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MODERN TECHNOLOGIES: FROM ALTERNATIVE METHODS TO ARTIFICIAL INTELLIGENCE

ІННОВАЦІЙНІ ТЕХНОЛОГІЇ: ВІД АЛЬТЕРНАТИВНИХ МЕТОДІВ ДО ШТУЧНОГО ІНТЕЛЕКТУ

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The modern hospitality industry faces quality instability due to the human factor, requiring new management tools. This article analyzes the integration of Industry 4.0 into the coffee industry. Using a systematic review and statistical analysis of deep learning (YOLOv8) and near-infrared (NIR) spectroscopy, the study objectifies raw material quality. Results show Custom-YOLOv8n achieves 99.5% accuracy in green bean defect detection. Predictive control of roasting thermodynamics via LSTM neural networks effectively automates the "first crack" point. Robotic baristas achieve high productivity with extraction stability. The scientific novelty is a "bionic" synergy concept between craft production and technological automation. The practical value lies in flavor profile digitization and cost optimization.

Keywords: coffee, hospitality industry, barista, artificial intelligence, craft technologies, YOLOv8, automation, FoodTech.

Сучасна індустрія гостинності стикається з серйозним викликом – нестабільністю якості кавової продукції, що значною мірою зумовлено впливом людського фактора на всіх етапах виробництва. Це об'єктивно вимагає впровадження новітніх автоматизованих інструментів управління та контролю. Метою статті є проведення комплексного аналізу процесів інтеграції передових технологій Індустрії 4.0 у сучасну кавову індустрію через призму розвитку ресторанних та інноваційних крафтових технологій. Актуальність статті зумовлена гострою необхідністю пошуку оптимального балансу між збереженням автентичності крафтового продукту - «третьої хвилі», та забезпеченням його стабільної високої якості в умовах масового попиту. Методологія дослідження базується на системному огляді спеціалізованої літератури, на глибокому аналізі ефективності застосування алгоритмів глибокого машинного навчання (зокрема архітектури YOLOv8) та спектроскопії у ближньому інфрачервоному діапазоні (NIR) для об'єктивізації оцінки якості сировини на етапі її приймання. Доведено, що використання оптимізованої моделі Custom-YOLOv8n дозволяє досягти високої точності виявлення дефектів зеленого кавового зерна на рівні 99,5%, що мінімізує економічні втрати підприємств. Науково обґрунтовано ефективність застосування систем прогнозного управління термодинамікою процесу обсмажування за допомогою рекурентних нейронних мереж (LSTM). Це дозволяє повністю автоматизувати контроль критичної точки «first crack» та виключити ризики помилок оператора. Встановлено, що практичне впровадження роботизованих систем бариста дає змогу досягати безпрецедентної продуктивності, забезпечуючи при

цьому абсолютну стабільність усіх фізико-хімічних параметрів екстракції. Наукова новизна роботи полягає у комплексній деконструкції дихотомії між ручним виробництвом та автоматизацією, що дозволило сформувати новітню концепцію «біонічної» синергії людини та машини. Практичне значення результатів полягає у розширенні можливостей для повної цифровізації смакового профілю кави, оптимізації витрат на сировину та суттєвому підвищенні конкурентоспроможності закладів готельно-ресторанного бізнесу.

Ключові слова: кава, готельно-ресторанний бізнес, бариста, штучний інтелект, крафтові технології, YOLOv8, автоматизація, FoodTech.

Statement of the problem. Coffee, one of the most widely traded commodities in the world, economy and a drink that daily consume billions of people, has gone beyond its historical role of a simple functional stimulator and became a complex a cultural, culinary and technological artifact.

The modern hospitality industry is currently at a critical stage, experiencing a transition that is as much philosophical as technological. On the one hand, there is a deep deepening coffee movement “Third” waves” – a cultural shift that considers coffee as an artisanal product, similar to fine wine, emphasizing the character of origin (terroir), varietal features and manual precision extraction. On the other hand, the industry feels seismic influence global digital transformation, or “FoodTech”, which implements automation, big data analytics and artificial intelligence (AI) at every stage chain creation value [2, p. 40].

Modern market coffee in Ukraine and the world demonstrates not only quantitative growth, but also significant high-quality evolution [6, p. 75]. Such evolution requires a deep understanding of the fundamental principles of restaurant management and the implementation of modern technological processes, which are extensively covered in the foundational works of Ukrainian scholars [3, p. 43; 16, p. 46].

