pesticide residues. These methods range from rapid field screening tests (e.g., ELISA) to highly sensitive mass spectrometric techniques (LC-MS/MS, GC-MS/MS) used in laboratory settings.

The reliability and acceptability of test results are a fundamental requirement, especially for entry into international markets. In this context, the concept of accreditation—what it means for testing laboratories and how it proves the scientific validity of the results—will be discussed in detail. Finally, with the globalization of food trade, the strategic importance of compliance with the pesticide regulations of exporting countries and the necessary legal and operational procedures to ensure this compliance will be examined.

2. WHAT IS A PESTICIDE?

Pesticides are chemical or biological substances used to control, eliminate, or reduce the effects of harmful organisms. The term “pest” refers to harmful living organisms, while the suffix “-cide” means a killing or destructive agent. With the development of modern agriculture, this concept has expanded beyond insecticides to include a wide range of substances used to combat weeds, fungi, bacteria, viruses, and rodents.¹ The example of pesticide application is shown in Figure 1

The modern use of pesticides became widespread in the mid-20th century with the introduction of DDT as an insecticide.² In Turkey, the systematic use of pesticides increased after the 1970s, and in the 2000s, the legal framework was strengthened through harmonization efforts with European Union legislation.³

According to the FAO and WHO, a pesticide is defined as a “chemical or biological agent used to prevent, destroy, or control harmful organisms.” This definition also includes plant protection products, growth regulators, defoliants, desiccants, and post-harvest protectants.⁴ Similarly, in the Codex Alimentarius and European Union legislation, the concept of pesticides is broadly defined to cover not only the production stage but also the processing, storage, and transportation stages of food.⁵

Effects of Pesticides

Due to their potent biocidal properties, pesticides can also affect non-target organisms. In humans, acute exposure may cause symptoms such as headaches, nausea, and respiratory difficulties, while chronic exposure can lead to hormonal disorders, neurological damage, and cancer.¹¹ In ecosystems, soil microbiota, beneficial insects, and aquatic life forms may be harmed; if pesticides belong to the class of persistent organic pollutants, they can accumulate in the food chain and lead to biomagnification.¹²

From a food safety perspective, pesticide residues represent a significant risk factor. In both the European Union and Turkey, Maximum Residue Limits (MRLs) have been established. Exceeding these limits poses serious health risks to humans. In Turkey, the Pesticide Residue Monitoring Program, implemented by the Ministry of Agriculture and Forestry, is carried out to control and minimize these risks.¹³



Figure 1. Pesticide application

3. HISTORICAL DEVELOPMENT OF PESTICIDES

The historical development of pesticides represents an important dimension of both agriculture and human civilization. For thousands of years, people have developed various methods to protect their crops from pests. This journey—from natural substances to synthetic chemicals and later to biopesticides—has not only increased agricultural productivity but also sparked significant debates regarding environmental impacts.¹⁴

One of the earliest written records of pesticide use dates back to around 2500 BCE, when the Sumerians used sulfur compounds.¹⁵ In ancient China, natural minerals such as arsenic and mercury were applied against agricultural pests. These substances were used in their natural forms, not as synthesized compounds like modern pesticides.

When examining the historical trajectory of pesticides, scientific publications indicate that the Sumerians, about 4,000 years before Christ, used insecticidal substances, while in the Far East around the 15th century, the Chinese frequently employed arsenic and mercury to protect gardens and landscapes from pests. Other research has shown that sulfur had already been recognized 3,000 years earlier as an effective agent against fungi and later against insects.

With the Industrial Revolution, agricultural chemicals gained significant importance. From the mid-1800s, copper sulfate, arsenic compounds, and nicotine extracts began to be used in

agriculture.¹⁶ In the 1880s, the Bordeaux mixture created a major breakthrough in viticulture by effectively controlling downy mildew, spreading rapidly across the world.¹⁷

In 1939, the Swiss chemist Paul Hermann Müller discovered the insecticidal properties of DDT, marking the beginning of the modern era of pesticides.¹⁸ During World War II, DDT was used extensively to combat malaria and typhus, and after the war, its agricultural use expanded rapidly. This period is often referred to as the “golden age” of synthetic pesticides, characterized by the widespread adoption of new chemical groups.¹⁹

In 1962, Rachel Carson’s groundbreaking book *Silent Spring* raised global awareness of the environmental harms caused by pesticides.²⁰ The establishment of the U.S. Environmental Protection Agency (EPA) in the 1970s and the ban on DDT were among the most significant developments of this period.²¹ Similarly, in Europe, pesticide regulations evolved, and monitoring and enforcement became more stringent.

In the 21st century, pesticide policies have increasingly shifted toward environmental sustainability. The use of biopesticides has expanded, and under the European Union’s Farm to Fork Strategy, reducing pesticide use has become a key objective.²² Today, pesticide management is transitioning from traditional chemical-based methods to Integrated Pest Management (IPM) approaches. The historical development of pesticides is summarised in Figure 2.



Figure 2. Historical development of pesticides

4. TYPES AND USES OF PESTICIDES

Areas of Use of Pesticides

The primary area of pesticide use is agriculture. According to the FAO, pesticide application reduces global agricultural crop losses by 30–40%.⁸ In addition, pesticides contribute to public health by controlling vectors such as mosquitoes, thereby preventing the spread of diseases like malaria and typhoid fever.⁹ However, these benefits can only be achieved when pesticides are applied at the right time, in the proper dosage, and by trained professionals.¹⁰ The areas of use of pesticides are schematised in Figure 3.

Classification of Pesticides

Pesticides are mainly classified into six categories based on the target organisms (Table 1) they are intended to control.⁶

Table 1. Classification of Pesticides

Class	Target Organism	Example
Insecticide	Insects	Organophosphates, Pyrethroids
Herbicide	Weeds	Glyphosate
Fungicide	Fungi	Carbendazim
Rodenticide	Rodents	Warfarin
Acaricide	Mites	Propargite
Nematicide	Nematodes	Metam sodium



Figure 3. Using Areas of Pesticides

Pesticide Regulations and Control (Turkey)

In Turkey, the use, sale, and residue levels of pesticides in food are strictly monitored through various regulations issued by the Ministry of Agriculture and Forestry (T.C. Tarım ve Orman Bakanlığı). These regulations aim to ensure food safety, environmental protection, and public health.

Licensing and Sale

Licensing:

All pesticides and similar substances intended for agricultural pest control are subject to official registration (licensing). During the licensing process, the Ministry reviews comprehensive chemical, toxicological, and ecotoxicological reports to evaluate product safety and environmental impact before approval.

Prescription-Based Sales:

Under the “Regulation on the Prescription-Based Sales Procedures and Principles of Plant Protection Products”, the traceability of pesticides has been ensured. Similar to medicines sold in pharmacies, these products are mostly sold through prescriptions issued by agricultural engineers authorized to prescribe plant protection products. This system allows for controlled use, prevents misuse, and ensures that pesticides are applied responsibly and safely under professional supervision.

Inspection System

Pre-Harvest Inspection:

Before agricultural products are placed on the market, officials from the Ministry of Agriculture and Forestry collect samples directly from the field and send them to accredited laboratories for analysis.

If the analysis reveals the presence of an unregistered (banned) pesticide, the product is destroyed, and legal penalties are imposed on the producer.

This procedure ensures that only legally approved plant protection products are used and that food reaching consumers complies with national and international safety standards.

If a licensed pesticide is detected but the residue level exceeds the permitted Maximum Residue Limit (MRL), the harvest is postponed or the product is destroyed to ensure consumer safety and compliance with food regulations.

Post-Harvest Inspection

Samples are also collected from markets, bazaars, and food processing facilities to ensure continuous control of pesticide residues in food products throughout the supply chain. This helps maintain traceability and consumer confidence in agricultural products.

