

COMPARATIVE STUDY ON CLASSICAL AND ROBOTIZED PACKAGING MACHINES IN THE FOOD INDUSTRY

Iuliana MERCE¹, Anda MILIN¹, Tabita ADAMOV¹, Ioan BRAD¹

¹ University of Life Sciences "King Mihai I" from Timisoara

RESEARCH ARTICLE

Abstract

In the context of the accelerated transformations driven by Industry 4.0, packaging processes in the food industry have evolved significantly, shifting from classical, predominantly mechanical systems to intelligent robotic solutions characterized by advanced automation, flexibility, and high efficiency. This paper presents a comparative study between traditional and robotic packaging equipment, analyzing the differences between them in terms of operational performance, precision, food safety, implementation and maintenance costs, as well as their impact on productivity. The results highlight that classical equipment, although still a viable option for small-scale units and stable production processes, is limited by technological rigidity, the need for manual adjustments, and the risks associated with human intervention. In contrast, robotic systems offer superior repeatability, rapid adaptability to product changes, optimized energy consumption, and full digital integration into modern production lines. The study emphasizes the essential role of automation in enhancing the competitiveness of the food industry and outlines the inevitable direction of advancement toward intelligent, sustainable, and fully autonomous packaging.

Keywords: (max. 5) automation; efficiency; productivity; food safety; modern technologies

#Corresponding author:

iulianamerce@yahoo.com

INTRODUCTION

Packaging represents one of the essential stages in the food industry, playing a crucial role in protecting products, extending their shelf life, and facilitating distribution and commercialization. Technological progress in recent decades has led to major transformations in packaging processes, marked by the transition from classical, predominantly mechanical equipment to robotized systems characterized by advanced automation, increased precision, and enhanced flexibility (Banu C., 2009).

Packaging and goods form an integrated system; therefore, packaging methods must take into account the interdependent relationships established between the components of this system. Current trends in packaging design and packaging technologies include:

- reducing the consumption of raw materials, resources, and energy;
- increasing product preservation time;
- improving packaging performance by combining different manufacturing materials;
- facilitating the reintegration of packaging materials into the environment in the post-consumer phase.

In the context of increasingly stringent requirements regarding food safety,

traceability, energy efficiency, and productivity, companies in the food industry face constant pressure to optimize their packaging processes. Classical packaging machines remain viable solutions in certain situations due to their lower costs and ease of maintenance; however, their limitations become evident in modern production lines where rapid adaptability and high operational speed are required.

On the other hand, robotized technologies provide precise product handling, seamless integration into fully automated production flows, and reliable operation over long periods. This study analyzes the differences between traditional and robotized packaging equipment, with the aim of identifying optimal solutions for various types of processes and sectors within the food industry.

MATERIAL AND METHOD

The comparative study was conducted through a documentary and technical analysis of the main categories of packaging equipment used in the food industry, with a focus on the functional and operational differences between classical and robotized systems. Specialized bibliographic sources, technical manuals, food industry standards, and recent articles on the implementation of robotic technologies were examined.

The comparison between the two types of equipment was carried out by analyzing several technical and economic criteria selected based on their relevance to the food industry.

For each criterion, the technical specifications of both classical and robotized packaging machines were identified, along with their respective advantages and limitations. The collected data were synthesized into a comparative table to provide a structured overview of the differences between the two categories of equipment.

RESULTS AND DISCUSSIONS

Technological transformations over the past two decades have brought profound changes to packaging processes in the food industry, marking a shift from conventional automation to advanced packaging systems based on artificial intelligence and industrial robotics.

These developments align with the broader paradigm of Industry 4.0, which involves the integrated digitalization of processes, the use of autonomous equipment, and continuous connectivity among components of the production chain.