Analysis of recent research and publications. The theoretical foundation of this study integrates food science, sensory analysis, and computer science. Deconstructing the evolution of coffee culture is essential to understand modern technological interventions across production stages.

The history of coffee consumption is classified into distinct "waves" that contextualize the friction between craft traditions and automation, as outlined by P. S. M. Boaventura et al. [14, p. 258]. The "first wave" focused on mass production, commodity availability, and rapid caffeine delivery, often neglecting taste. Brands like Folgers and Nescafé epitomize this era, serving as a baseline evaluated in automated service research by Y. Ji et al. [18] and B. Lin & A. S. Mattila [19, p. 964]. The "second wave" saw the rise of major chains like Starbucks, introducing the "third place" concept and popularizing espresso-based drinks. While quality improved, bean characteristics were often masked by syrups and milk within a highly standardized approach analyzed by O. Yu. Davydova [4, p. 112].

The "third wave" drives modern craft production, treating coffee as an artisanal product with unique organoleptic properties tied to its terroir. This movement emphasizes supply chain transparency, lighter roasting, and manual brewing, as noted by S. M. Lohvinkov and V. L. Bezsonnyi [12, p. 115]. However, relying on manual barista skills introduces significant extraction variability. This "consistency gap" during peak hours due to human fatigue represents the core challenge that modern FoodTech addresses, as emphasized by I. M. Litvinova & O. F. Protasenko [11, p. 48], S. M. Lohvinkov & V. L. Bezsonnyi [12, p. 115], and V. V. Zhukov & T. M. Khaustova [8, p. 158].

FoodTech optimizes food manufacturing, preparation, and consumption through IT, AI, and biotechnology, addressing environmental sustainability and food safety, as discussed by O. Yu. Davydova and S. I. Sysoieva [6, p. 75]. Domestic scholars highlight process automation and AI integration to secure competitive advantages, explored by A. A. Ivashura [9, p. 36], Yu. V. Kolesnyk [10, p. 91], and L. P. Maliuk & N. V. Polstiana [13, p. 54]. Globally, the AI market in coffee manufacturing is projected to grow exponentially from USD 324.88 million in 2025 to over USD 1.47 billion by 2034 (CAGR of 18.3%), signaling a permanent infrastructure shift in hospitality.

Highlighting previously unresolved parts of the overall problem. Increasing consumer standards have bifurcated the industry's development trajectory. The first direction provides priority authenticity, ritual and human narrative that manifests itself in the spread specialized coffee shops and mastery alternative brewing methods such as Pour-over, Chemex and Aeropress. In this paradigm, the barista is seen as a master whose intuition and sensory sharpness are paramount.

The second direction provides priority efficiency, speed and consistency, which due to the emergence of “smart cafes” and completely automated systems that strive minimize variability human factor [16, p. 46].

Any coffee preparation technology, regardless of whether it is performed... is a method of “controlled extraction” – physicochemical process dissolution soluble aromatic coffee compounds matrices in water. The challenge has always been the control of a complex matrix of variables: water temperature, contact time, turbulence fluids and distribution sizes particles. Historically management these variables was an art form that depended from subjective experience [14, p. 258; 15, p. 4710; 5, p. 20]. Today the emergence of artificial intelligence offers mechanism transformation this art into an exact science, “digitizing” taste and smell to achieve what is often called “the ideal reproducibility” [17].

Formation of the objectives of the article (task statement). The purpose of the study is to conduct a comprehensive analysis integration modern technologies into the ecosystem preparation coffee, as well as, definition possibilities, boundaries and intersections between traditional manufacturing coffee and automated technologies, predicting that the future of the restaurant business lies in synergy these two aspects. Using artificial intelligence, starting from spectral analysis green beans and ending predicted management thermodynamics roasting, restaurant branch maybe to break new ground levels software quality and sustainability development.

Summary of the main research material. Object of research: technological processes production, processing and preparation coffee in modern industries hospitality and agriculture. Subject of research: transformation technologies preparation coffee under the influence of artificial intelligence, computer vision, robotics and sensory analysts, as well as their further impact on product quality, sensory consistency and economic efficiency. Structural integration these technologies in everything chains creation The cost is shown in Fig. 1.

In the study used polyhedral methodological approach to ensure integral analysis.

