

## Next-Generation Food Manufacturing: AI as a Catalyst for Productivity and Quality Enhancement

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### ABSTRACT

Artificial Intelligence (AI) applied in the industries of food manufacturing is revolutionizing the food manufacturing businesses at the levels of productivities, quality control, and operations of the industries. In this review, we discuss adopting AI technologies (such as machine learning, computer vision and predictive Analytics) throughout the various levels of food production which begins with the product formulation, raw material inspection, processing, packaging and distribution. Using AI, real-time monitoring is now a possibility, and the accuracy and human error have been minimized, so the safety level and consistency of the food product have improved a lot. It also plays an important role in predictive maintenance, the optimizing of the supply chain and energy management that assists manufacturers to reduce the downtimes, the expenditures and the wastes. With the active participation of the case studies of the enterprise leaders and startups, the examples of the AI successful application in real life is revealed in this article. Despite all its great benefits, a number of challenges such as the large implementation cost, the quality of data, as well as staffing changes still remain. However, when active innovation and strategic approach combine their efforts, AI has a massive potential to transform the face of food manufacturing process like never before, making it smarter, more environmentally-friendly, and audience-centered than ever.

## INTRODUCTION

The food production sector is the engine of the contemporary global economy that feeds billions of people and is experiencing a complex search in the jungle of the challenges such as the expansion of the population to be fed, the absence of supplies, workforce shortage and high standards of safety. The legacy traditional manufacturing processes are also most likely lacking in the aspects of adaptability, efficiency and precision since consumers switch to customized, secure, and sustainable products [1]. This has created an urgent need to change technology at every level of food production lifecycle that begins with cooking and harvesting of raw materials and involves packaging and distribution.

Artificial Intelligence (AI) is growing into a significant agent of change to respond to these rising demands. Man-made intelligence like decision making, pattern recognition and predictive analytics are some of the functions that AI possess and is an example of computer system that can perform [2]. The AI technologies, e.g. machine learning (ML), computer vision, robotics, and natural language processing (NLP), will most likely be introduced to food manufacturing so that the production line is tracked and managed, the processes are optimized, the quality could be enhanced, and the levels of waste should also be reduced [3].

AI in the food industry is not a revolution, and the emergence of computer capabilities, data, and what algorithms can do recently triggered the use of AI to the previously quantified levels. Real-time analysis of data collected with the use of the Internet of Things (IoT) devices together with sensors can be done due to the current availability of AI, and it can provide actionable information on process improvement, early correction of faults and remote supply chain management in extremely high volumes of data [4]. Moreover, forward maintenance and demand are possible because AI allows predicting what will happen and not, smart inventory is possible, and productivity and profitability go up as well [5].

The other crucial thing of AI of food manufacturing is that it is capable of quality and safety improvement. Such systems are faster and more accurate in inspecting the products than human labor and defects, contamination or appearances which are inconsistent. The ingredients can also be found along the food supply chain by using AI-powered analytics, which elevates the concern with food safety, and allows consumers and regulators to know about it [6].

This review article aims to carry out the in-depth review about the impact of AI on the manufacturing environment of food products. It will research the underlying technology, actual practice at both levels of production and subsequent improvement in efficiency and quality [7]. In addition, it shall comment on the challenges which are present, i.e. the shortage of data, the regulatory barriers, and the

workforce adjustment, in addition to mentioning of the opportunities and trends which are ahead. The review will assist the researcher, industry and policymakers to maximize the full potential of AI in food manufacturing since it establishes the landscape and long-term direction of technology in the industry [8].

### **ARTIFICIAL INTELLIGENCE PILLARS IN MANUFACTURING INDUSTRY**

Artificial Intelligence (AI) is grouping of tools in computing in which computer programs and machines can act as people in think, intelligence and problem solving ability. The intelligent automation and data-driven decision making, which are based on AI apply to the case of the food manufacturing industry because this industry allows the manufacturers to increase the performance and improve the efficiency and get rid of the errors in the changing market conditions [9]. In order to be able to identify with AI as a revolution in the contemporary food production systems, it is relevant to know the fundamental technologies that are packed in it.

