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Modern Trends in Food Production: The Role of AI in Smart Food Factories

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ABSTRACT

The integration of Artificial Intelligence (AI) in food production is revolutionizing the industry by enhancing efficiency, improving food safety, and driving sustainability. Smart food factories powered by AI are optimizing production processes through automation, predictive maintenance, and real-time quality control. AI-driven supply chain management is reducing food waste, ensuring better resource allocation, and streamlining logistics. Furthermore, AI is playing a crucial role in developing personalized nutrition and alternative protein sources, catering to evolving consumer demands. Despite its numerous benefits, AI adoption in food manufacturing faces challenges such as high implementation costs, data privacy concerns, and workforce displacement. Overcoming these obstacles requires investment in AI training, regulatory frameworks, and ethical AI deployment. Looking ahead, advancements in robotics, block chain integration, and AI-powered 3D food printing will further shape the future of food production. By addressing these challenges and leveraging AI responsibly, the food industry can create safer, more efficient, and sustainable food production systems for the future.

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INTRODUCTION

Global food industry is undergoing a sea change, as technological advancements are making, food safe, preservative free, quality improved and sustainable as the world population is increasing day by day and world need more resourse of food [1-4]. One of these advancements in particular is that Artificial Intelligence (AI) is having a significant role in the development of future food production. Smart Food Factories have changed the primitive norms of traditional food manufacturing as they are infused with automation, data analytics, and machine learning algorithms to make production processes smarter, with less waste, and safer food [5]. This is not only a matter of technological evolution, but also of adaptation to the increasing demand of the world in feeding itself and confronting issues such as resource scarcity, labor shortage, and environmental concerns. In the past years, traditional food production model was dependent on the automatic labor, basic automation, linear supply chains and created inefficiencies and inconsistencies [6]. Now with the rising global population and evolving consumer tastes, the food industry needs to make way for AI powered solutions which will increase productivity, safety and work towards sustainability. Advanced image recognition and sensor technology is allowing AI to streamline processes, predict maintenance issues before they happen and guarantee that rigorous quality control is met [7].

Given the necessity of adopting greater efficiency in food production, one of the main drivers behind the adoption of AI in food production is its efficiencies. Vast amounts of data are taken in by sensors, machines, supply chains and then analyzed by AI powered systems to identify patterns and make real time decisions. It helps manufactures to improve their energy consumption, higher productive yield rates, lowering operational costs [8]. For example, predictive analytics allows food producers to predict equipment failures in order to minimize downtime and consequently keep production continuous.

AI is drastically improving food safety and quality control. With smart cameras, machine vision, deep learning algorithms can quickly detect defect, contaminant or inconsistency in food product at a greater level of accuracy than trained human inspectors [9]. Using AI powered inspection systems can thus analyze multiple parameters like texture, color, shape and so on to guarantee that only high quality products reach the consumer. In addition to benefiting consumer trust, this goes a long way in assisting companies to adhere to stricter food safety measures [10].

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In addition, AI is enabling the emergence of personalized nutrition solutions enabled by data driven insights to fuel the creation of food products customized to user's dietary needs and tastes. Consumer behavior, genetic data and health conditions are analyzed by AI algorithms that either recommend or come up with food products customized to meet each individual's requirements. As consumers are better seeking for personalized and healthier food options, this trend is picking up the pace [11]. The application of AI is changing Food Production to innovative smart manufacturing techniques that improve efficiency, safety and sustainability. Although introducing AI in food factories is a competitive tool it is also something needed for food companies who want to remain in front of the pack in an evolving landscape. As AI develops, its contribution to food production will only grow and support us in building smarter, safer, and more efficient food production [12].

THE EVOLUTION OF FOOD PRODUCTION: FROM TRADITIONAL TO SMART FACTORIES

Production of food has changed significantly throughout the years from manual and highly labor intensive processes to the more automated and intelligent manufacturing systems that we see today. Such transformation has been influenced by technological developments, changing consumer needs, and necessity to achieve improved efficiency, safety and sustainability. This evolution of an increased demand for food coupled with a decreasing supply has led to the rise of smart food factories powered by Artificial Intelligence and automation, promising unmatched increased productivity and quality control [13]. The production of food had been always done manually and by a lot of hands. Food was processed by means of traditional methods, including the use of hand milling, fermenting, and preserving food by means of salt and smoke. However, these processes were slow, inconsistent and reliance on human expertise. As the Industrial Revolution began, the use of mechanized equipment brought the first big shift in agriculture due to the possibility of mass production and increased efficiency [14].