1. Systematic review literature and meta-analysis: critical analysis academic articles, technical documentation and industry reports of algorithms deep learning (YOLO, CNN) in rural economy. This includes review indicators efficiency (accuracy, completeness, mAP) for objective assessments effectiveness of artificial intelligence compared to baseline indicators for humans.

2. Comparative analysis innovative organizations in the field of "artificial coffee" for example works coffee shops «Kaffa Roastery» (Finland)- analysis methodologies creation artificial intellect conical mixtures for understanding creative potential algorithms. Demetria (Israel / Colombia)- rating application sensory read prints fingers in the supply chain. Artly & Cafe X (USA) – rating operating room mechanics and throughput abilities robotic service systems.

3. Technological rating – deconstruction physical and digital mechanisms of "smart" roasting (Cropster) and automated cooking for understanding controlled variables (thermodynamics, hydrodynamics).

4. Statistical market – analysis, synthesis of market growth data, surveys consumers of market perception (TAM model) and economic forecasts to determine future trajectories development industries hospitality.

Integrating artificial intelligence into coffee the industry is not monolithic development, but ubiquitous penetration into the entire chain creation value "from" "grains to the cup". Stages research structured chronologically, according to the production life cycle coffee: from analysis raw materials to thermal processing, extraction and maintenance.

Quality of the final drink in principle limited quality green (unroasted) beans. Traditionally rating quality is subjective, time-consuming a process that performed by people who "disassembled the cups" and visually sorted. This stage, as is known, is prone to errors due to human error fatigue and the subjectivity of sensory perception.

Visual Inspection is the primary method of removal defects (for example, black beans, sour beans, damage insects), which can spoil party. Mechanical color sorters exist for decades, but they don't always can to detect and distinguish complex defects. Systems computer vision based on artificial intelligence allow solve this problem.

According to the study by Ji et al. [18], architecture – based models YOLOv 8, reached unprecedented accuracy in detection defects in real time. In comparative research models YOLOv 8 demonstrated average accuracy (mAP) 0.995 (99.5%) in detection various classes defects that much surpasses older architectures such as YOLOv 4 (mAP 0.628),