Other technologies focusing on the AI in the manufacturing industry are machine learning (ML) and deep learning (DL). Machine learning enables machines to use past information and improve themselves as they continue to acquire experiences without the need to program the machine. An example is that ML algorithms may predict equipment breakdown based on sensor data to identify how the recipe could be optimized based on the knowledge of how ingredients interact with one another as well as the perception among consumers [10].

Deep learning is a subset of ML, and its use case neural networks have multiple levels to figure out massive amounts of unstructured information in the form of pictures, video, and audio. Computer vision Computer vision systems involve the use of deep learning to identify defects, to identify shapes, and to check packaging during a food production process [11]. Such systems can be quicker and accurate as well as human inspectors and they can sustain the same quality of products. The other area of AI is termed as Natural language processing ( NLP ) and this allows machines to be able to read and understand human language. In food manufacturing, NLP may facilitate automated documents, regulatory compliance audit, and customer review examination [12].

The same applies to the reinforcement learning that is becoming an effective tool, particularly, in such scenarios when dynamical environments are associated with the trial and error method of learning what constitutes the most effective tactics by AI agents. It is useful in the robotic articulation and adjustable process control and in uncertain manufacturing systems. AI feeds on information and the internet of things (IoT) plays one of the major roles in informing it [13]. In food factories, IoT networks help to integrate its equipment, sensors, and systems to always monitor such parameters as temperature, pressure, humidity, and production speed.