Rapid progress in mechatronics, power electronics, advanced sensor technology, and industrial informatics has enabled the emergence of equipment capable of surpassing the limitations of classical machines. Increasingly strict requirements regarding food safety, processing accuracy, reduction of cross-contamination, and the need to adapt processes to a wide variety of products have driven companies to adopt robotic systems in primary, secondary, and tertiary packaging stages (Schwab K., 2017).

The implementation of industrial robots in the food sector has occurred progressively—initially for simple, repetitive operations (pick & place), and later for more complex tasks such as:

- handling delicate products (soft fruits, pastries, portioned meat);
- high-speed packaging on automatically synchronized lines;
- intelligent labeling and visual inspection;
- palletizing and autonomous warehousing.

For several decades, classical packaging machines formed the backbone of production lines in the food industry. These machines are characterized by predominantly mechanical or electropneumatic mechanisms and are designed

to perform standardized operations such as dosing, forming, filling, sealing, and labeling. They remain widely used today, particularly in small and medium-sized enterprises, due to their low cost, robustness, and operational simplicity (Stan E., 2004).

However, technological advances and the demands of the modern market—product diversification, stricter hygiene standards, and the need for greater flexibility and efficiency—have highlighted the limitations of traditional systems, placing them in contrast with robotized and digital packaging technologies.

From a technical standpoint, classical packaging machines are composed mainly of mechanisms driven mechanically or electromechanically, with motion transmitted through traditional components such as gears, cams, belts, shafts, and basic pneumatic systems.

At the core of these machines lies a linear, relatively rigid logic of operation, where each component performs a repetitive cycle calibrated for a specific product type or packaging format. This construction provides high durability but significantly limits the machine's ability to adapt to changes in the production flow.

Control of classical equipment is generally achieved through analog systems or older-generation electronic controllers that allow only a limited number of automatic adjustments. Fine settings—such as feed speed, dosing pressure, or sealing temperature—require direct operator intervention, introducing an inherent degree of variability into the process.

For instance, in vertical form-fill-seal machines (VFFS), cutting and sealing parameters are manually stabilized, and even small temperature fluctuations can affect packaging quality, especially with sensitive products or films with varying properties. This reliance on human intervention underscores the limitations of classical technology in meeting increasingly strict requirements for repeatability and uniformity.

The materials from which classical packaging machines are built are generally durable and compliant with sanitary regulations; however, their complex mechanical configuration, consisting of many moving components, can make cleaning procedures difficult. The dosing, transport, and sealing sections often include hard-to-reach areas where food residues may accumulate, requiring thorough manual sanitation.

This not only consumes time but also increases the risk of contamination when cleaning is not performed properly.

In general, classical packaging equipment is characterized by higher energy consumption compared to modern machines. Mechanisms based on mechanical, hydraulic, or simple pneumatic actuators do not always include efficient energy-recovery systems or automatic consumption management, which leads to increased operational costs—especially for large producers or continuous processes (Stan E., 2004).

Despite these limitations, classical machines remain valued for their structural reliability: a well-maintained machine can operate for decades with minimal intervention. This characteristic explains their persistence in many factories, where they still represent the "backbone" of packaging processes.

Robotized packaging equipment, on the other hand, stands out through a series of technical features that fundamentally differentiate it from classical machines, representing a true paradigm shift in the organization of food production.

These systems are designed not only to automate repetitive tasks but also to recreate the entire packaging process in an intelligent, adaptive manner that is deeply integrated into the digital infrastructure of the modern factory (Groover, M.P., 2020).

Types of automated equipment include:

- wrapping machines: used to close boxes and apply packaging seals, ensuring optimal product safety;
- labeling machines: apply labels containing product information, barcodes, or QR codes, ensuring traceability and compliance with regulations;
- complete packaging lines: integrating multiple functions such as filling, closing, labeling, and palletizing into a single automated system.

Modern automatic packaging machines follow a systematic seven-step process (Kairui Machinery, 2025):

Step 1: Product receiving and identification – Products enter the system through automated feeding mechanisms. Barcode scanners and RFID readers instantly identify each item. This identification process determines: product type and specifications, suitable packaging materials, required handling methods.