In the start of the 20th century, assembly line techniques started to be adopted by factories like in automobile manufacturing industries. It enabled food companies to increase production, establish uniformity in product types and reduce costs. Nonetheless, these early food production systems were still limited, as they needed a large amount of manual labor and lacked precision control over the quality aspects [15]. In the mid-20th century automation began to start making a bigger role for food

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manufacturing. The conveyor belts introduced, mechanized mixing, automated packaging systems drastically increased production speed, and consistency. Early systems of computer controlled systems to monitor and regulate processes were also implemented by companies, thus reducing human error [16].

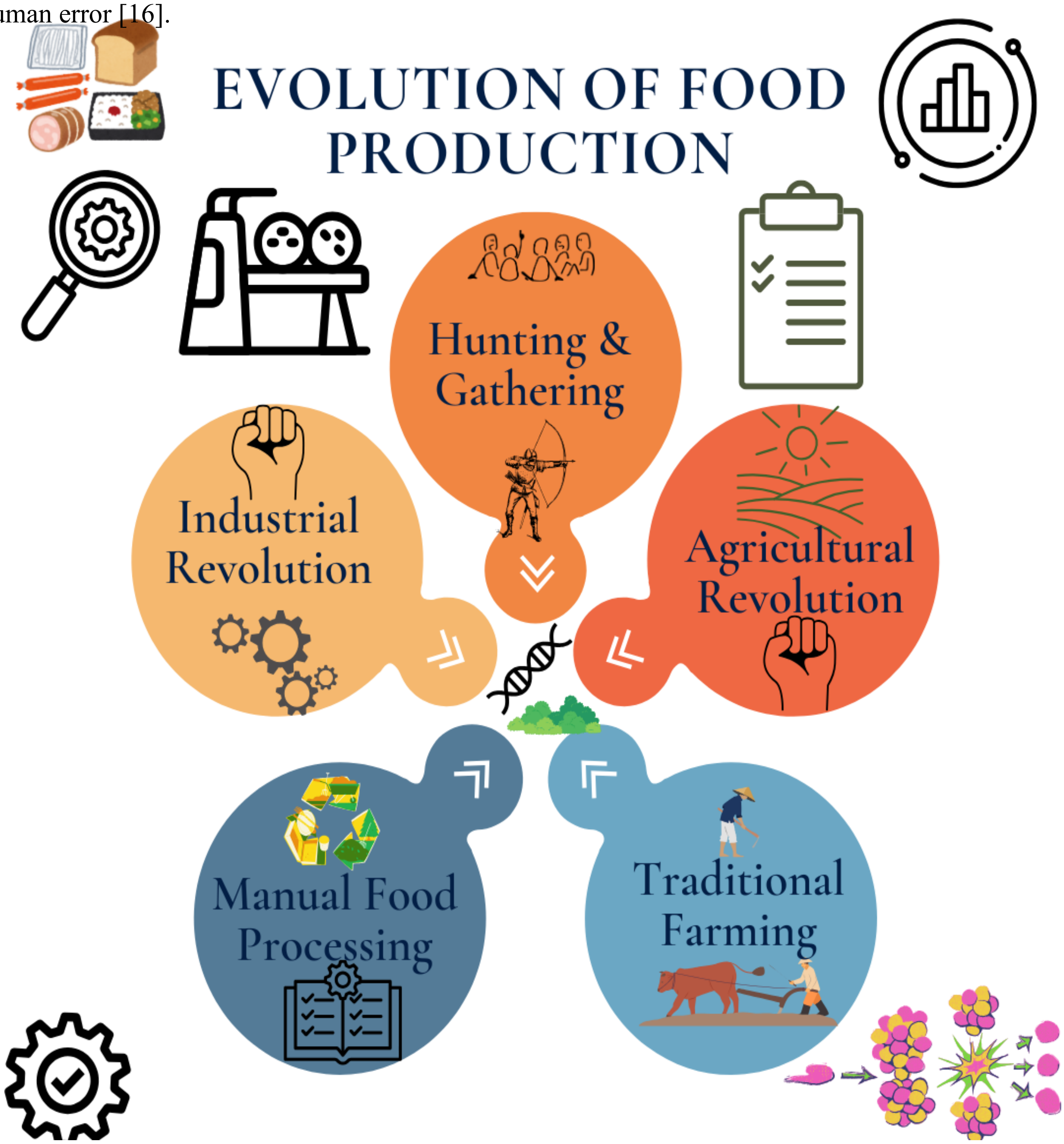

Figure: 1 showing evolution of food production

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It’s in the late 20th and early 21st centuries that digital technologies emerge in food production. Robotics and PLC's made robotic technology efficient and precise, which allowed for tasks like slicing, sorting and packaging to be done with little human involvement. They hastened efficiency, promoted cleanliness and greatly diminished opportunities for contamination. The era of smart factories where AI, Internet of things (IoT), and big data analytics coexists for highly automated, and intelligent food production facilities has arrived today [17]. Smart food factories are different from traditional factories in that they integrate connected sensors, real time data processing, and machine learning algorithms for maximizing all production aspects.