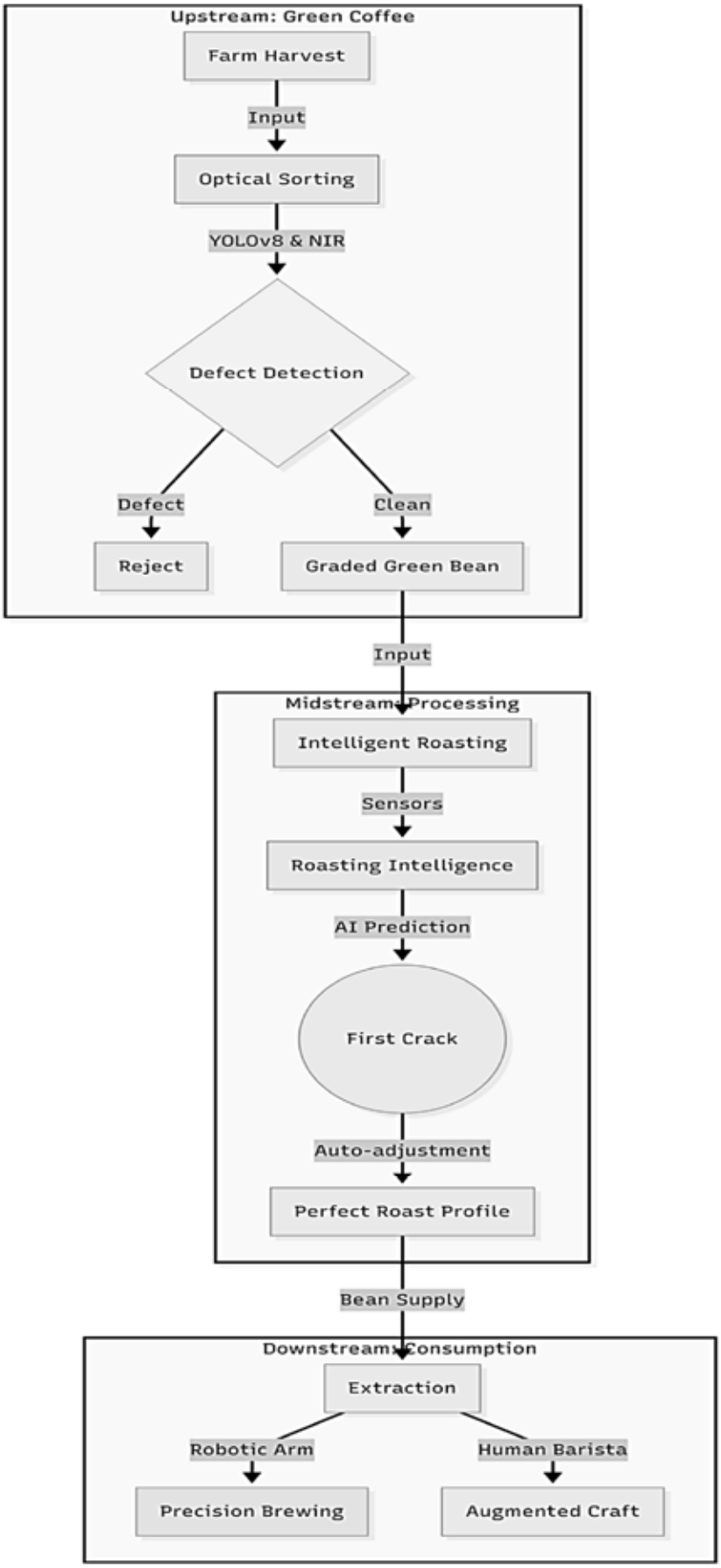

Figure 1. The "bionic" coffee value chain: integrating artificial intelligence from farm to cup

Source: formed by the authors

or standard convolutional networks, such as ResNet -50 (Table 1).

Based on the data from Ji et al. [18], a visual comparison of average accuracy (mAP) for different architectures of the models is shown in Fig. 2, which emphasizes a significant difference in productivity between outdated and modern algorithms.

Value these The data is deep. The ability "Custom – YOLOv 8 n" models reach 99% level recall means that it almost does not miss defective grains, level consistency, unattainable for human sorters during long-term changes. In addition, these systems can classify grains by species (arabica against robusta) with precision over 97%, preventing food fraud in the supply chain.

Besides visual defects, “Third wave” emphasizes complexity taste. Such companies like Demetria have become pioneers in the use portable sensors Near-Infrared (NIR) radiation for creating a “sensory” imprint” green coffee.

Mechanism is as follows. The sensor emits light in the grain; light absorbed or reflected depending from availability certain chemical bonds. Artificial intelligence algorithms analyze these spectral data, comparing thousands of them previous samples that were physically roasted and processed Q - estimators.

Digitization result is that the system can provide final flavor notes (e.g., “citrus”, “nutty”, “chocolate”) and rating qualities green coffee on the SCA scale (Association specialized coffee) to her roasting. The application of sensory analysis

Table 1

Comparative effectiveness of deep learning models training in detection defects coffee beans

Architecture models	Separate ability entrance	Precision	Recall	F1-score	mAP (Average accuracy)	Computational load
Custom-YOLOv8n	640x640	0.977	0.990	0.983	0.995	Low (optimized for real – time operation)
Standard YOLOv8	640x640	0.959	0.944	0.946	0.952	Low
YOLOv7	640x640	0.775	0.777	0.776	0.826	Average
YOLOv5	640x640	0.863	0.701	0.694	0.674	Low
YOLOv3	640x640	0.741	0.680	0.709	0.707	High