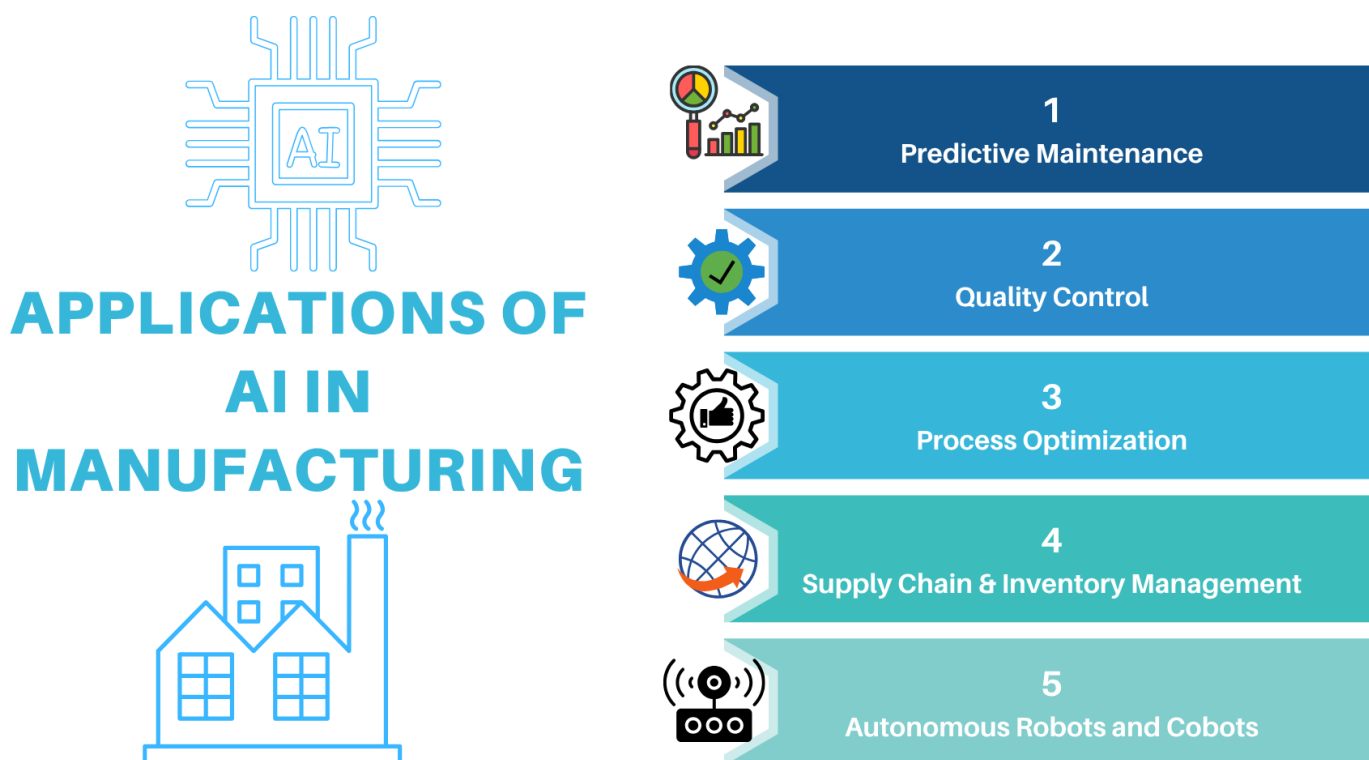


Figure: 1 showing the Applications of AI in manufacturing

This kind of data streams is entered into the input of AI algorithms that form trends, anomalies and give optimization recommendations in real-time. One can take the example wherein smart sensors placed on mixers and conveying belts can even detect the variations in consistency, texture or color and trigger necessary corrections. With AI as the power source of the predictive analytics, one can predict changes in demand to reduce wastage and to make the supply chain logistics leaner [14].

The trend in which AI is linked to Industry 4.0 (digital transformation of the manufacturing industry by automating and using cyber-physical systems and cloud computing) has accelerated the rate at which food is produced. Such an ecosystem might have AI that acts in collaboration with the robotic, digital twins, blockchain and cloud platforms to create an intelligent and agile world of manufacturing [15]. With the help of the technologies that involve AI, the manufacturers will become capable of simulating the production runs and predict the outcomes and make immediate corrections without necessitating a production halt. It will allow mass customization; that is, personalized products in terms of nutrition can be produced or allergen-free products without sacrificing efficiency and the need to increase the price [16].

## THE USE OF AI ON PRODUCTIONS PHASES AROUND FOOD PROCESSES

AI is bringing a revolution to the food manufacturing business through the front, middle and back line production with smart automation, control and data driven decision-making. During all processes of raw material conversion, product creation, further processing, and packaging, AI technologies are effective, do not cause losses and ensure a homogeneous level of quality [17]. During the innovation of new foods, AI is gaining increased significance because it conducts numerous *in silico* blending, predicts blending of the ingredients, sensory impact, and how to enhance nutritional value of the new food [18]. Huge data like the composition of the ingredients, preference and nutrition rules can be stored using machine learning algorithms and new formulation can be presented. To put it into perspective, AI will help in producing its plant-based substitutes of animal-based products that will taste, appear, and feel like their predecessors. This reduces the time that new products take to reach markets and customer satisfaction, by formulation adapted to new trends in health concern and diets [19].

The quality assurance process begins with the process of inspecting of raw materials received. Visual examination is tedious and in most occasions unreliable. The computer vision system based on AI and deep learning can now process real-time analysis of size, color, shape of raw materials like grains, fruits and vegetables, and the surface defect [20]. The reliability of these systems in detecting contaminants, foreign object or spoilage is 99.9 percent and when high level of quality in the input into the production line has been produced then anything short of this is not acceptable [21].

AI in the food processing will make such important parameters as temperature, pressure, moisture, mixing rate monitored and controlled in real-time. Such parameters are optimised via historical and real time data predictive models so that the process would be uniform and energy saving. This may be embodied e.g. in the baking process or pasteurization process where AI algorithms adjust the heat used and the time in use dynamically and in response to prevailing conditions without having products ruined by excessive heating or lack of heating [22]. More AI is being used on smart packaging to enhance not only traceability, but also customer communication. Labels or QR codes, when combined with AI and IoT, allow the manufacturers a chance to track products between them and the end-users and notify them in real-time about the source, nutritional value, or expiry date [23]. The application of machine vision within an automated labeling system will allow speeding up and regularly correcting the label errors not only in their orientation and location and the content within them [24]. Artificial intelligence (AI) also contributes to sustainability because it cuts on the wastes in various stages of production. With help of predictive analytics, it is possible to project better and predict demand and, therefore, it will be possible to regulate the amounts of production and reduce

overproduction. AI can also be used to configure dynamic inventory to ensure there are no spoilages and storage costs are removed. In addition to that, the food manufacturing process can also be made even friendlier to this planet, as AI helps to avoid water and energy wastage costs [25].