Predictive maintenance is one of the most important features for smart factories where AI systems use data from the machines to detect potential problems before they happen. Its usage results in less downtime and lower maintenance costs, hence ensuring continuous production. AI powered quality control systems utilize machine vision for fast inspection of products, equipped for finding defects and contaminants more reliably than human inspectors [18]. Another major advancement is that of AI based supply chain management. Out of date, these traditional supply chains were often slow and reactive leading to inefficiencies and waste.

Using AI, food manufacturing can forecast demand patterns, optimize stock degrees as well as make certain timely shipment of uncooked products. Consequently, less food waste gets produced, which means lower costs, and the entire production becomes more sustainable [19]. Block chain technology and real time monitoring systems are helping to make the smart factories more effective in enhancing food safety. Using AI, food compliance can be carried out in every stage of food production: starting from sourcing raw materials to final packaging. This can also help eliminate foodborne illnesses [20].

The demand for higher efficiency, quality, and sustainability of food production has led to the transformation of methods of provision from traditional ways to smart factories. Early food production was still dependent on manual labor but modern food factories are using AI, automation and data analytics to optimise every phase of manufacturing [21]. Technology will continue to evolve towards the smart food factory, where these smart factories will become even more sophisticated, to help port the world to the more sustainable and efficient food industry it needs.

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ARTIFICIAL INTELLIGENCE IN FOOD PRODUCTION: AN OVERVIEW

Frankly, AI (along with it's sister technology, Machine Learning) is revolutionizing food production, and introducing AI (or Machine Learning to be more politically correct) into food production is introducing smart technologies that will improve their quality, efficiency, and safety. AI systems are being implemented in the food manufacturing process to automate, utilize AI for predictive analytics and make decision making data driven. It is this technological shift that industry is using to meet the challenges of growing consumer demand, worker shortages, food safety issues and sustainability [22]. With the use of AI, food manufacturers can improve production, decrease waste, and produce original food products compatible with today's consumer inclinations. The last stages include getting raw materials, production, and lastly, labeling products [23]. Therefore, Machine learning algorithms, robotics, and computer vision systems are applied in food processing to increase the accuracy and efficiency of these operations. The following is some of the areas where AI is making impact:

Typically, traditional quality control methods involve human inspector to check for defects and irregularity in food products. But, AI powered systems with the help of machine vision and deep learning algorithms are able to evaluate products with more accuracy and speed. AI can identify subtle defects, contaminants, or abnormalities in food items and that only premium products will reach the consumers [24]. It eliminates human error and improves the safety of food. Food production may be disrupted because of equipment failures, downtimes, and so on causing financial losses and delays. Predictive maintenance systems powered by AI take a look at the sensor data of machinery, and try to figure out the early signs of wear and tear. Predictive potential failures before they occur enables manufacturers to pre schedule maintenance reducing downtime and extending equipment lifespan [25].

The use of robots that can carry out repetitive jobs, for example, sorting, cutting, packaging, palletizing – are increasingly taking on food production using AI. They can perform their tasks with great precision at consistent intervals and at a consistent pace; this translates to efficiency, which, in turn, lowers the labor costs. Also, food products can be handled delicately by AI driven robotic arms so that chances of damage and waste during processing can be reduced to a minimum. Disruption of the supply chain can affect exactly what can be sold, as well as the cost of that food. Through the use of AI algorithms, market trends, weather patterns and logistical data are analyzed and optimized for

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supply chain operations [25].

AI predicts how demand is likely to fluctuate and optimizes inventory levels; manufacturers use AI to cut waste, enhance delivery times and reduce operating costs. There is an emerging trend in consumer preference to shift to personalized and healthier food options. AI is also at the center of developing new tailored food products depending on personalized eating needs, health conditions or even tastes [26]. These AI driven platforms analyze consumer data to personalize nutrition plans as suggestions and come up with new food products that fulfill the dietary needs of certain consumer groups.

Manufacturers have a very important priority to ensure food safety. From sourcing raw materials, through the processing and production processes, to the final distribution, fully fledged AI powered block chain systems and IoT sensors track the entire food production operation. These technology devices enable the real time monitoring of food quality, alerting for risky contamination possibilities and also for assurance of compliance with safety regulations [27]. AI driven traceability systems also enable quick identification and recall of contaminated products and, as a result, make consumers less susceptible to health risks. The use of AI in food services is catching up as companies realize that it will help increase efficiency, reduce costs and ensure food is all the more quality [28]. Especially, labor shortages can be addressed with AI driven solutions because repetitive tasks we used to need humans for now can be automated. Besides, AI enables sustainable practices, such as minimizing the usage of resources, consumption of energy, and the waste of food.