QR Code Tracking System

Since 2019, Turkey has implemented a QR code tracking system that enables full traceability of pesticides from the manufacturer to the distributor and finally to the farmer. This digital system allows authorities to monitor every stage of the pesticide's movement, prevent illegal trade, and strengthen overall regulatory transparency and control.

5. PESTICIDE ANALYSIS: DETECTION METHODS, RAPID TESTS, LABORATORY TESTS, APPLICATIONS, AND LEGISLATION

Pesticide analysis is an indispensable component of modern agricultural systems in terms of food safety and environmental protection. These analyses are conducted to detect pesticide residues in food products, water, soil, and environmental samples, ensuring compliance with legal residue limits. According to the regulations of the European Union (EU), FAO, WHO, and Turkey, pesticide analyses must be performed in accordance with specific methodological standards.²³

Purpose and Importance of Pesticide Analysis

Accurate and reliable analysis of pesticide residues plays a crucial role in protecting human health, preventing environmental pollution, and ensuring the safety of international trade.

These analyses aim to:

- Verify the compliance of pesticide residues in food with the legally established Maximum Residue Limits (MRLs),
- Prevent residue limit violations in export products,
- Strengthen product safety and traceability,
- Protect consumer health.

In developed countries, pesticide residue analyses form the foundation of official control and monitoring programs, ensuring that agricultural products meet both domestic and international safety standards.²⁴

Sample Types Used in Pesticide Analysis

Pesticide analyses are not limited to fresh produce; they can be performed on a wide variety of matrices to monitor contamination across the food chain and environment. The main sample types include:

- Fresh fruits and vegetables
- Cereals and processed food products
- Water samples (surface and groundwater)
- Soil samples
- Animal-based food products (milk, eggs, meat)
- Air and environmental dust samples

The sample preparation techniques vary depending on the matrix type, as each material requires different extraction, purification, and analytical approaches to ensure accurate and reproducible results.²⁵

Sampling and Sample Preparation Process

One of the most critical stages in pesticide analysis is the sampling process. Sampling must be conducted based on the principles of randomness, representativeness, and homogeneity to ensure reliable analytical results.

During sample preparation, the most widely used method is the QuEChERS technique (Quick, Easy, Cheap, Effective, Rugged, and Safe).

Advantages of the QuEChERS Method

- It is fast and easy to apply,
- Allows the extraction of multiple pesticides in a single procedure,
- Is cost-effective,
- Requires minimal amounts of solvents.

General Steps of the QuEChERS Method

Sample Preparation – The food sample is homogenized.

Extraction – Pesticides are extracted from the sample using a solvent such as acetonitrile.

Salt Addition and Phase Separation – Sodium chloride and magnesium sulfate are added to promote separation of the aqueous and organic phases.

Cleanup (d-SPE) – Unwanted compounds are removed using dispersive solid-phase extraction (d-SPE) adsorbents (Figure 4.).

Analysis – The purified extract is analyzed using GC-MS (Gas Chromatography–Mass Spectrometry) or LC-MS/MS (Liquid Chromatography–Tandem Mass Spectrometry) instruments.²⁶

Because it provides rapid, cost-efficient, and multi-residue detection, QuEChERS has become a globally adopted standard method for pesticide residue analysis in food and environmental testing laboratories.

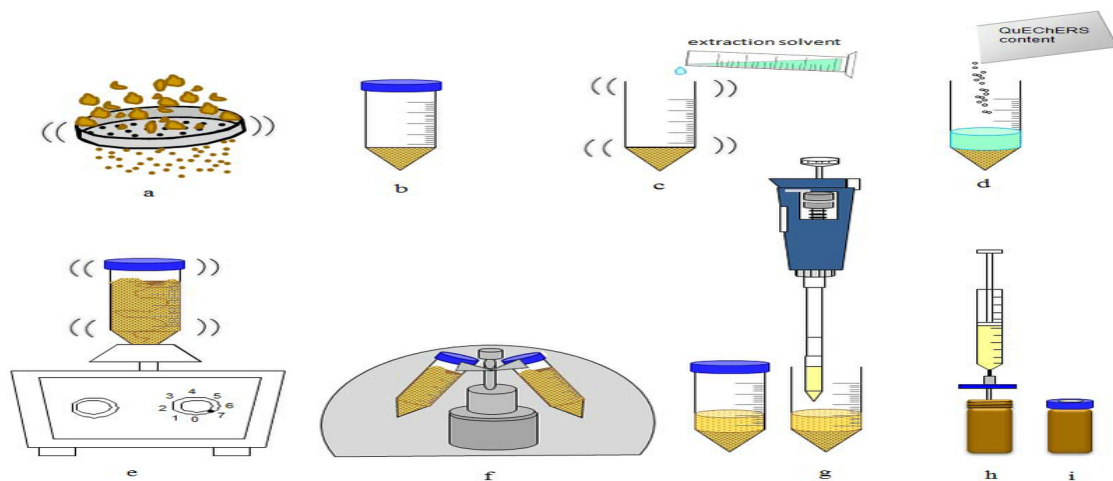


Figure 4. Schematic representation of the QuEchERS method

Pesticide Analysis Methods

The main analytical techniques used in pesticide residue analysis include the following:

- GC-MS (Gas Chromatography–Mass Spectrometry):

Used for the determination of volatile and semi-volatile pesticides. It provides high sensitivity and specificity, making it ideal for compounds such as organochlorines and pyrethroids.

- LC-MS/MS (Liquid Chromatography–Tandem Mass Spectrometry):

Applied to the analysis of non-volatile or thermally unstable pesticides. It is widely used for modern multi-residue methods and provides excellent accuracy in detecting low concentrations (Figure 5).

- HPLC (High-Performance Liquid Chromatography):

Suitable for the analysis of polar pesticides that may not be amenable to GC techniques. It is often used for compounds such as carbamates or herbicides.

- ELISA (Enzyme-Linked Immunosorbent Assay):

Utilized for rapid screening tests. It allows quick preliminary detection of pesticide residues before confirmatory analysis in the laboratory.

- FTIR and NIR (Fourier Transform Infrared and Near-Infrared Spectroscopy):

Serve as supportive qualitative techniques for identifying certain pesticide classes based on their molecular vibration patterns.²⁷