### **AI AND INCREASED PRODUCTIVITY**

In the contemporary and competitive world of food manufacturing industry, productivity is a factor of business that is of great importance. Artificial Intelligence (AI) in the food manufacturing process provides the manufacturing companies with the instruments of automation and maximizing the throughput by reducing the downtimes. Be it predictive maintenance or the optimization of the supply chain, AI will offer plenty of solutions to enhancing the productivity that would not compromise the quality and safety [26].

One of the key benefits of the AI in food production is the automation of routine procedures and making the equipment more efficient. The use of smart robots and other automated mechanisms assists the manufacturing industries to reduce manual work as they could be carried out quicker with low chances of a wrong reaction [27]. Monotonous works, such as sorting, packaging, or palletizing, are also the perfect fields where automated systems can be used since AI-enhanced robots cannot fatigue and can only produce more with no reduction in accuracy [28].

In addition to the automation, predictive maintenance with the use of AI has become a critical tool that helps to increase the level of uptime during operations. By examining sensor data of a machine, predictive maintenance uses the same AI algorithms when predicting the damage and treat it before it is able to break down [29]. By furthering the prediction of failure of different parts of the device and incorporation of preventive maintenance services, the manufacturers will be able to prevent the sudden halting of the costly equipment and extend its life cycle. This capability will streamline the work in the production lines, and a significant part of the expenses on the maintenance costs will be saved, and the productivity will increase [30].

AI also provides a central role in supply chain management to enhance prediction and optimization of stocks. The traditional method of supply chain management uses historical track records and manual interventions and could lead to stock out, over production or ineffective waste of products in the inventory. AI can, nevertheless, analyse meaningful data accessible in real-time on various sources such as sales, weather conditions, and consumer habits with a high chance of predicting the future demand. Such predictions will enable the producers to plan their productions, avoid run-outs and shelving of the products [31].