KEY APPLICATIONS OF AI IN FOOD PRODUCTION

Food production is also being fostered by AI. AI powered R&D tools are being used by companies to produce plant-based and lab grown meat alternatives as a response to the increasing demand for vegetarian and ethical food options. Apart from that, AI powered data analytics assist food brand to know about consumer preferences and market trends letting them to introduce new products as per the change in tastes [29]. Although benefits of adopting AI in food production are manifold, there are still certain challenges. It’s expensive to implement an AI driven system initially requires a high investment cost, potential data privacy issues when implementing AI systems as well the required skilled AI professionals. Moreover, incorporating AI in the production infrastructure can also be

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complex and time consuming [30].

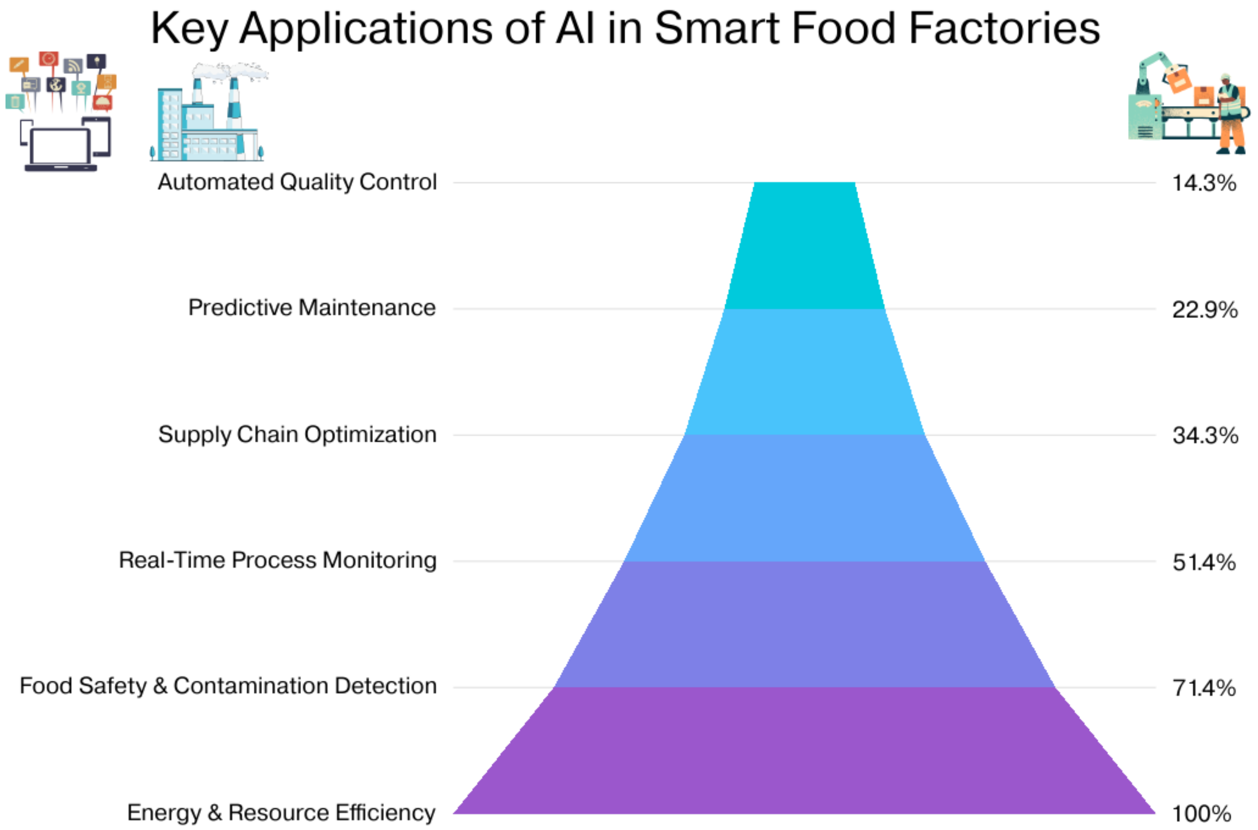

Figure: 2 showing key applications of AI in food industry

Still, while AI tech is advancing and making inroads, food production is likely to become more reliant on it in the future. AI powered smart food factory, the company also envisions highly autonomous, efficient and sustainable smart food factories possible and will lead the new era of intelligent food manufacturing. Embracing AI will help those companies that do to achieve competitive advantage by delivering high quality, safe, innovative food products to a global market in which demand is evolving [31]. The introduction of automation, efficiency, and precision into manufacturing processes is changing food production through the use of AI. AI is changing how the food industry works in terms of quality control, supply chain optimization and personalized nutrition. With this evolution of technology, AI is expected to serve as the main element which will transform food production into a much smarter, safer and sustainable one [32].