Step 2: Sorting and orientation – Conveyor systems transport products to sorting stations. Robotic arms position items according to destination requirements. Proper alignment ensures correct packaging orientation, appropriate spacing between items, and efficient use of materials.

Step 3: Selection of packaging material – The system automatically selects suitable packaging materials. Intelligent algorithms consider product characteristics and protection needs. Material options include: cardboard boxes of various sizes, protective plastic packaging, foam inserts for fragile items.

Step 4: Packaging and cushioning – Products are securely placed into containers. Automatic cushioning systems add protective materials as needed. This step prevents product movement during transport, damage from impacts or vibrations, and quality issues upon delivery.

Step 5: Sealing and labeling – Packages receive appropriate sealing using automated equipment. Labeling systems add shipping information and tracking codes. Sealing technologies include thermal sealing for plastics, adhesive tape application, and mechanical closure systems.

Step 6: Quality control and verification – Automated inspection systems perform complete checks. Weight sensors verify that the package contents meet specifications. Quality control includes: seal integrity testing, visual inspection systems, dimensional accuracy verification.

Step 7: Sorting and dispatch – Finished packages move to sorting areas. Integration with shipping systems directs items to the correct dispatch locations.

Essentially, robotic technology is based on the ability of equipment to operate autonomously, performing complex operations with a level of precision that is difficult to achieve through conventional mechanical means.

Unlike classical machines, whose operation depends on rigid mechanical sequences, robotic equipment functions through sophisticated algorithms integrated into next-generation programmable control systems.

As a result, the robot's movements—whether involving product handling, packaging positioning, or sealing—are executed with consistent accuracy, leading to unprecedented

uniformity in the technological process (Bolton W., 2018).

An often underestimated yet essential aspect is process ergonomics. Robotic systems take over repetitive, monotonous, or hazardous tasks, relieving operators from activities that cause fatigue, physical strain, or exposure to high temperatures. Instead of performing physical interventions, the operator's role shifts toward monitoring, supervision, and data management.

Consequently, human labor becomes safer and more specialized, while errors caused by operator fatigue are completely eliminated.

Another important characteristic is the adaptability of robotic equipment to modern industry requirements, which involve frequent

packaging changes, product diversification, and process customization. Robots can be reprogrammed quickly to handle new formats without the need for extensive mechanical adjustments. In a competitive market where manufacturers must respond rapidly to commercial demands, this flexibility becomes a major advantage.

In terms of energy consumption, robotic packaging systems are designed to minimize losses and improve resource efficiency. Processes are energetically optimized through algorithms that adjust speed, force, and operation intensity as required. In addition, modern technologies allow the monitoring of consumption and the automatic adaptation of equipment settings to its load conditions.

Table 1

Comparative Table Between Classical and Robotic Packaging Equipment in the Food Industry