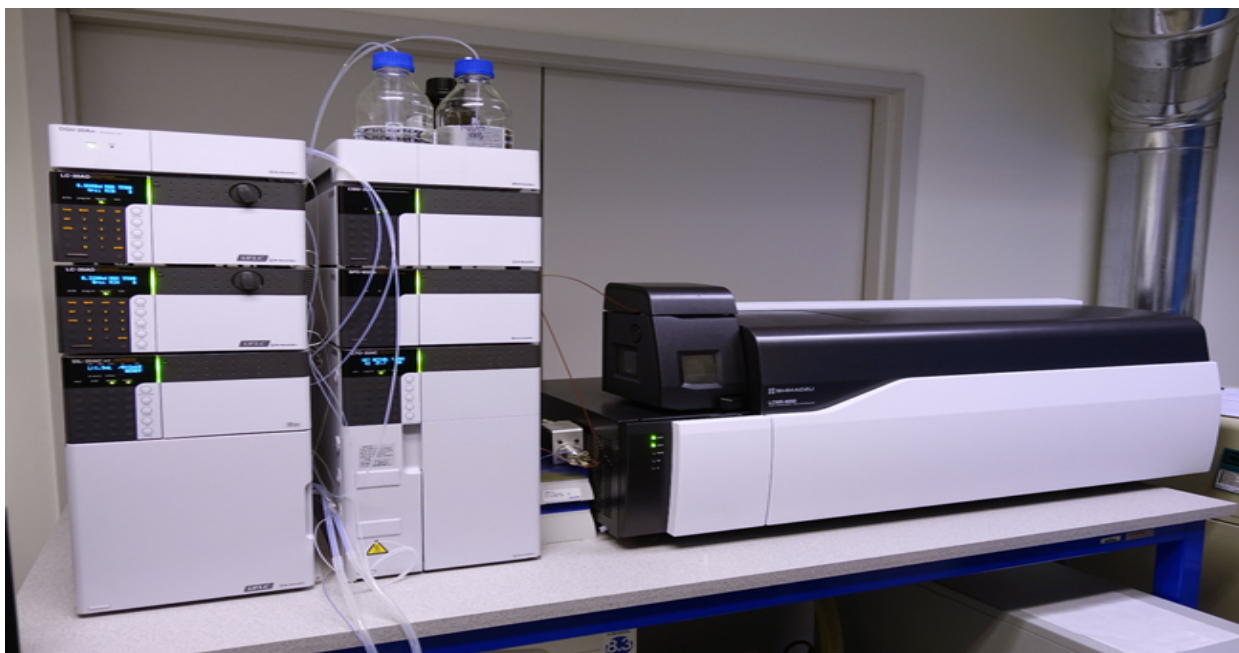


Figure 5. LC MS/MS System

Verification, Quality Control, and Accreditation

The reliability of analytical results in pesticide testing depends on rigorous validation and quality control procedures. Laboratories operating under the ISO/IEC 17025 standard are required to perform method validation to ensure analytical accuracy, consistency, and reproducibility (Figure 6).

Key Quality Parameters

- **Accuracy:** The closeness of measured values to the true or accepted reference value.
- **Repeatability:** The consistency of results obtained under the same conditions within a short time frame.
- **Recovery Rate:** The percentage of analyte recovered from a sample during analysis, indicating extraction efficiency.
- **LOD (Limit of Detection):** The lowest concentration of a substance that can be reliably detected but not necessarily quantified.
- **LOQ (Limit of Quantification):** The lowest concentration that can be quantitatively determined with acceptable precision and accuracy.

In addition, laboratories are required to participate in international proficiency testing (interlaboratory comparison programs) to ensure external quality assurance and demonstrate the competence and reliability of their analytical performance.²⁸

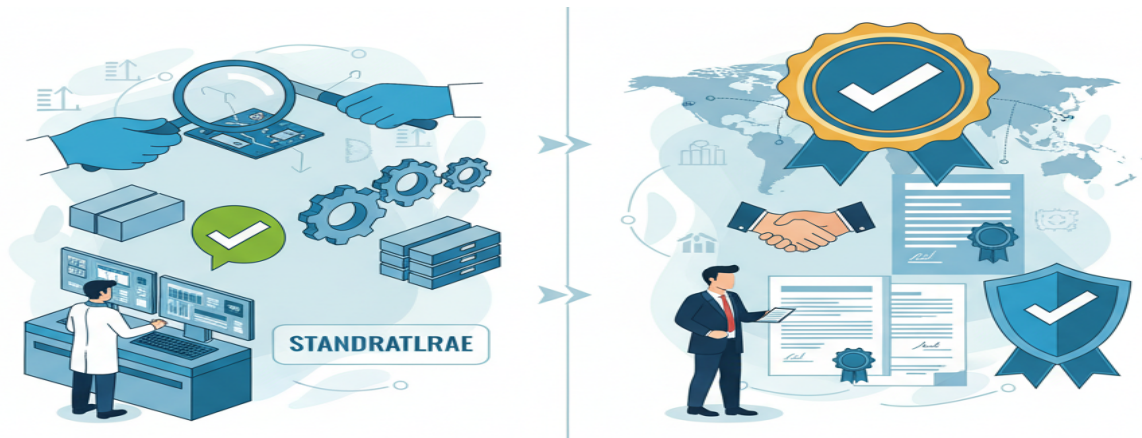


Figure 6. Validation Process

Legal Framework and Maximum Residue Limits (MRLs)

The foundation of pesticide analysis lies in national and international legislation that establishes residue limits and testing requirements.

In the European Union, pesticide residue limits are defined under Regulation (EC) No 396/2005.

In Turkey, the corresponding regulation is the Turkish Food Codex Regulation on Maximum Residue Limits of Pesticides (TGK).

The FAO/WHO Codex Alimentarius standards also serve as the international reference framework for global food trade and export certification.²⁹

When MRL values are exceeded, the marketing of products may be prohibited, export shipments may be rejected, and administrative or legal sanctions can be imposed on producers or exporters.

Rapid Testing and Digitalization

The future of pesticide analysis is shifting toward faster, more portable, and environmentally friendly technologies. Emerging trends in this area include:

- Portable sensor systems capable of on-site pesticide detection,
- Rapid ELISA kits for preliminary screening,
- Spectral scanning techniques such as FTIR/NIR and Raman spectroscopy,
- Artificial intelligence–assisted data analysis for automated interpretation and pattern recognition.³⁰

These innovations will enable reliable pesticide testing outside traditional laboratory environments, making it possible to perform real-time monitoring in the field, during transport, or at export control points—thus strengthening food safety, traceability, and international compliance.

6. RELIABILITY OF TEST RESULTS AND THE CONCEPT OF ACCREDITATION

The reliability of analyses conducted in strategic areas such as food safety, public health, environmental protection, and international trade depends not only on the technical competence of laboratories but also on systematic quality management, standardization, and accreditation. The reliability of test results is of critical importance for establishing accurate and effective decision-making mechanisms.³¹

In analyses that directly affect human health, such as pesticide testing, test results must be error-free, repeatable, and in full compliance with internationally recognized standards.

The Concept of Reliability of Test Results

The concept of reliability of test results refers to ensuring the accuracy, repeatability, and traceability of measurement results in accordance with national or international standards. For a laboratory to be considered reliable, it is not sufficient to merely possess advanced technical equipment. Every stage of the measurement process must be systematically defined and controlled. This concept encompasses all stages of the analytical workflow, including sampling, sample preparation, analysis, data evaluation, and reporting.³²

The reliability concept is also closely linked to risk management. Measurement errors can lead to incorrect decisions. For example, an erroneous pesticide test result may cause a safe product to be withdrawn from the market or allow a hazardous product to be sold, leading to both economic losses and public health risks. Therefore, the reliability of test results is not only a technical issue but also a strategic one, essential for ensuring trust, safety, and effective decision-making in food safety systems.

Accuracy, Precision, Repeatability, and Traceability

There are four fundamental concepts that ensure the reliability of analytical measurements: accuracy, precision, repeatability, and traceability.³³

- Accuracy:

Refers to the closeness of a measured value to the true value. Accuracy is achieved through proper instrument calibration and the selection of an appropriate analytical method. The more accurate a measurement is, the more reliable it is considered to be.

- Precision:

Means obtaining results that are very close to each other under the same measurement conditions. When precision is high, the measurement variance is low, indicating consistent performance.

- Repeatability:

Refers to obtaining similar results when the same measurement is repeated in the same laboratory, by the same person, under identical conditions. If repeatability is low, it may indicate a problem with the method or the equipment.

- Traceability:

Means that measurement results can be referenced to a national or international standard through an unbroken chain of comparisons. Traceability provides the legal and scientific foundation for measurement reliability.

These concepts are not limited to analytical chemistry—they are fundamental criteria for evaluating test reliability in all technical disciplines, including biology, environmental sciences, and engineering.

Quality Control Systems and External Quality Assurance

Quality control systems are standardized procedures applied to ensure the consistency and accuracy of results produced by laboratories.³⁴ They are generally divided into two main categories: Internal Quality Control (IQC) and External Quality Control (EQC).