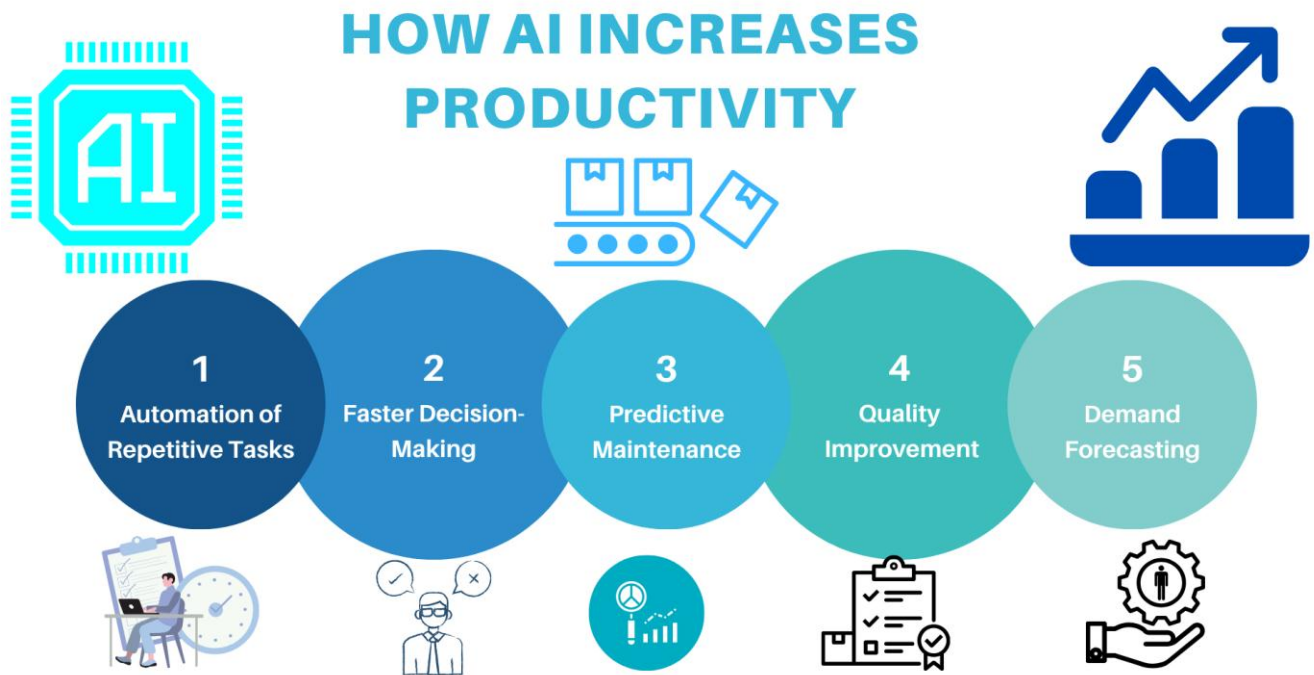


Figure: 2 showing how AI increases productivity

Implementation of AI also improves the logistics aspect of supply, optimizing the routes of supplying raw materials and reducing the costs of their delivery, ensuring the timely replenishment of the production material. Better demand planning and smart inventory will enable manufactures to stock up their materials and products just in time, so there will be no need to expend excessive amounts of money storing them plus no danger of going overstocked or perish [32]. The construction of energy is also another place where AI will increase growth. The cost of energy in food manufacturing may be vast in terms of percentage of operation cost. This will be done by the use of AI-based systems, which would allow observing the energy consumption in real-time and identify the most inefficient areas or ways to reduce the consumption the least [33]. AI possibly will provide an efficient management of the use of energy by automating the controlling systems of energy to switch lights; heaters, air-conditioners and machines on and off in a bid to conserve the energy during the day.

Water and raw materials as well as packaging can also control the resource consumption resource consumption of AI. To illustrate, AI algorithms can be applied to optimize the amounts of wastewater below the number of waste needed, which is consumed during certain stages of processing or even suggest alternative, more sustainable packages to reduce the amount of generated waste and lead, therefore, to the higher sustainability of the overall production process [34]. Not only can the AI be applied to make the manufacturing process more environmentally friendly because it can be used to maximize the use of resources, but also enables to optimize the costs of operation, consequently,

making the process more efficient and environmentally friendly [35].

### **AI-BASED ENHANCEMENT OF QUALITY AND SAFETY**

The safety of a food product and quality assurance of products are among the priorities in food production to which a compromise is impossible. Any minor lapse in these areas can result in endangering the health of the consumers with legal repercussions and tarnishing brand image. Soon, the tools that provide the opportunity to trace, monitor and detect everything throughout the whole production process will transform the quality control and food safety management spheres by using Artificial Intelligence (AI) [36]. AI can give accuracy, standardization and flexibility which cannot be achieved by hand processes due to the analysis of data in real time and the smart automation of the process.

AI will also manage to enhance food safety as it will offer 24 hours monitoring, as in this way, one can become aware of a danger in time and implement mitigation actions. Contaminants, foreign materials, or inadvertent processing in computer vision systems are all potential uses of deep learning algorithms [37]. The other illustration is that AI-based visual inspection machines are more capable of examining the food products on molds, discoloration, and mechanical defects than human workers. This will ensure that good contaminated will be identified and will never be taken in the production line to reach the consumers. IoT device and sensor can also be integrated with AI through which they can observe the critical control points within the processing environment [38]. The parameters of ambient conditions (temperature, humidity, microbe loading) might be continuously measured to detect the breaches of the safety requirements. The ML models will be used to predict the risks of contamination based on the trends and the real-time indications that will be given out by the use of the sensors. It is possible to act in advance of the issue being out of hand [39].

It has to have traceability to meet regulatory requirements as well as to address the instances of necessity to handle recall in a short and efficient manner. The AI objective plays a huge role when creating smart traceability systems that track the ingredients and products in the supply chain. With support of AI, block chain technology can also be applied to leave clear and irreversible history of each transaction or touch point in order to improve accountability and reduce fraud [40]. Additionally, AI will enable conducting the regulatory compliance checks through crosschecking the production data and the regulatory requirements, or internal company policies. The use of Natural Language Processing (NLP) tools can scan through the documentation documents to identify labeling errors or allergen disclosures and they will enable the production of final goods according to the recommendations of local and international safety standards [41].