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Staying focused on the various applications of AI in Smart Food Factories will help us to understand how it can improve processes, reduce product defects, boost production capacity and enhance the efficiency levels in food manufacturing, both on a macro and the micro level. Artificial Intelligence (AI) is changing the food business by increasing how proficiently things are done, the total amount of waste incurred, and the quality of products [33]. AI driven solutions are being integrated in smart food factories to maximize production processes, ensure food safety and meet the changing needs of the consumers. At various stages of food production, including packaging and distribution, systems powered by AI are being used, from ingredient sourcing. Smart food factories use AI for some of these key applications. Manufacturers place top priority to ensure the food quality and safety. According to the traditional methods, this is based on the manual inspection but in this case it would take a long time and may be prone to human error. This process is being revolutionized using AI powered computer vision and machine learning algorithms to allow automated inspection systems [34].

Cameras and sensors are used to ‘see’ food products and analyze then for defects, inconsistencies, and contamination. For example, real time detection of foreign objects, color, texture, spoilage with machine vision technology. It also speeds up microbial detection by identifying humidity and temperature, guaranteeing acceptable safe food items get to consumers [35]. Machinery breakdowns which are unexpected result into disruptions of food production processes, financial losses and delays. With the use of sensors and IoT technology continuously monitoring equipment performance, AI powered predictive maintenance systems are able to track equipment performance. It also collects the data about machine vibrations, temperature, and operational patterns, and the data can be fed to an AI algorithm that helps detect early signs of wear and tear [36].

Food manufacturers can reduce downtime and repair costs by scheduling the maintenance in advance, by predicting the equipment failures before it takes place. In addition to improving operational efficiency, this extension in time extends the life of expensive machinery. For industries that deal with perishable goods, Predictive maintenance is useful because production delays can lead to serious losses [37]. Food processing is being automated with AI powered robots handling tasks like sorting, slicing, mixing, and packaging among others. These robots work with an incredible level of precision and consistency making it easy for work to be done without requiring human labor and working

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efficiently [38].

For example often robotic arms with AI can handle the most delicate items such as fruits, vegetables, pastries. Advanced imaging for classification, separation, for size, shape & quality are used by the AI-powered sorting systems. AI driven sensors on robots can exactly cut and trim meat during processing for meat, eliminating waste and improving yield. Packaging and labeling are also automated [39]. Robotic AI systems can accommodate packaging size, accurately label item, and seal the product. The reason for this is that it not only boosts efficiency, but also keeps one from having to have direct contact with food items.

Supply chain management in the food industry is complex because it involves several stakeholders supplying meat from various animals to fulfil the shifting demand while logistics is an issue. Manufacturers are using AI to streamline their supply chains with the study of large data to enhance procurement, designing creation and the scattering of the item [40]. Demand forecasting models fueled by AI predict consumer preferences making use of historical data, market trends, and influences that include weather conditions and economic changes. Through this, manufacturers can adapt their production lists in accordance to the demand, consequently, lowering the levels of overproduction and cutting back on food waste. AI helps with inventory management as well by keeping track of the stock levels in real time and recommending the best stock up plan. It helps make sure that raw materials as well as end products are available as and when required, i.e., no shortage or surplus. Further, AI based route optimization systems assist the logistics companies in saving on transportation cost and duration of deliveries by selecting most efficient routes [41].

Consumer are moving toward more healthy food, as well as more personalized food. The customized food products being developed with AI are tailored to each person's dietary needs and lifestyle. Nutrition analysis platforms that AI powered analyzes consumer's data such as health conditions, dietary restrictions and preferences to provide them with personalized meal plan and other food products. In a similar way, AI can recommend gluten-free, low-carb or high-protein food items based on a person's health profile [42]. In product development, AI is also assisting food manufacturers to create new and innovative recipes and formulations. To create new flavors, textures and nutritional compositions of their products, machine learning algorithms analyze consumer reviews, ingredient interactions and market trends. The process of research and development (R&D), where companies

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research new products and test them before they are brought to the market, is greatly accelerated [43].

Food production is undergoing a transformation through the means of AI that is bringing in smart technologies and helping become more efficient, of high quality, and sustainable. AI is being used for AI powered quality control systems, predictive maintenance, robotics, supply chain optimization and personalized nutrition amongst others; to drive innovation in every step of the food manufacturing process [44]. With continually developing AI technology, the role of AI in the smart food factories will also expand, which develops a smarter, efficient, safe, and consumer-centric food industry. AI driven solutions companies will have the advantage and will be ahead of the market demands on the quality of food ingredients as well as the adherence to the high standards of food safety [45].