Internal Quality Control (IQC)

Internal quality control refers to the system implemented within the laboratory itself to evaluate the daily accuracy and stability of measurements.

Standard solutions, control samples, and statistical analyses are used to monitor processes.

Deviations are identified and corrected immediately to maintain analytical consistency.

Routine checks ensure that instruments and methods perform within the required tolerance limits.

External Quality Control (EQC)

External quality control involves the participation of laboratories in proficiency testing programs organized by independent institutions.

The laboratory's results are compared with international reference values or the performance of other accredited laboratories.

This system verifies the objectivity and comparability of internal measurements on a global scale.

In addition to these two pillars, instrument calibration, staff training, documented procedures, and periodic audits are essential components of the quality control system.

Without an effective quality control framework, it is impossible to obtain reliable analytical results or ensure confidence in the outcomes of pesticide analyses and other laboratory tests.

The Concept of Accreditation

Accreditation is a formal system that certifies a laboratory's compliance with specific standards.³⁵ The main purpose of accreditation is to verify the laboratory's technical competence through an independent authority. The ISO/IEC 17025 standard is the most widely used accreditation framework worldwide for testing and calibration laboratories.

The accreditation process (Figure 7) covers multiple components, including personnel competence, equipment suitability, method validation, documentation structure, quality management, and internal audit systems. An accredited laboratory guarantees that its measurements and test results are recognized internationally.

To achieve accreditation, a laboratory must document and demonstrate compliance in the following areas:

Personnel qualifications and technical competence,

Traceable calibration of equipment,

Validation or verification of analytical methods,

Control of environmental conditions,

Traceability of samples,

Data integrity and reporting procedures.

During this process, laboratories are evaluated by an authorized accreditation body (such as TÜRKAK, DAkkS, UKAS, etc.). The assessment includes not only document reviews but also on-site inspections to verify actual operational practices.

The key advantages of accreditation for laboratories include:

- International and national acceptance of test results,
- Increased customer confidence,
- Fulfillment of legal and regulatory requirements,
- Enhanced institutional reputation,
- Improved efficiency and systematic management practices.

For these reasons, accreditation has evolved beyond a mere technical requirement, becoming a strategic and commercial tool that strengthens reliability, competitiveness, and trust in laboratory operations.



Figure 7. Accreditation Process

ISO/IEC 17025 Standard — Key Components

ISO/IEC 17025 is an international standard that certifies the technical competence of testing and calibration laboratories.³⁶ The standard consists of two main components:

Management Requirements: Quality policies, procedures, documentation, record management, internal audits, and continual improvement.

Technical Requirements: Personnel competence, suitability and calibration of instruments, traceability, environmental conditions, and method validation.

Through this standard, laboratories across different countries can “speak the same language,” allowing analytical results to be comparable and mutually recognized, thereby enhancing confidence in trade and cooperation.

Although it shares structural similarities with the ISO 9001 Quality Management System, ISO/IEC 17025 is far more detailed in terms of technical requirements.

Management Requirements

Management requirements define the organizational structure of the laboratory and form the foundation of its quality management system. Within this framework:

- A written quality policy and objectives must be established.
- Roles and responsibilities must be clearly defined.
- Documentation and record management systems must be implemented.
- Internal audits must be conducted regularly, and management review meetings held periodically.
- A risk-based thinking approach should be adopted to anticipate and control potential risks.

These requirements ensure that the laboratory operates in a consistent, transparent, and traceable manner.

Technical Requirements

Technical requirements are the provisions that guarantee the reliability of measurement results. These include:

- Personnel competence (education, experience, qualification records),
- Suitability, calibration, and traceability of instruments and equipment,
- Use of verified and validated analytical methods,
- Monitoring of environmental conditions (e.g., temperature, humidity),
- Sample traceability and data integrity,
- Measurement uncertainty calculations,
- Proper reporting of analytical results.

Full implementation of technical requirements represents one of the most critical phases of the accreditation process.

Measurement Uncertainty

One of the most important elements of ISO/IEC 17025 is the evaluation of measurement uncertainty. This expresses the confidence interval associated with a test result. Correct calculation of uncertainty ensures the scientific validity and comparability of analytical data across laboratories.

Traceability

Traceability refers to the ability to relate measurement results to national or international standards through an unbroken chain of calibrations. Laboratories must have their instruments calibrated in authorized calibration laboratories and maintain proper documentation of this traceability. This system ensures global comparability and credibility of results.

Continuous Improvement

ISO/IEC 17025 is not merely a set of rules to follow—it is a dynamic framework that encourages laboratories to continually improve their processes. Key elements of this improvement cycle include:

- Internal audits,
- Nonconformity records,
- Corrective and preventive actions (CAPA), and
- Management reviews.

Through this continuous improvement mechanism, laboratories enhance their efficiency, reliability, and overall quality performance, maintaining compliance with evolving scientific and regulatory standards.

Proficiency Testing (Interlaboratory Comparisons)

Proficiency testing (PT) refers to comparative testing programs conducted among laboratories.³⁷ In these programs, the same sample is distributed to multiple laboratories, and the results obtained are compared to evaluate laboratory performance.

The main objectives of proficiency testing are to:

- Conduct interlaboratory comparisons,

- Verify method performance,
- Evaluate measurement uncertainty, and
- Promote continuous improvement in analytical quality.

International Recognition of Accreditation and Its Role in Trade

Accreditation is recognized not only at the national level but also internationally. Through Mutual Recognition Arrangements (MRAs) established by the International Laboratory Accreditation Cooperation (ILAC), test results issued by accredited laboratories are accepted in all member countries.³⁸

This is particularly important for agricultural and food products intended for export. Test reports from accredited laboratories are accepted more quickly and reliably by official authorities and importing countries.

The international recognition of accreditation has become a strategic tool in the global economy—reducing technical barriers to trade, enhancing trust and reliability, and facilitating cross-border commerce. Accredited laboratories are the cornerstones of this system, enabling the mutual acceptance of test results between countries.⁴⁰

Through this mechanism, test results produced in one country are recognized globally without the need for repetitive testing, fostering mutual confidence in the reliability of analytical data.

International Accreditation Systems: ILAC and IAF

The international accreditation framework was created to build confidence among nations. Two key organizations underpin this system:

ILAC (International Laboratory Accreditation Cooperation)

IAF (International Accreditation Forum)

These organizations establish a global trust network through Mutual Recognition Arrangements (MRA/MLA) among accreditation and certification bodies.⁴¹

As a result, for example, an analysis performed in a TÜRKAK-accredited laboratory in Turkey can be accepted in Germany or the United States without the need for additional testing. This system saves both time and cost for laboratories and exporters alike.

ILAC and Mutual Recognition Arrangements (MRA/MLA)

ILAC is the leading international organization in the field of laboratory accreditation. The Mutual Recognition Arrangement (MRA), developed in the late 1990s, enables the mutual recognition of laboratory accreditation results among ILAC member countries.⁴²

The main objectives of these agreements are to:

- Prevent duplication of testing and certification in international trade,
- Increase confidence in accredited organizations,
- Reduce technical barriers and promote free trade,
- Facilitate faster market access for products.

Advantages of International Accreditation in Trade

The international recognition of accreditation provides numerous advantages for global trade.⁴³

- One test, multiple acceptance: A product tested once can be accepted in multiple countries.
- Cost and time savings: Eliminates redundant testing processes.
- Competitive advantage: Accredited test reports enhance a company's credibility in international markets.
- Regulatory compliance: Reduces technical barriers to trade under the World Trade Organization (WTO) and the Technical Barriers to Trade (TBT) Agreement.