# AI CONTRIBUTION TO QUALITY ENHANCEMENT

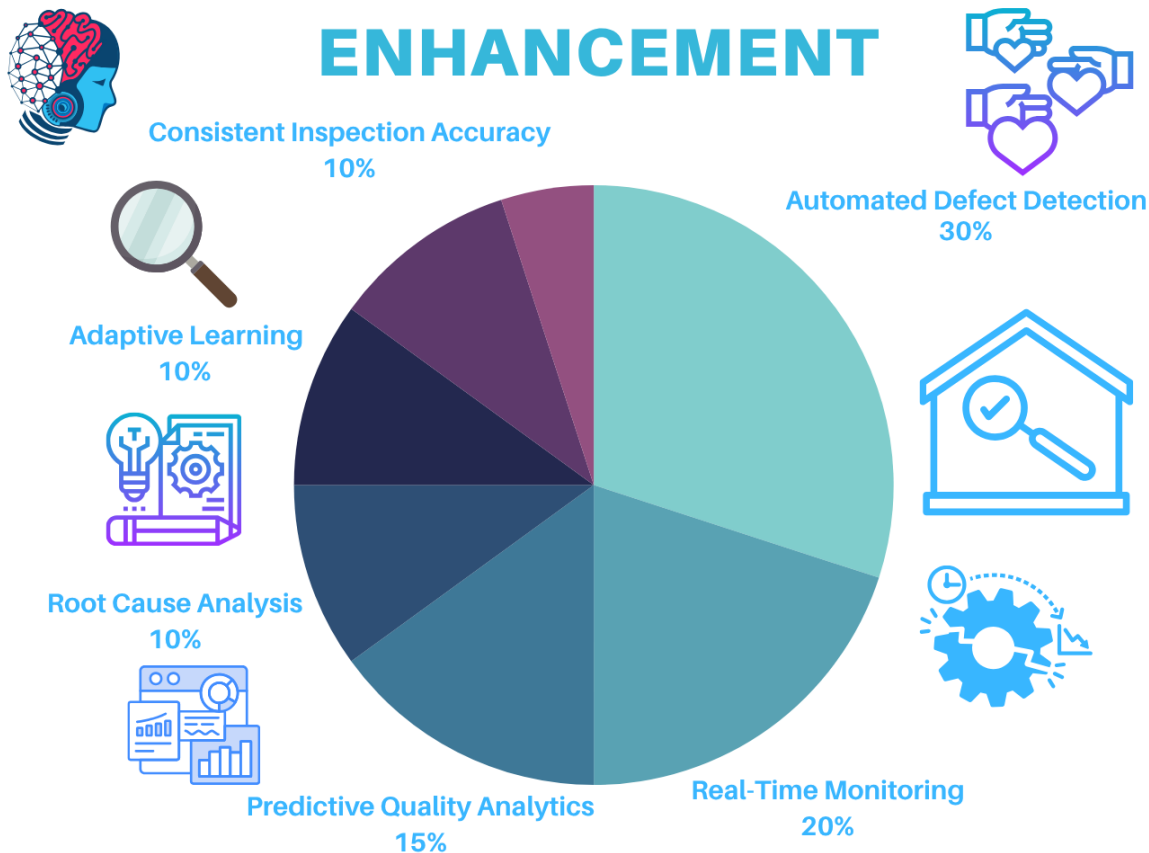


Figure: 3 showing the Ai contribution to quality enhancement

They are also useful to provide consistency of products and sensory quality because the control of formulation, processing conditions, and packaging are under precise control by the AI systems. As an example, machine learning models can be able to forecast what happens to the taste, texture or appearance upon varying either quality of the ingredient or processing time and adjust operations accordingly [42]. AI systems will ensure that all products manufactured in any one single batch meet the desired specification, minimizing the variability and keeps consumers happy. With the use of AI, food producers are able to detect the hazards before they happen occur, make safety measures, be within the regulatory limits, and ensure production of quality food products anytime. Credibility and openness being promoted in the world food supply chain is promoted by the technology because it protects the health of the population [43].