BENEFITS OF AI IN FOOD PRODUCTION

No longer is Artificial Intelligence (AI) just for science fiction movies. The food production industry is integrated with the help of AI, which is packed with lots of benefits as it improves the efficiency, minimises waste and even improves the overall quality of the products. The food factories which utilize AI driven automation, machine learning and data analytics to make processes more environmentally friendly and cost effective are called through smart food factories. Besides streamlining the production process, the use of AI helps to ensure well established safety standards, improves consumer experiences, and fuels innovation in food technology. Here are a few of the main advantages of the use of AI in food production [46]. Through the use of AI powered automation, food production becomes a lot more efficient as processes are shortened in time. AI driven robotic systems are doing the work of sorting, packaging or quality inspection which had always been done manually before. They are able to work faster and more accurately than humans and factories are able to produce more foods quickly and at a more consistent rate [47]

Enhancing productivity also involves predictive analytics. Algoys analyze real time data scanned from the factory floor using AI driven algorithms, to optimize production schedules, identify inefficiencies, and suggest ways of improvement. Thus, this allows food manufacturers to satisfy customers' demands without having to spend time or wasting resources. In the food industry, food safety is at the top of the priority list in which AI is serving in minimizing contamination risk [48]. Machine vision and deep learning are applied to AI-powered inspection systems that inspect food

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products for defects, contaminants and inconsistencies using machine vision and deep learning more accurately than human inspectors. They are able to analyze multiple parameters — color, texture, and shape — to make sure only goods of the highest standard reach the customer in the first place [49].

Food safety is increased through use of AI powered traceability systems by tracking every step from raw material source all the way to final product packaging. With the distribution of [block chain] technology and [AI] together, monitoring of food safety standards can be done in real time, allows for compliance with any local regulations, and it makes product recall more efficient when needed. A major challenge in the industry is food waste, but AI is aiding manufacturers in reducing waste and sustainability among other things [50]. Predictive analytics powered with AI forecasts demand trends and therefore only procures necessary amounts of raw materials. This helps avoid overproduction and avoid waste arising from having excess stock.

In addition, AI helps in the management of resources by improving the efficiency of energy and water use in the food processing plants. Operational data is analyzed by smart sensors and machine learning algorithms to find means of reducing resource waste so as to make production more environmentally friendly. It also makes for a contribution in the globe's attempt to have green food production and also helps firms cut their carbon print [51]. The implementation of AI in food production brings remarkable cost saving through lowering labour costs, waste minimization and enhancement of energy efficiency. Automated processes decrease the requirement for manual labor, supplying companies with more time for the human resources to do more effective and strategic activities. Predicting the maintenance of machinery is also useful in preventing a sudden machine breakdown, reducing repair cost and production downtime [5200].

With artificial intelligence in the supply chain, manufacturers can utilize best price sourcing for ingredients, reduce transportation costs and minimize waste in inventory. The financial efficiencies of AI are making it an investment worthy of interest to food manufacturers in an increasingly competitive industry. AI is changing the way supply chain management forecast demand, plan for logistics and manage inventory [53]. Almost all traditional supply chains suffer from these inefficiencies due to unpredictable demand fluctuations and delays in procuring raw material. Predicted demand is therefore analyzed using AI driven predictive models that analyze market trends, historical sales data and other external factors (weather conditions etc.) to come up with predictions.

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Besides, AI logistics management systems make the best use of transportation routes and optimize delivery time and fuel consumption. It guarantees that perishables arrive in optimal condition thus reducing wastage and losses. In addition to this, AI also helps manufacturers to keep a real time visibility of their supply chain operations to able to make better decisions and respond to disruptions faster [54].

AI is helping in developing customized food products to meet the needs of consumers according to their dietary requirements or preferences in food consumption. AI powered algorithms are looking at consumer data to recommend, or even create, food products according to health needs specific to an individual. By analyzing genetics information, life style habits and medical history, for example, AI can provide personalized menu recommendation or even come up a new food formulations to fulfil individual's nutritional needs [55]. It makes the customer satisfied with this level of personalization and on the other hand the chances of business of the food manufacturers are also increased. While AI is helping companies to analyze consumer trends and preferences, it has actually accelerated product innovation. With machine learning algorithms processing massive amounts of market data, comprehensive research, in conjunction with large quantities of available data, the food industry is able to create new flavors, healthier products, and novel textures of food based on consumers' shifting needs [56].

Food production is changing with the help of AI, improving efficiency, increasing safety, and reducing waste, while being the engine of innovation. AI technologies used in the smart food factories can reduce cost and optimize the production process, and also deliver high quality food products to the consumers [57]. The role of AI in the food manufacturing industry will keep growing as AI evolves, making the industry more sustainable, more consumer focused, and more financially efficient. Companies that integrate AI enabled solutions will not only rise above competition but also play a huge role in making the future of world food production smarter and more sustainable [58].