These benefits are particularly important for exporters in the agriculture, food, chemical, pharmaceutical, environmental, and energy sectors.

The WTO-TBT Agreement and the Role of Accreditation

The World Trade Organization's Technical Barriers to Trade (TBT) Agreement aims to ensure that member countries' technical regulations do not unnecessarily restrict trade. Within this framework, test results from accredited laboratories play a critical role in reducing technical barriers.⁴⁴

The WTO-TBT Agreement promotes the acceptance of internationally recognized test reports and supports the use of accreditation systems. Consequently, for sensitive analyses—such as pesticide residue testing—there is no need for repetitive testing across different countries.

EU Legislation and Global Harmonization

The European Union (EU) is one of the leading regions that uses accreditation as a legal instrument. The Regulation (EC) No 765/2008 establishes the framework for the European accreditation system.⁴⁵

Under this regulation, all EU member state accreditation bodies are integrated into the ILAC–IAF mutual recognition system. This ensures that tests performed within any EU member country are recognized across all member states, while mutual recognition agreements with third countries provide a secure and transparent system for international trade.

In summary, the global accreditation infrastructure, supported by ILAC, IAF, and WTO-TBT principles, ensures that test results are trusted, comparable, and internationally recognized—a cornerstone for food safety, fair trade, and economic cooperation worldwide.

The Position of International Accreditation in Turkey (TÜRKAK)

In Turkey, accreditation services are carried out by the Turkish Accreditation Agency (TÜRKAK). As a full member of ILAC (International Laboratory Accreditation Cooperation) and IAF (International Accreditation Forum), TÜRKAK's accreditations are recognized internationally.⁴⁶

This provides a significant advantage, especially for exporters in the agriculture and food sectors. For example, a pesticide residue analysis report issued by a TÜRKAK-accredited laboratory in Turkey is accepted in the EU or any other ILAC member country without the need for re-testing.

The Strategic Role of Accreditation

Accreditation is not merely a technical requirement; it is a strategic tool for establishing trust in international markets. It offers a competitive advantage for companies and serves as a foundation for trade policy for governments.⁴⁷

Its strategic impacts include (Figure 8):

- International credibility,
- Enhanced brand value and reputation,
- Acceleration of export processes,
- Strengthening of food safety policies,
- Reduction of technical trade barriers.



Figure 8. The Strategic Role of Accreditation

Digitalization and the Global Future of Accreditation

The international recognition of accreditation is being further strengthened by digitalization trends. LIMS (Laboratory Information Management Systems), blockchain-based traceability technologies, digital signatures, and AI-supported verification systems enable the faster and more transparent global sharing of test reports.⁴⁸

In the coming years, these technologies are expected to become increasingly integrated into the ILAC and IAF frameworks, leading to a further reduction of technical barriers to trade and enhanced global trust and efficiency in accredited testing systems.

Continuous Improvement and Training

Quality management and accreditation are not static systems; they require laboratories to maintain an ongoing cycle of continuous improvement. The implementation of new analytical methods, updating of personnel training programs, and enhancement of documentation processes are essential components of this system.³⁹

Additionally, internal audits, management reviews, and risk assessments play a vital role in ensuring the sustainability, effectiveness, and continuous development of the quality management system.

Digitalization and Next-Generation Assurance Systems

Today, digitalization is one of the most important factors supporting the reliability of test results. LIMS (Laboratory Information Management Systems), blockchain-based traceability systems, electronic signatures, and AI-powered analytical software enhance both data security and the transparency of testing processes.

Through these technologies, test results are protected against manipulation, recorded with time stamps, and made retrospectively traceable, ensuring full accountability and integrity throughout the analytical workflow.

7. PESTICIDE REGULATIONS IN EXPORTS

Fresh fruit and vegetable (FFV) exports hold strategic importance for countries with strong agricultural potential. This sector not only supports agricultural production but also has multifaceted positive impacts on national trade and economic growth.

Because FFV exports generate foreign currency income, they make a significant contribution to the balance of trade. The inflow of foreign exchange also helps to stabilize the national currency and improve a country's external debt repayment capacity.⁵⁰

Moreover, the agricultural production sector plays a major role in job creation and rural development. Processes such as production, harvesting, packaging, transportation, and

marketing of fresh produce are labor-intensive, providing a vital source of income for rural populations and helping to reduce rural-to-urban migration.⁵¹

FFV exports also drive the improvement of production techniques and quality standards. The high quality and hygiene requirements demanded by export markets⁵² encourage producers to adopt modern agricultural practices, certification systems, and Good Agricultural Practices (GAP). The international market's expectations have accelerated the adoption of Food Safety and Quality Management Systems (FSQMS), triggering a structural transformation within the sector.⁵³

This transformation not only enhances the competitiveness of exported products but also improves the quality of goods offered to the domestic market. However, to maintain competitiveness in global markets, key challenges include addressing pesticide residue issues, establishing strong marketing organizations, and overcoming the shortage of R&D resources.⁵⁴

Globally, the fresh fruit and vegetable trade has strategic significance for both the global economy and food security. The volume and direction of this trade are determined by each country's production capacity, logistical infrastructure, and quality standards.

In terms of production, the People's Republic of China is the world leader by a wide margin, followed by major producers such as India and the United States. Turkey, accounting for approximately 2–2.5% of global fresh vegetable production, typically ranks among the top five producers worldwide.⁵⁵

In fresh fruit exports, competitiveness is shaped by logistical advantages and market access. According to historical data, Spain, the United States, Chile, the Netherlands, and Italy are among the leading global exporters in the FFV sector.⁵⁶

Turkey's Position and Volume in the Global Market

Thanks to its favorable climatic conditions, Turkey is a major producer and exporter in the global fresh fruit and vegetable (FFV) market. In recent years, the export value of Turkish FFV has shown a significant upward trend, reaching 3.5 billion USD in 2024. Among exported products, tomatoes ranked as the most exported item. Traditionally, the Russian Federation remains Turkey's largest buyer in FFV exports.

Although the European Union (EU) is generally a net importer in the global FFV trade, it also stands out as a significant exporter for certain products. The EU represents one of the largest and most demanding FFV markets in the world. Due to its high quality and certification

standards (such as GlobalG.A.P.), exports to the EU are considered a benchmark for product quality.

Within the EU, intra-community trade is extremely high, but exports from member states are also substantial thanks to their logistical strength and advanced marketing systems. For instance, Spain (notably for citrus fruits, tomatoes, and peppers) and the Netherlands (for greenhouse and re-exported products) are recognized as global leaders in FFV exports.⁵⁶

In addition to its own production, the EU is highly dependent on imports, especially during the winter season and for tropical products such as bananas and citrus fruits.⁵⁷

For Turkey, the European Union is the second most important and strategic export market, following the Russian Federation. Among EU countries, Germany and Romania are Turkey's leading destinations for FFV exports. According to 2023 data, Turkey's FFV exports to Germany amounted to 349 million USD, and to Romania 291 million USD, making them the top EU importers of Turkish produce.⁵⁸

When exporting to the EU, compliance with pesticide residue limits, quality, and hygiene standards is one of the key prerequisites for market access.⁵² These environmental and technical requirements imposed by the EU also serve as a driving force for modernization within Turkey's agricultural production sector.

In conclusion, the fresh fruit and vegetable export sector represents a strategic area of economic activity that directly contributes to economic growth, employment, and the advancement of agricultural technologies—strengthening Turkey's position as a reliable and competitive supplier in the global market.

Pesticide (Plant Protection Products) Legislation in Turkey

In Turkey, the pesticide (Plant Protection Products – PPP) legislation is meticulously regulated by the Ministry of Agriculture and Forestry with the aim of harmonizing national standards with the European Union (EU), protecting human health, and enhancing the competitiveness of Turkish agricultural exports in international markets.