Source: formed by the authors

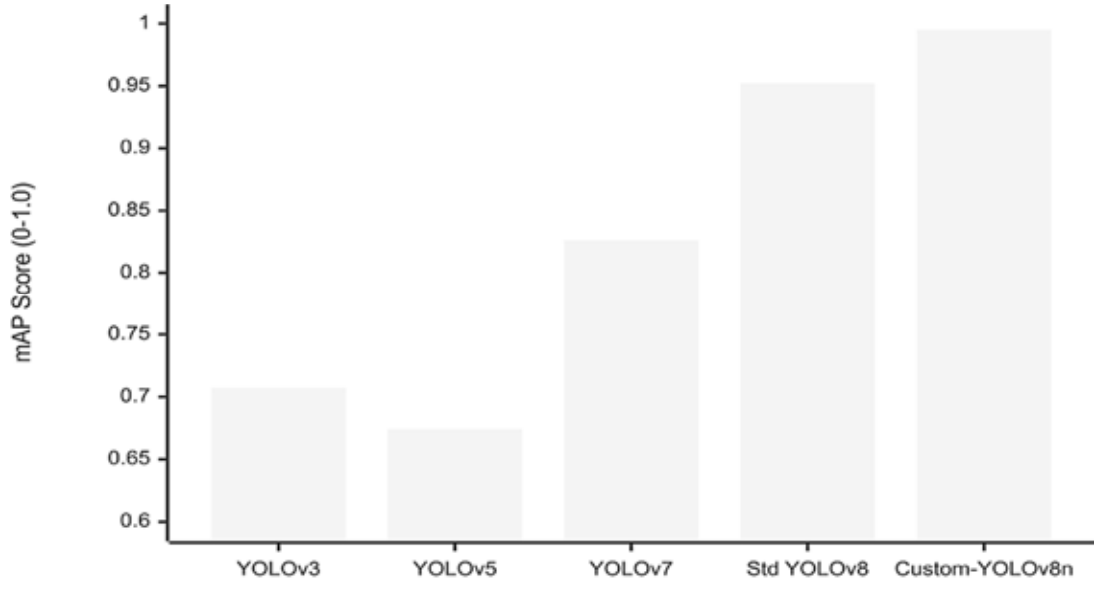

Figure 2. Comparative analysis average accuracy (mAP) for detection models objects

Source: formed by the authors

and innovative technologies for evaluating raw food materials, as well as complex quality management systems, are highly prioritized in modern Ukrainian restaurant practices to ensure product consistency [12, p. 115; 8, p. 158]. This democratizes the market: a small farmer using a smartphone and a sensor can objectively prove to the buyer high quality his/her harvest, ensuring fair compensation based on data, not subjective assessments buyer.

Roasting is the most complex step, a thermodynamic balancing act in which the roaster controls the heat input to develop flavor without burning the cellulosic structure. It is a nonlinear process involving endothermic (heat absorption) and exothermic (heat release) phases.

Modern roasting software such as Roasting Intelligence by Cropster, uses artificial intelligence to transform roasting from a reactive task to a predictive one. The mechanism of this predictive control loop, in particular with respect to the expectation of the "first crack", is depicted in Fig. 3.

Predicting "first crack" is the critical point where moisture inside the grain evaporates, causing the grain to expand and make an audible crack. This releases steam and heat (exothermic flash) that can destabilize the roasting environment. Cropster's AI analyzes the roasting curve in real time and predicts the exact moment of first crack within minutes.

Temperature Crash and Failure Management: A common defect is a "crash" (a sudden spike in temperature) or "fall" (a drop in temperature) after the first crack, resulting in a burnt or smoky flavor. AI algorithms monitor the rate of rise (RoR) and alert the roaster to adjust gas pressure before the thermal pulse causes a defect, ensuring the smooth, falling RoR curve required for optimal flavor development.

The synergy between artificial intelligence and traditional technologies is best demonstrated by the "AI- conic" project of the Finnish roasting company Kaffa.

Kaffa conducted an experiment. It tasked artificial intelligence, using models like GPT