## CASE STUDIES AND INDUSTRY IMPLEMENTATIONS

One of the technologies to have its real-life implementation in the production of food is the Artificial Intelligence (AI) contributing to the revolutionary impact of the groundbreaking idea on the efficiency, quality, and sustainability. Various enterprises across the globe in one case a multinational

company or a startup company have been in a position to adopt the AI-powered services in order to facilitate efficient business operations and establish a competitive edge [44]. Such industry application and case studies may be applied to provide some of the pointers of the practical application and lessons that we have learned in the integration of AI.

Among the top players in the food industry, Nestle, PepsiCo, Kraft Heinz, and Unilever are among those who actively invest in AI technologies. To give one such an example, Nestle has been teaching AI to enhance quality control by implementing computer vision on production line to ensure mistakes in the process of packing and product oddities are noticed in real-life. This has aided a lot in reducing the satisfaction and product recall [45]. PepsiCo has deployed AI-based predictive maintenance at its production centers, which allows the company to gain an understanding of when its tools will break down to take the most out of the maintenance process. This has saved much time wastage and made the plant more productive. Similarly, Unilever can make the most out of the energy used and the minimum wastage in the manufacture of ice cream by disrupting machine-learning algorithms and the outcome of the same would be decreased prices and environmental friendliness [46].

JBS, a dimensionally giant of the meat manufacturing industry in the world, uses AI-powered robotics and vision-based technology in the processing sector of the meat manufacturing industry to grade carcasses and to cut automatically. The systems increase accuracy, reduce dependence on labor and ensure standard quality of products. Another outstanding example is that of a Chilean food-tech company NotCo that creates plant-based alternatives to animal products with a customized AI-based platform called Giuseppe [47]. Giuseppe makes molecular ingredients observations of thousands of ingredients and identifies plant mixtures that can come up with the best result in terms of taste similarity to conventional food products. Such technological change allowed NotCo to develop plant-based milk, mayonnaise, and burgers with a high consumer reception [48].

The utilization of AI in the bakery business case is represented in the largest bakery business of the world Grupo Bimbo that has applied the strategies in the route planning decision by using the optimal-level demand forecast. Using point-of-sale and logistics data, AI enables one to reduce transportation costs, reduce the duration of delivery and avoid the lack of products or their excess [49]. It can be concluded on the best practices of such industry implementations is that generally the first step should be the piloted programs in order to start with a low scale and then continue to scale the AI adoption, data quality and integration across the systems, and employee or workforce training and alignment with the human skills and AI technology [50]. The common challenge here is the need to achieve cross-functional collaboration between IT team, engineering team and production team so that the process of implementing AI can be smooth. Despite the presented case studies indicating that the use

of AI can be efficient only in the case of its strategic application, AI will also bring innovation and long-time resilience to food production [51].

### **Issues and Future Of AI In Food Manufacturing**

Despite the various opportunities presented by the introduction of Artificial Intelligence (AI) in food manufacture, there are a lot of challenges that go with it that ought to be addressed to realize its full potential. These are technical, economic and organizational problems. At the same time, the potential of AI in the specified industry is quite high, and its advance in the following years must accelerate even more changes [52].

The accessibility and the quality of data is among the primary challenges of AI implementation in food production. AI models require large quantity of information that is both, structured and unstructured to account. Still, a good part of the food processing plants lacks digital technologies to envision such information record, store, and manage such information to the greatest advantage [53]. Besides, data random structure, the loss of data, incorrect sensor calibration can reduce the credibility of AI results. The second technical issue is the unification of AI system with the existing legacy devices [54].

In many situations, food processing plants have still machinery that is way older, which is not connected and compatible with the current age AI platforms. Any replacement or up gradation of such systems is expensive and operationally disruptive. Automation with AI could be very expensive and this could serve as a deterrence to small and medium-sized enterprises (SMEs). The cost can be there in the form of the hardware process, software, cloud services, and professional staff. Further, the ROI may not be immediate and this is the only factor that can degrade the early adoption [55].