These regulations cover all aspects related to:

The authorization (licensing) of pesticides for use on specific crops and pests,

The determination and publication of usage conditions and application periods,

The establishment of residue limits in agricultural products,

The control and monitoring of pesticide residues in agricultural commodities, and

The procedures related to the import and export of agricultural products concerning pesticide residues.

Licensing and Placing on the Market of Pesticides

The procedures for defining the pests and crops where pesticides can be used, approving newly introduced pesticides, and authorizing their placement on the market are regulated by the “Regulation on the Licensing and Placing on the Market of Plant Protection Products.”⁵⁹

All operations under this regulation are conducted by the Ministry of Agriculture and Forestry.

This regulation outlines the studies and procedures required for:

Obtaining licenses for pesticides used to protect plants and plant products during cultivation and storage,

Assessing potential adverse effects on human, animal, and environmental health, and

Setting rules for classification, packaging, and labeling of plant protection products.

Summary of Key Rules under the Regulation:

- To be used in Turkey, a pesticide (PPP) must be licensed by the Ministry. During the licensing process, the product’s efficacy and its potential impacts on human health and the environment are thoroughly evaluated.
- Any active substance to be licensed for the first time in Turkey must, as a rule, already be licensed in the European Union (EU) or in one of the G8 countries. This ensures that safety and quality standards remain high.
- Companies applying for a license must obtain a “Plant Protection Product Business Permit” from the Ministry and employ qualified technical personnel.
- Withdrawal and Disposal: The collection and destruction of expired or de-registered products are the responsibility of the license-holding company.

Maximum Residue Limits (MRLs)

The Maximum Residue Limit (MRL) is defined as the highest level of pesticide residue legally permitted in food or agricultural commodities.

When pesticides are applied to crops to control pests, the residue on the product gradually degrades and dissipates over time due to factors such as temperature, humidity, acidity, rainfall, and sunlight.⁶⁰ However, even after these natural processes, trace residues may remain on the harvested product.

The MRL value is determined through a statistical evaluation based on the following parameters:

- The Acceptable Daily Intake (ADI) — the maximum amount of pesticide that can be consumed daily without health risk,
- The consumption levels of the agricultural product for which the pesticide is registered,
- The results of residue trials conducted during registration studies, and
- The data from field inspections and residue monitoring programs (Figure 9).



Figure 9. MRL determination steps

The improper use of pesticides during the production of plant-based raw materials carries the risk of residue formation throughout the food chain, which can pose a significant threat to consumer health.^{61, 62, 63} Pesticide use is strictly regulated, and farmers are required to comply with the principles and application timings specified on the product label.⁶⁴

When pesticides are applied at the right time, in the correct dosage, and with adherence to the pre-harvest interval, the residues remaining on harvested crops will stay below the established Maximum Residue Limits (MRLs).

In Turkey, the permissible levels of pesticide residues in food products are regulated by the Turkish Food Codex Regulation on Maximum Residue Limits of Pesticides (2021).⁶⁵ The purpose of this regulation is to ensure a high level of consumer protection by defining the procedures and principles governing the maximum allowable residue levels of pesticides in plant- and animal-origin foods.

Upon examining the annexes of the regulation:

Annex 1A is a table that contains the list of plant and animal products to which the MRL values are applicable. The table also indicates which parts of each product are to be included in the analysis. An example image for Annex 1A is provided in Figure 10.

Code Number	Category	Group	Main products of the group or subgroup (1)	Scientific name	The part of the product to which MRL applies
		Subgroup			
100000	Fresh or frozen fruits; hard-shelled fruits				
110000		Citrus fruits			After removing the stem, the entire product
110010			Grapefruit	<i>Citrus paradisi</i>	
110020			Orange	<i>Citrus sinensis</i>	
110030			Lemon	<i>Citrus limon</i>	
110040			Lime	<i>Citrus aurantiifolia</i>	
110050			Mandarin orange	<i>Citrus reticulata</i> ; ssm: <i>Citrus deliciosa</i>	
110990			Others		

Figure 10. Sample image for Annex 1A

Annex 1B contains the list of similar products to which the same MRL (Maximum Residue Limit) applies. It is particularly important because it specifies under which product group less commonly produced and/or imported items are classified for residue limit assessment.

Annex 2 represents the most comprehensive and critical section of the Regulation. It includes the specific pesticide residue limits permitted in food products.

This section lists both the acceptable MRL values for pesticides registered in Turkey and the pesticides for which no MRL determination is required. An example image for Annex 2 is provided in Figure 11.

Active Ingredient	Products and Product Groups to Which the MRL Applies	MRL (mg/kg)	Notes
Acetamiprid (R)	0120100-Pistachio	0,07	
	0120060-Hazelnut	0,07	
	0120110-Walnut	0,07	
	0130010-Apple	0,4	
	0130020-Pear	0,4	
	0140020-Cherry (sweet)	1,5	
	0140030-Peach	0,2	
	0151000-Grape	0,5	
	0161030-Table olive	3	
	0163050-Pomegranate	0,01*	
	0211000-Potato	0,01*	
	0231010-Tomato	0,5	
	0231020-Pepper	0,3	
	0231030-Eggplant	0,2	
	0232010-Cucumber	0,3	
	0232020-Gherkin	0,6	
	0232030-Squash	0,3	
	0233030-Watermelon	0,2	
	0253000-Grapevine leaf (grape leaf and similar types)	0,01*	
	0401090-Cotton seed	0,7	
0402010-Oil olive	3		
0500030-Corn	0,01*		
0900010-Sugar beet	0,01*		

Figure 11. Sample image for Annex 2

Annex 3 generally functions as a continuation, correction, or special notes section related to the MRL tables in Annex 2.

Annex 4 contains the list of prohibited pesticides whose use has been completely banned in Turkey. The sale and use of these 217 banned pesticides are strictly forbidden, and penalties are imposed for any violations.

Annex 5 includes the list of pesticides for which no MRL determination is required in imported products. This annex currently lists 156 pesticides that do not require MRL specification for import control purposes.

The European Union (EU) regulates the use of pesticides and the residue limits in food through two of the strictest legal frameworks in the world, aiming to protect food safety and environmental health. This system is primarily based on two main regulations:

Regulation on the Authorization of Plant Protection Products – governing the approval, market placement, and use of pesticides within the EU, ensuring that only products proven safe for humans, animals, and the environment are permitted.

Regulation on Maximum Residue Levels (MRLs) – setting the legal limits for the amount of pesticide residues allowed in or on food and feed of plant and animal origin.

Together, these regulations form the backbone of the EU's integrated pesticide management and consumer protection policy, ensuring that food available on the market is safe, traceable, and environmentally sustainable.

Authorization (Placing on the Market) of Pesticides

This process determines whether a pesticide (active substance) can be used and placed on the EU market, and it is primarily regulated by Regulation (EC) No 1107/2009.⁶⁶

The main objective of this regulation is to allow only substances proven to pose no unacceptable risk to human health, animal health, or the environment. To achieve this, the EU applies a two-step authorization system:

Active Substance Approval:

First, the active substance (the pesticide itself) must be evaluated and approved by the European Commission following an extensive toxicological and environmental risk assessment. This is a long and scientific process that involves a comprehensive review of safety data and risk studies.

Product Authorization at National Level:

Once an active substance is approved, commercial pesticide products containing that substance must then be authorized by individual Member States, taking into account local agricultural practices and environmental conditions.

The Regulation also establishes strict exclusion criteria that prevent the approval of hazardous substances. For instance, carcinogenic, mutagenic, or toxic to reproduction (CMR) substances, as well as those proven to be endocrine disruptors, are generally not approved or are explicitly banned.