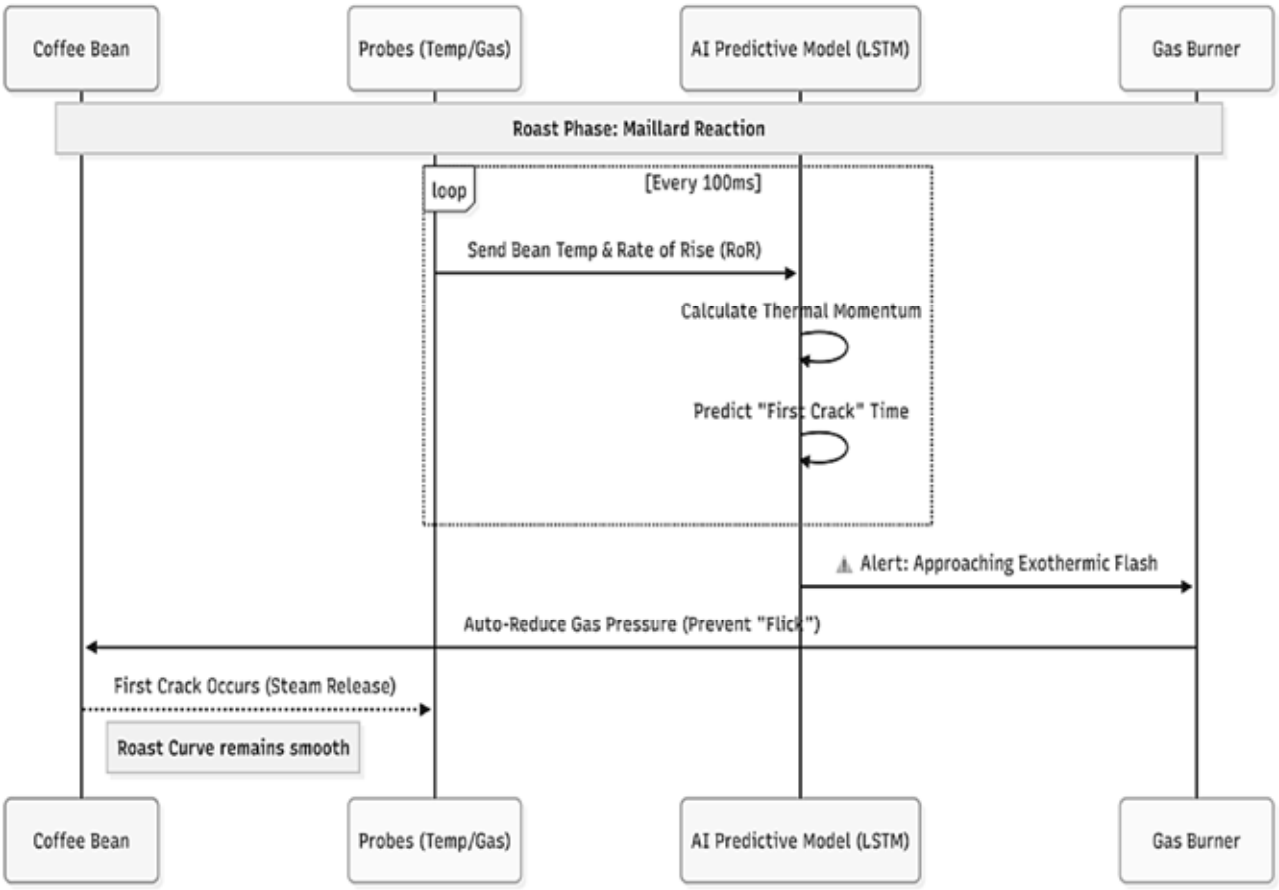

Figure 3. The process of predictive control based on artificial intelligence in thermodynamics roasting

Source: formed by the authors

and Copilot, to create a coffee blend that would perfectly match the tastes of coffee lovers, using data from its entire collection of green beans.

During the experiment, the AI suggested a complex blend of four beans: Brazilian, Colombian, Ethiopian and Guatemalan. The approach is unconventional. Coffee roasters typically blend 2-3 origins to avoid “mixing” the distinctive flavors.

The result of roasting and blind cooking the AI recipe was declared “perfect” by human experts without the need for adjustments. The AI identified a subtle balance of sweetness (Brazil/Colombia) and acidity (Ethiopia/Guatemala) that human intuition had missed. This result proved that AI can function as a creative partner, analyzing vast datasets of flavor interactions to suggest new culinary experiences. This approach fully aligns with the modern paradigm of craft beverage technologies, where traditional manual methods naturally evolve into comprehensive digitalization [9, p. 36].

Downstream production coffee – brewing is the stage at which consumer interacts with the product. It should be noted that this stage characterized by the largest instability. Yes, the influx consumers, an inattentive barista or wrong pounding can spoil high quality roast.

Robotic barista systems, such as Cafe X and Artly, use 6-axis industrial robotic manipulators to replicate the movements of a human barista with millimeter accuracy.

Unlike humans, the robot does not feel tired and works quite stably. It tamps the coffee with exactly the same pressure, for example 13.6 kg, and controls the water temperature with an accuracy of up to a tenth of a degree for each individual portion 24 hours a day.

Baristas are using computer vision to create incredible latte art. The Artly system uses deep learning computer vision to observe the milk being poured in real time. It adjusts the flow rate and pitcher position to create intricate latte art patterns (rosettes, hearts, animals, etc.), a skill that would normally take humans years to master.

The throughput of barista robots is twice that of human baristas. A typical robotic kiosk can produce over 100 drinks per hour, far surpassing a single barista, who on average produces 30-50 complex drinks per hour [10, p. 91]. This efficiency is crucial for high-traffic areas such as airports.

Although technical opportunities robots proven, their perception consumers remains complex [19, p. 966].