CHALLENGES AND LIMITATIONS OF AI IN THE FOOD INDUSTRY

AI is positively disrupting the food industry by making it more efficient, reducing food waste and food safety, however, it has its challenges and limitations. There are a plethora of challenges that go into the implementation of AI in smart food factories, from high costs and technical complexities to

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ethical concerns and workforce disruptions. It is important for food manufacturers and policy makers to comprehend these challenges in order to come up with a way to integrate AI in food production while dealing with risks [59]. The high initial investment for infrastructure, software and skilled personnel is one of the main barriers that hinder the adoption of AI in Food Industry. AI driven smart factories need gigantic capital for constructing them by purchasing robots, Algorithm of machine learning, Sensors and systems to process data. The investment costs prove to be prohibitive for small and medium-sized food businesses and the use of AI is much more common for large corporations [60].

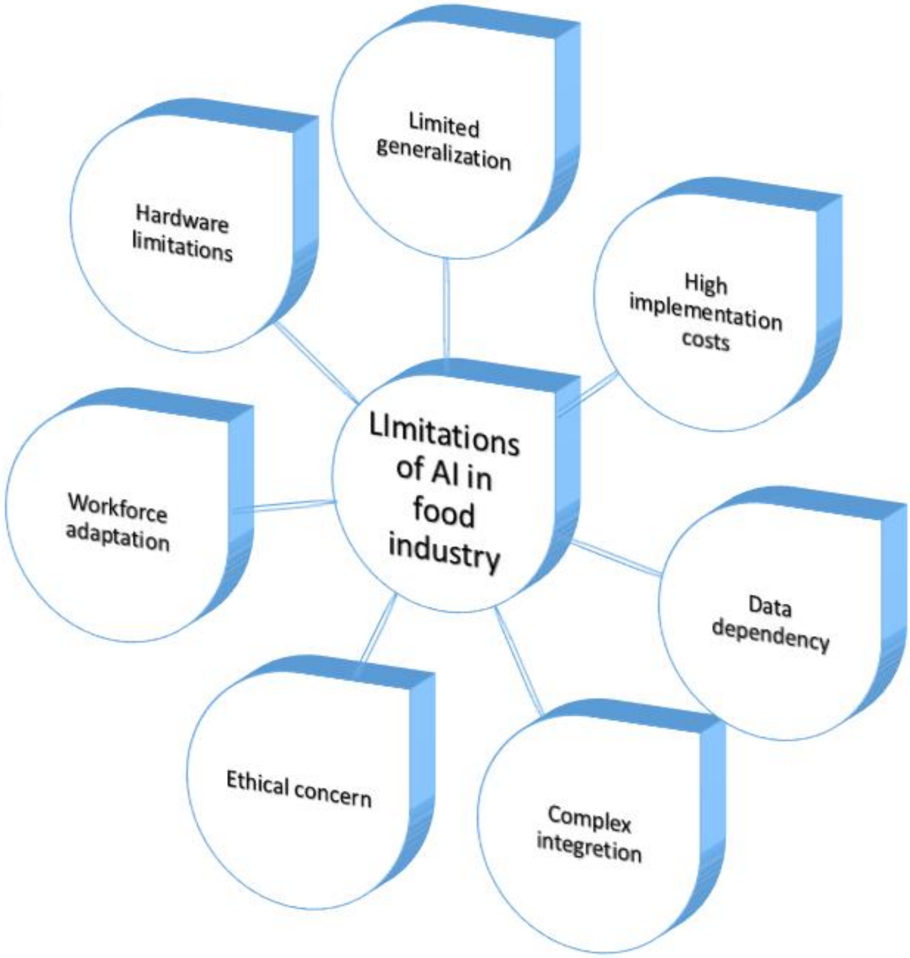

Figure: 3 showing limitations of AI in food industry

Integration of the AI to already existing food production lines is also complicated and time taking. Traditional food factories run with legacy systems which are not compatible with the type of AI driven

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automation. The retrofit of these systems is very expensive and requires extensive modifications, now production can be disrupted and additional costs can be incurred. Implementation of AI in food production is dependent on knowledge in machine learning, data analytics and robotics. Yet, the food industry is in short supply of skilled professionals capable of developing, managing and maintaining the AI systems [61]. Traditional methods of food production are relied upon by many food manufacturers; who may not have the right expertise to switch to AI driven systems. Training already employed personnel to collaborate with AI assisted machines and software is expensive concerning the time that it takes and the resources it requires. Without the proper training of the workforce, the workforce may not be able to adapt to new technologies and this would lead to inefficient and erroneous processes in the production of new technology [62].

Collecting and analyzing data has become necessary for AI powered food factories to achieve optimal production processes. This however is dependent on data and raises questions of privacy and cybersecurity. Food manufacturers can be gathering huge amounts of information regarding supply chain management, production efficiencies and how consumers behave. However, if these datasets are not secured properly, they are prone to cyber-attacks, data breaches, and unauthorized entry [63]. Supply chain disruptions, financial loss, and food safety standards threaten by Cybersecurity threats. It is also equally important for the AI powered systems to have solid security mechanisms in place like encryption, firewalls, real time monitoring and other safety measures to avoid the data integrity being put under the cloud of cyber threats [64].