Setting Maximum Residue Levels (MRLs) in Food

The second major area of regulation relates to consumer protection, governed by Regulation (EC) No 396/2005.⁶⁷

The main purpose of this regulation is to protect consumer health by establishing maximum legal limits (MRLs) for pesticide residues that may be present in food and feed. It applies not only to products produced within the EU, but also to imported goods, making it one of the most influential rules affecting international trade.

If a specific MRL has not been established for a pesticide (for example, if it is not authorized for use on a given crop), a default limit of 0.01 mg/kg is automatically applied. In practice, this means that no detectable residues of that pesticide should be found in that product.

The EU Green Deal and the “Farm to Fork” Strategy

Under the European Green Deal, the EU’s Farm to Fork Strategy aims to make food systems fair, healthy, and environmentally friendly. One of its central goals is to reduce both the use and the risk of chemical pesticides by 50% by 2030. It also promotes the sustainable use of pesticides by revising existing rules and encouraging non-chemical alternatives such as Integrated Pest Management (IPM).

In summary, the EU maintains one of the strictest and most comprehensive pesticide regulatory frameworks in the world: Regulation (EC) No 1107/2009 governs which pesticides can be used, and Regulation (EC) No 396/2005 controls how much residue can remain in food. Together, they form a dual regulatory system that ensures maximum protection for consumers, the environment, and fair global trade.

Export Procedures

The export of fresh fruits and vegetables involves strict procedures, as it carries potential risks in areas such as food safety, biodiversity, and commercial interests. While these procedures vary from country to country, they generally focus on three main areas:

- Plant Health and Quarantine
- Food Safety and Quality (MRLs and Standards)
- Logistics and Trade Documentation

Although these procedures are similar in structure, they differ depending on the importing country's regulations — including specific MRL values, pesticides to be analyzed, additional treatments required for certain pests, and bilateral trade preferences.

In Turkey, all export procedures related to agricultural products are managed by the Ministry of Agriculture and Forestry. The General Directorate of Food and Control is responsible for the inspection, quality verification, and food safety certification of export products.

Local and provincial Directorates of Agriculture and Forestry implement these procedures in the field. They perform physical inspections, official sampling, and direct samples to accredited laboratories for analysis and certification.

Although the Ministry establishes the legal framework and inspection system, exporters' associations and private sector companies also play an active role in the process.

From Farm to Foreign Shelves

Although the export of fresh produce may seem procedural, in practice it is a long and detailed process that extends from the farm to the shelves of a foreign market.

The exported product must meet the physical, visual, and quality requirements (shape, size, color, maturity, appearance) set by the importing country.

Additionally, importing countries often require documentation proving that the products are free from diseases, harmful insects, and weed seeds, to protect their own ecosystems and agriculture.

The most critical criterion in fruit and vegetable exports is that pesticide residues must remain below the legal limits. Since these legal limits vary by country, the target export market must be identified during production planning, and appropriate pesticide programs must be applied accordingly.

Educating farmers on these requirements enables them to plan their production for export markets, thereby increasing the commercial value and marketability of their products while ensuring consumer access to safe food.

Export Procedure Steps

- The process begins when the exporting company applies to the Provincial Directorate of Agriculture and Forestry.

- After the application, an authorized inspector assigned by the Ministry visits the warehouse or cold storage facility where the products are stored.
- The inspector conducts a physical inspection, checking the packaging, labeling, and general condition of the products.
- At the same time, the Plant Quarantine Directorates issue a Phytosanitary Certificate after examining the products for potential quarantine pests.
- The inspector also verifies whether the product meets quality standards such as size, maturity, and appearance.
- Following this inspection, official samples representing the export batch are taken for pesticide residue analysis. These samples are sealed and sent to authorized and accredited laboratories.
- The samples must accurately represent the entire batch, and if necessary, be transported under a cold chain to the laboratory as quickly as possible to ensure integrity.
- Analyses must be carried out only in laboratories authorized by the Ministry of Agriculture and Forestry (Figure 12).

Laboratory Analysis Process

Once an official fruit or vegetable sample reaches the laboratory, it undergoes a detailed multi-step analytical process:

Sample Preparation:

The entire sample is homogenized using special grinding equipment to ensure uniformity. Pesticide residues are then extracted using specific solvents and methods. The extract is further cleaned to remove compounds that may interfere with the analysis or damage instruments.

Analytical Methods:

The prepared extract is analyzed using highly sensitive instruments. Laboratories typically employ liquid chromatography (LC) for non-volatile pesticides and gas chromatography (GC) for volatile compounds. Both methods can detect pesticide residues with extreme precision, often at levels as low as parts per million (ppm) or parts per billion (ppb) — like a unique chemical fingerprint of each pesticide.

Reporting:

The results are compiled into an official report that details the type and quantity of each detected pesticide, the analytical methods used, and the relevant legal limits.

If all residue levels fall below the target country's MRLs, the report is marked "Compliant", granting export approval.

However, if even a single pesticide exceeds the limit, the report is marked "Non-Compliant." This may result in the rejection, return, or destruction of the entire batch.

Such outcomes can lead to major financial losses for exporters and may cause the company to be blacklisted by the importing country's customs authorities, damaging both the company's and the nation's reputation — and potentially hindering future export opportunities.



Figure12. Schematic representation of the inspection and analysis stages in exports

Although export procedures are generally similar, the requirements of importing countries can differ significantly. For example, while MRL levels for exports to the European Union (EU) are almost the same as those applied in Turkey, exports to Russia may involve different MRL thresholds for the same product group.

Similarly, Japan enforces stricter quarantine measures than most other countries for the import of fresh fruits and vegetables.

Therefore, if a product is intended for export, the target country should be identified at the beginning of production, and all processes — including pesticide selection, dosage, and application schedules — should be planned accordingly

8. CONCLUSIONS AND RECOMMENDATIONS

- Pesticides remain the most effective tool for preventing yield losses caused by agricultural pests and are widely used across the world.
- Pesticides vary greatly depending on their chemical composition and the type of pest they are designed to control.
- Internationally recognized analytical methods and highly sensitive instruments are used for pesticide detection.
- Laboratories conducting pesticide analyses for export must comply with both national and international accreditation requirements and are subject to rigorous inspections.
- Exports contribute positively to the national economy by generating income, creating new markets, reducing unemployment, and promoting rural development.
- The export of fresh fruits and vegetables follows specific procedures. Although Turkey and the EU share similar frameworks, there are minor procedural differences in practice.
- In non-EU countries, export criteria may differ considerably; therefore, it is essential to determine the target export market at the start of production to ensure compliance and export success.

REFERENCES

1. Akdoğan, N., Divrikli, Ü., & Elçi, L. (2012). Pestisit kalıntılarının belirlenmesi. *Akademik Gıda*, 10(1), 125–132.
2. Carson, R. (1962). *Silent Spring*. Boston: Houghton Mifflin.
3. Katip, A. (2019). Bursa ili tarımsal pestisit kullanımının değerlendirilmesi. *BEÜ Fen Bilimleri Dergisi*, 8(1), 197–205.
4. FAO & WHO. (2014). *International Code of Conduct on Pesticide Management (Rev.)*. Rome: FAO.
5. Codex Alimentarius Commission. (1993). *Codex Classification of Foods and Animal Feeds*.
6. Altıkat, S., Turan, T., Ekmekyapar, A., Torun, H., & Bingöl, M. Türkiye’de pestisit kullanımı ve çevreye olan etkileri.
7. FAO. (2007). *Manual on the Submission and Evaluation of Pesticide Residues Data*. Rome: FAO.
8. FAO. (2016). *Pesticide Atlas*. Rome.
9. WHO. (2020). *The WHO Recommended Classification of Pesticides by Hazard*. Geneva: WHO.
10. U.S. EPA. (2015). *Pesticides and Their Impact on Children: Key Facts*. Washington, D.C.: EPA.
11. Tözün, M., & Akar, E. (2022). Türkiye’de gıda numunelerinde pestisit kalıntıları. *ESTÜDAM Halk Sağlığı Dergisi*, 7(1), 177–191.
12. Böll Stiftung. (2023). *Pestisit Atlası*. Heinrich Böll Stiftung Türkiye.
13. T.C. Tarım ve Orman Bakanlığı. (2022). *TGK Pestisitlerin Maksimum Kalıntı Limitleri Yönetmeliği Rehberi*. Ankara.
14. Ware, G. W. (1983). *Pesticides: Theory and Application*. W.H. Freeman.