Analysis Criterion	Classical Packaging Machines	Robotic Packaging Machines
Operating principle	Mechanical or electromechanical operation, based on rigid repetitive sequences and manual adjustments.	Autonomous, digitally controlled operation with AI algorithms and real-time synchronization.
Level of automation	Low to medium automation; requires human intervention for feeding, adjustments, and supervision.	Advanced automation; fully automated workflow with minimal operator intervention.
Productivity	Constant productivity, limited by operator pace and mechanical wear.	High productivity, continuous 24/7 operation with no variation in work rhythm.
Operational flexibility	Low flexibility; format changes require time and mechanical adjustments.	Very high flexibility; rapid reprogramming and adaptation to new products without mechanical changes.
Precision and repeatability	High variability; precision depends on adjustments and operator skill.	Constant millimetric precision, excellent repeatability due to sensors and intelligent systems.
Packaging quality	Non-uniform over time; risk of dosing or sealing errors.	Consistent and uniform; automatic visual inspection and real-time correction of deviations.
Food safety	Higher risk of contamination due to manual handling; difficult-to-clean internal mechanisms.	Minimal risk; no human contact, food-grade surfaces, superior hygiene.
Investment cost	Low initial investment, accessible for small businesses.	High initial investment, amortized over the medium and long term.
Operational costs	High labor costs, frequent maintenance, higher energy consumption.	Reduced operational costs: optimized consumption, predictive maintenance, reduced labor.
Maintenance	Requires regular mechanical intervention; repairs rely on inexpensive but frequent classical parts.	Digital, sensor-based maintenance; rare and planned downtime.
Integration in production flow	Integrated through simple conveyors with manual synchronization.	Fully digitally integrated (PLC, SCADA, IoT), continuous communication between modules.
Ergonomics and work impact	Repetitive, physically demanding tasks; risk of fatigue and accidents.	Eliminates repetitive labor; operators shift to technical and supervisory tasks.
Sustainability	High energy consumption, higher material losses.	Reduced, optimized consumption; significant reduction in food and material waste.
Optimal use cases	Small units, stable production, low product diversity.	Intensive, diversified production adapted to modern market requirements.

Automation of packaging processes offers numerous advantages, including increased productivity, reduced costs, and improved product quality. However, it is also important to consider the disadvantages. One of the major drawbacks of automation is the high initial cost of acquiring and implementing the equipment.

In addition to the price of the machines themselves, installation, programming, and staff training costs must also be taken into account. For small companies or those with limited financial resources, these expenses may represent a significant barrier.

Automated equipment requires regular maintenance to operate at maximum capacity. These maintenance operations can be costly and require qualified personnel. In the event of malfunctions, production lines may be halted, leading to delivery delays and financial losses.

Alongside maintenance, automation also involves risks associated with software updates and compatibility with other systems, adding an additional layer of complexity and cost.

Automation increases dependence on technology, which can become problematic in cases of operational disruptions, technical errors, or cyberattacks. In such situations, the entire production line may be compromised, affecting deliveries and, consequently, customer satisfaction.

To minimize these risks, companies must invest in cybersecurity and establish well-defined contingency plans to manage possible technical issues.

Ultimately, automated packaging machines operate far more quickly than a human team, enabling the production of significantly larger quantities of packaged goods. This makes them an ideal choice for large enterprises handling substantial product volumes. Moreover, the margin of error is considerably lower in automated processes, resulting in an overall reduction in waste.

Although the initial investment in an automated packaging system may seem costly, the long-term savings are substantial. Automation not only accelerates production but also eliminates the need for manual labor, contributing to significant cost reductions over time. Considering the large volume of products that can be efficiently packaged with an automated system and the reduction of generated waste, the equipment pays for itself rapidly, making operations more profitable in the long run (VLM Poliplast, 2025).

The period 2020–2035 represents one of the most dynamic stages in the history of the food industry, characterized by a rapid transformation toward digitalization, intelligent automation, and complete integration of advanced technologies into production and packaging processes.

The fast pace of technological innovation, rising market demands, and increasing pressure regarding food safety are driving companies to adopt increasingly sophisticated robotic solutions that far exceed the capabilities of traditional machines (Schwab K., 2017).

The packaging market is experiencing long-term changes: shifts in demographic conditions, evolving customer requirements, rising purchasing power in emerging countries, and the growing use of technological solutions have triggered a rethinking of packaging materials and manufacturing processes.

In the future, the expansion of classical packaging functions through additional “smart” features (such as traceability, specific interaction or reaction with the packaged product, or embedded sensors) will provide new opportunities for differentiation from competitors. It remains uncertain whether this expertise will be developed by packaging producers to offer complete solutions to their clients, or whether Smart Packaging competence will remain with the customers themselves.

In many areas of the packaging industry, operational excellence has already become a core element of companies’ identity in ensuring efficient production. In numerous factories, efficiency has been maximized due to strong competitive pressures.