Adoption model technology (TAM) shows that theirs implementation caused by “perceived” “usefulness” and “perceived simplicity use”. Studies have shown that only 58% of consumers ready use a robot barista to reduce waiting times. However experience coffee “third” waves” deep rooted in hospitality and humanity communication [2, p. 40]. Critics argue that works deprive of “emotional values” of the cafe experience [1, p. 90]. So, robotic systems now best suitable for “functional” coffees environments (transport nodes, offices), and not for " empirical “environments” (urban cafes), where the human factor remains premium difference.

Integration these technologies has wide economic consequences, creating a platform for sustainable developmnt and growth of the coffee market.

Artificial intelligence – based roasting much more energy efficient. Preventing roasting defects that lead to losses parties, and optimizing thermal curve, smart roasting ovens reduce gas consumption and emissions carbon. Furthermore, addressing the ecological aspects of supply

Table 2

Comparative analysis works human barista and robotic systems

Operating indicator	Human barista	Robotic barista (e.g., Artly, Cafe X)
Sequence extractions	Variable (high variation in hours peak)	Absolute (almost zero variance)
Pass ability	~30-50 drinks / hour (continuously)	100+ drinks/hour (24/7 productivity)
Acquisition skills	Months / Years teaching	Instant (update) software provision
Possibility latte art	Depends from individual talent	Reproducible using computer vision
Customer interaction	High (emotional communication, hospitality)	Low (novelty, transactional efficiency)
Hygiene	High risk transmission vectors	Contactless, minimized risk

Source: formed by the authors

chain management and proving the economic efficiency of robotic FoodTech solutions are vital for the sustainable development of modern food enterprises [9, p. 36; 13, p. 54; 20, p. 295]. In addition, the exact artificial intelligence – based agriculture helps farmers optimize water and fertilizer use, reducing influence environmental cultivation environment.

Predicted fast coffee market growth from artificial intelligence (18.3% CAGR) indicates that investors are considering these technologies as necessary for sustainable activities enterprises industry in conditions changes climate (which threatens yields coffee) and shortages working forces [2, p. 40].

Thus, the comprehensive integration of artificial intelligence and robotic systems into the coffee industry is not merely a global trend, but a necessary vector for the modernization of the domestic hospitality sector. As highlighted in the foundational manuals and recent studies by Ukrainian scholars, the evolution from traditional craft methods to digitalized FoodTech solutions requires a balanced approach to quality management, ecological sustainability, and economic efficiency. This synergy of human creativity and algorithmic precision forms a new paradigm for restaurant enterprises, effectively preparing them for future market challenges.

Future studies will focus on analyzing the economic payback periods for robotic barista systems in the Ukrainian market and developing complex AI models capable of simultaneously predicting the thermal curve of roasting and the chemical composition of the final extract.

Conclusions. The transformation of the coffee industry from a subjective cultural approach to a data-driven high-tech ecosystem is not a future opportunity, but a present-day reality.

Conducted research confirms that integration of artificial intelligence into production and manufacturing coffee “from farm to cup” with elements automation, is a modern driver of steady increase quality, stability and sustainability development industries. Results conducted research indicate a synergistic effect between traditional and innovative technologies.

Artificial intelligence tools like Cropster and Demetria act as “exoskeletons” for coffee professionals, improving their natural sensory abilities with the help of objective data. The focus of the "third wave" on the terroir actually is carried out thanks to artificial intelligence, which provides transparency and accuracy sorting, necessary for identification and preservation unique characteristics of grains.

It has been proven that such mechanical aspects cooking, like tamping, profiling pressure etc., more efficient perform intellectual machines that frees up the human barista's time for implementation more creative processes such as: development new recipes, process maintenance, creation atmospheres hospitality etc.

Application algorithms YOLOv 8 and near infrared spectroscopy has solved the problem of inconsistency in sorting green coffee. Achieving 99% accuracy in detecting defects, artificial intelligence allows get guaranteed high-quality raw materials that meet the highest standards, reducing number waste and increasing value final product.

Development perspective industries hospitality provides reasonable combination traditional technologies and innovations. Successful enterprises future will be those who effectively will use artificial intelligence to provide a “craft” experience on a “commodity” scale.

Enterprises industries hospitality will work more effective if will use artificial intelligence during execution labor-intensive, mechanical processes, giving advantage over the main factor successful development – intelligence, creativity and creative people's approach.

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