15. Zettler, J. L., & Arthur, F. H. (2000). Historical overview of stored product protection. *Journal of Stored Products Research*, 36(1), 1–6.
16. Unsworth, J. (2010). History of pesticide use. IUPAC Report.
17. Pimentel, D. (1995). Amounts of pesticides reaching target pests: environmental impacts and ethics. *Journal of Agricultural and Environmental Ethics*, 8(1), 17–29.
18. Müller, P. H. (1948). Nobel Lecture: DDT and the Insect Problem.
19. Bourguet, D., & Guillemaud, T. (2016). The hidden and external costs of pesticide use. *Sustainable Agriculture Reviews*, 19, 35–120.
20. Carson, R. (1962). *Silent Spring*. Houghton Mifflin.
21. U.S. EPA. (2020). Pesticide regulation and DDT ban history.
22. European Commission. (2020). Farm to Fork Strategy – for a fair, healthy and environmentally-friendly food system.
23. FAO/WHO. (2019). *Pesticide Residue Analysis Manual*. Rome.
24. Ambrus, A., & Hamilton, D. (2011). *Pesticide Residues in Food and Drinking Water*. Woodhead Publishing.
25. Hernández, F. et al. (2012). Current use of high-resolution mass spectrometry in the environmental sciences. *Analytical and Bioanalytical Chemistry*, 403, 1251–1264.
26. Anastassiades, M. et al. (2003). QuEChERS method for pesticide residues. *J AOAC Int*, 86(2), 412–431.
27. Alder, L. et al. (2006). Mass spectrometric analysis of pesticide residues in food. *J Chromatogr A*, 1136(1), 1–37.
28. ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories.
29. European Commission. (2005). Regulation (EC) No 396/2005 on maximum residue levels of pesticides.
30. Xu, X. et al. (2020). Emerging technologies for pesticide residue analysis: trends and perspectives. *Trends in Analytical Chemistry*, 131, 116024.

31. EURACHEM/CITAC. (2016). Guide to Quality in Analytical Chemistry.
32. Ambrus, A. (2004). Reliability of measurement results in pesticide residue analysis. *Accred Qual Assur* 9, 288–297.
33. Ellison, S. L. R., & Williams, A. (Eds.). (2012). *Eurachem/CITAC Guide: Quantifying Uncertainty in Analytical Measurement*.
34. ISO. (2010). ISO 15189 Medical laboratories — Particular requirements for quality and competence.
35. ILAC. (2018). Introduction to ISO/IEC 17025:2017.
36. ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories.
37. Thompson, M. et al. (2006). The International Harmonized Protocol for Proficiency Testing of Analytical Chemistry Laboratories.
38. ILAC-G8:09/2019. Guidelines on the Reporting of Compliance with Specification.
39. ISO 9001:2015. Quality management systems — Requirements.
40. ILAC. (2020). ILAC Mutual Recognition Arrangement (MRA) Overview.
41. IAF & ILAC. (2019). Building confidence in global trade through accreditation.
42. ILAC. (2015). ILAC MRA - Enhancing the acceptance of accredited test reports.
43. WTO. (2018). *Technical Barriers to Trade Agreement: Principles and Applications*.
44. WTO. (2014). *TBT Agreement and International Standards*.
45. European Commission. (2008). Regulation (EC) No 765/2008 setting out the requirements for accreditation.
46. TÜRKAK. (2022). *Turkish Accreditation Agency Annual Report*.
47. OECD. (2021). *The strategic role of accreditation in trade facilitation*.
48. ILAC-IAF. (2023). *Digital transformation in accreditation systems*.
49. Ministry of Trade of Türkiye. (2023). *Export strategy and the role of accredited laboratories*.

50. Şenalp, M. E. (1982). Türkiye Yaş Meyve-Sebze Üretim ve İhracat İmkanları. T.C. Gıda, Tarım ve Hayvancılık Bakanlığı Yayınları.
51. Tarım ve Orman Bakanlığı. (2019). Yaş Meyve ve Sebze Çalıştay Raporu.
52. Özdemir, S., & Şengül, H. (2008). Türkiye'nin Avrupa Birliği Ülkelerine Yaş Meyve-Sebze İhracatı ve Avrupa Birliği Çevre Politikalarından Kaynaklanan Teknik Engeller. Ç.Ü Fen Bilimleri Enstitüsü, 18(3), 119-129
53. Sevim, K. (2016). Yaş Meyve ve Sebze İhracatında Kalite Yönetim Sistemlerinin Önemi. Uluslararası Ticaret ve Pazarlama Dergisi, 1(1), 54-68.
54. Niyaz, Ö. C., & Demirbağ, N. (2011). Türkiye Yaş Meyve Üretim ve İhracatının Son On Yıllık Döneminin Değerlendirilmesi. Dergipark.
55. Uludağ İhracatçı Birlikleri. (2018). *Yaş Meyve Sebze Sektör Raporu*.
56. Doğaka. (2015). *Yaş Sebze Meyve Sektör Raporu*. Doğu Akdeniz Kalkınma Ajansı.
57. Kızılaslan, H., & Yalçın, A. (2018). Avrupa Birliği ve Türkiye'de Yaş Meyve ve Sebze Pazarlama Sistemleri. Sosyal Bilimler Araştırmaları Dergisi.
58. EİB (Ege İhracatçı Birlikleri). (2024). *Yaş Meyve Sebze ve Meyve Sebze Mamulleri İhracatı 6 Ayda 3 Milyar Doları Aştı*.
59. Tarım ve Orman Bakanlığı. (2024). *Bitki Koruma Ürünlerinin Ruhsatlandırılması ve Piyasaya Arzı Hakkında Yönetmelik*. Resmî Gazete.
60. Yasir M., Hossain A., Anubhav Pratap-Singh, A. (2025) Pesticide Degradation: Impacts on Soil Fertility and Nutrient Cycling. *Environments* 2025, 12(8), 272.
61. Chmielewski J, Łuszczki J, Czarny-Działak M, et al.(2021) Environmental exposure to xenoestrogens (XEs) and related health effects. *J Elem.* 2021;26(3):717–730.
- 62 Chmielewski J, Czarny-Działak M, Wróblewska I, et al.(2021) The challenge of Endocrine Disrupting Compounds (EDCs) in the current environment for public health. *J Elem.* 2021;26(4): 893 – 903.
- 63 .Leskovac A, Petrović S. Pesticide Use and Degradation Strategies: Food Safety, Challenges and Perspectives. (2023). *Foods*. 12(14):2709.

64. Gamage A, Gangahagedara R, Gamage J, et al.(2023) Role of organic farming for achieving sustainability in agriculture. *Farming Syst.* 2023;1(1):100005.
65. Türk Gıda Kodeksi Pestisitlerin Maksimum Kalıntı Yönetmeliđi (2021) Resmi Gazete. 31611.
66. Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC
67. Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC Text with EEA relevance.