To further exploit efficiency levers, companies are increasingly focusing on inter-factory production network planning. Additionally, interfaces are reduced through stronger customer integration. Another key driver for improving efficiency is the automation of production and logistics.

In the future, for detailed optimization, enterprises will rely even more on the transparency provided by Industry 4.0-compatible production machines. Optimization will be carried out within automation solutions, meaning that interdisciplinary IT expertise will become more important than ever in production.

Digitalization is no longer a buzzword but a major factor of efficiency and effectiveness across all industrial sectors, including the

packaging industry (Horváth & Partner Management Consulting, 2021).

CONCLUSIONS

The comparative analysis of classical and robotized packaging equipment clearly demonstrates that the food industry is undergoing a profound technological transformation driven by the principles of Industry 4.0. Classical packaging machines continue to play an important role in small-scale or highly standardized production environments, where low investment costs, structural robustness, and operational simplicity offer tangible benefits. Their mechanical reliability and long service life still make them viable solutions for certain producers with stable processes and limited product variability.

However, the results of this study show that the limitations of traditional equipment—reduced flexibility, dependence on manual adjustments, variable precision, increased risks of contamination, and higher long-term operational costs—significantly restrict their suitability for modern industrial requirements. As consumer expectations evolve and traceability, hygiene, and productivity standards become increasingly stringent, classical equipment no longer provides the responsiveness and consistency required in contemporary production chains.

In contrast, robotic packaging systems represent a qualitative leap in technological capability. Their high adaptability, autonomous functioning, advanced sensor integration, and digital connectivity enable superior operational accuracy and repeatability, along with continuous optimization of energy and material consumption. Moreover, robotic solutions dramatically reduce human contact with food products, considerably improving hygiene conditions and safety standards. Enhanced ergonomics and the shift of human labor toward monitoring and supervision contribute to safer workplaces and increased professionalism.

Despite their higher initial investment, robotic systems become cost-efficient in the medium and long term through reduced labor

requirements, minimized waste, predictive maintenance, and shorter production cycles. They also offer strategic advantages by supporting rapid format changes, diversified product portfolios, and seamless integration into digitally coordinated production ecosystems.

Overall, the study confirms that robotization is not merely an optional modern upgrade but a strategic necessity for companies seeking competitiveness, sustainability, and compliance with future industry standards. While classical equipment will maintain niche relevance, especially in low-complexity production environments, the long-term direction of the food industry is unequivocally oriented toward intelligent, interconnected, and fully automated packaging systems.

In this context, the transition to robotic technologies becomes a key factor for achieving operational excellence, ensuring product safety, and supporting the sustainable growth of food processing enterprises in an increasingly demanding and dynamic global market.

REFERENCES

- Banu, C. (coord.). *Treatise on Food Industry*, vol. I–III. Bucharest: ASAB Publishing House, 2009–2010.
- Bolton, W. *Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering*. Pearson, 2018.
- Ciobanu, C. *Packaging and Food Product Packaging Technology*. Galați: Academica Publishing House, 2019.
- Groover, M.P. *Automation, Production Systems and Computer-Integrated Manufacturing*. Pearson, 2020.
- Schwab, K. *The Fourth Industrial Revolution*. World Economic Forum, Geneva, 2017.
- Stan, E. *Machines and Equipment for the Food Industry*. Bucharest: Technical Publishing House, 2004.
- *** Horváth & Partner Management Consulting – *The European Packaging Industry in 2025: Trends, Perspectives and Success Factors in a Competitive Market Environment*, 2021.
- *** Kairui Machinery – *What Are Automatic Packaging Machines?*, <https://www.packagingmachineinc.com/ro/What-Are-Automatic-Packaging-Machines-id45595885.html>, website accessed on 5.11.2025.
- *** VLM Poliplast – *Automatic Packaging or Manual Packaging?*, <https://vlmpoliplast.ro/ambalare-automata-versus-ambalare-manuala/>, website accessed on 3.11.2025.