There is also a need to augment the requirement to retrain the existing labor force to say to AI systems. In the process of AI manifestation in the business environment, even though there is a likelihood of a reduced need of utilizing manual labour to perform routine tasks, employees with skills related to analysis of data, machine learning, and systems management will be necessary. The digitalization with the lack of proper training courses can lead to the loss of the labor force or to the denial of the change [56]. The use of AI in food manufacturing also has an ethical and regulatory problem. Certain issues are associated with algorithmic bias, data privacy and cybersecurity risks that are to be eliminated. Regulating systems are still not entrenched to manage the consequences of AI-directed the process of determining in activities that are safety oriented like warehousing of food and labeling [57].

Despite all these the future of AI in food manufacturing is quite bright. This should also be easier to operate in general with the development of more user-intuitive low-code AI platforms, even at the

hands of non-technical people. Using the better edge computing and 5G connection, the features of real-time monitoring and control can be expanded. Digital twins, block chain integration and generative AI are newborn technologies that will probably give them the new chances of innovation [58]. The AI is going to play the leading role in supporting the preservation of personalized nutrition, precision fermentation, and fully automated dark factories that are oriented on the principles of efficiency and hygiene. AI-based food production is a sustainable perspective in the direction of which one should go, taking into account that, despite these obstacles, such a direction is achievable thanks to strategic investments, clarification of the rules, and unity of the sectors.

### CONCLUSION

The implementation of the Artificial Intelligence (AI) to the food production is an innovative step as far as the food manufacturing process, monitoring and delivery is concerned. As stressed in the current review, AI cannot be regarded as only an additional tool but among the most important drivers of innovation, effectiveness and quality of the whole-process production. It may be linked to product improvement, ingredient optimization, and subsequent processes of packaging, safety inspection, and supply chains, among others, but the utilization of AI is immense and potent at the same time.

The mystery of these processes in machine intelligence and how they are conducted can be lifted by learning the basics of manufacturing AI, particularly in machine learning, deep learning, natural language process, and reinforcement learning. The discussed technologies may be, constantly enhanced, and the mentioned machines are analyzing the arriving information, computing the input, and adjusting themselves in real-time without requiring attentiveness on the part of humans. Linkage of AI in addition to the industries 4.0 technologies like cloud computing and Internet of things (IoT) are transforming the production ecosystems rendering them to become smarter and self-governable entities.

Application of AI in every step of food production has come with unmatched accuracy and functionality. It has assisted the manufacturers to streamline the formulation processes and be on the watch of the quality of raw materials, real-time control of the processing parameters as well as the wastes. The predictive analytics can further be used in production to match with the transformation of the market demand to reduce the cost of the inventory and environmental impact, with AI-based packaging systems and labeling verification that can be used in producing products that are traceable and compliant.

Speaking about the enhancement of productivity, the utilization of AI has such significant results as the shortening of the time of equipment breakdowns because of the predictive maintenance of the equipment, the saving of resources through the effective use of resources, and the automation of less

important procedures. The implication of this enhancement is amplified work, reduction in operational expenses, and output performance in overall equipment effectiveness (OEE). In addition to that, AI is capable of guaranteeing the quality and safety of the situations that can result in timely recognition of hazards, enforcement of compliance and control of sensory qualities which are central to consumer and regulatory satisfaction.

The case studies of the actual industry buttress the fact that AI has been trending in the industry. Both Large Organizations and small companies are utilizing AI to catalyze innovation, operational excellence, and customer happy. Automation of quality control at Nestle and product generation at NotCo gives certain practical benefits and lessons to be learned by the potential user of these technologies. Nevertheless, the road is not rosy. The larger challenges remain the poor data quality, cost of implementation, integration, and preparedness of the workforce. The development of the technology should also consider ethical issues, cyber-security, and uncertainty in regulation.

However, the future of AI in food production is bright, and new discoveries, like the introduction of digital twins, generative AI, and the block chain useage, may bring the industry to the new dimension of efficiency and customization. AI is not a technological fad; instead of being a strategic level tool, it allows the production of food to be sustainable, safe, and scalable. AI is set to change the food processing industry even more as an increasing number of individuals embrace technology and it becomes more intelligent and robust in the future.

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