Ethical and legal issues that come with AI in food production are around transparency, bias and accountability. Historical data is used to train the AI algorithms and it is possible for this to have biases that may impact the decision making processes in food manufacturing. Take, for instance, AI pricing models which, unintentionally, may give other suppliers an edge over their competitors, thus creating the semblance of uncompetitive markets; it is unfair to some suppliers. Moreover, AI adopt in food production should meet food safety regulations and industry standards and guidelines [65]. With the progression of AI technology, existing policies need to be updated by regulatory bodies so that there is ethical and responsible offering by AI driven food factories. To ensure that AI is not misused and is fair, it is important to come up with clear guidelines regarding AI governance for the food manufacturing industry [66].

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Automation of the food industry with the help of AI and robotics is feared to displace jobs and reduce the workforce. However, the machines can be AI driven to perform repetitive tasks like sorting, packaging and quality control much more efficiently than the human workers which is causing job fear that AI would replace many jobs in the industry. But at the same time, AI eliminates jobs that require manual labor, but also demands new job profiles for AI developers, machine learning specialists and data analysts [67]. Still, reskilling and up skilling programs are needed in order to retrain displaced workers and make them eligible to enter those roles. To prevent major unemployment resulting from large scale of automation, the companies have to strike a balance between automation and human labour while getting the advantage of AI driven efficiencies [68].

Most of the information that powers the functioning of AI systems for food production is aggregated into vast datasets. However AI algorithms are trusted only when accuracy and reliability of the algorithms are dependent on the quality of the data they are trained on. Incorrect predictions, failure of quality, wasteful production processes can all arise from inaccurate, biased and incomplete data. For example, demand forecasting AI models may be inaccurate because they use obsolete or insufficient data. It could lead to overproduction or underproduction, and in the financial loss, and in food waste [69]. Highly critical for AI driven food manufacturing to work at its optimal level; the collection of high quality and real time data. For many such manufacturers—particularly small ones, and especially traditional ones—AI holds the potential to be an intimidating and messy affair with high risk and nothing to show for it. There are some companies that would rather continue operating on standard techniques instead of risking it on investing in AI automated processes [70].

Even workers who fear they will be replaced by AI also show reluctance against change. To overcome this resistance, management has to ensure transparent communication about the benefits of AI, training programs for employees and implement the AI driven processes gradually so that business can adapt themselves seamlessly from traditional processes to AI processes. AI lowers food waste and optimizes the use of the resources, but it is not always the friend of the environment. AI based food production systems use huge amount of computing power and can be equally energy intensive [71]. Putting aside for the moment the electronic waste generated by the production and maintenance of AI driven machinery, can be put in place to manage the waste responsibility. To mitigate challenges on AI's environmental balance, food manufacturers need to consider adopting energy efficient AI

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models, derive power from renewable energy sources and adopt sustainable disposal practices [72].

Although AI holds huge potential to change food production, it has its drawbacks and challenges. Implementation for AI driven food factories is expensive, workforce disruptions and data security issues might also arise as a reason to avoid implementing AI driven food factories and ethical issues must be taken into account for the proper and responsible execution of AI driven automated food factories. Nevertheless, these challenges can be addressed by strategic planning, investing in AI education and training, and working together with industry and policymakers [73]. With this, the adoption of AI in the food industry is set to increase as the ability for AI technology increases. Proactively solving these challenges and investing in AI driven solution will give them competitive advantage and enable sustainable, safe and efficient food production. If the food industry embraces AI responsibility, addressing these limitations, the full potential of the smart food factories and a more innovative and resilient food supply chain for the future is going to be achieved [74].

FUTURE TRENDS AND INNOVATIONS IN AI-DRIVEN FOOD MANUFACTURING

With increasing technology and the need for the food manufacturing industry to become more efficient, sustainable, and to provide personalized nutrition, artificial intelligence (AI) has a rapidly evolving role in the industry. Working on AI which is continuously evolving, makes smart food factories more intelligent, adaptive and efficient. The main concepts of AI driven food manufacturing for future are automation, food safety, food waste reduction and food innovation with AI created product while considering customer preference. Here are some of the most attractive future trends and innovations in the AI-driven food production [75]. Thanks to AI, it is possible to produce personalized food products that could be built on a basis of personal dietary needs, genetic data, and personal health conditions. As it can analyze huge dataset, AI can assist manufacturers to build bespoke meal plan and food formulation based on customers' needs and health objectives [76].

For example, nutrition platforms powered by AI suggest diets obtained through the use of machine learning, which takes into account health history, habits of lifestyle, and genetic makeup of an individual. Food manufacturers also have started to rely on AI to customize food, allowing the customers to customize ingredients, flavors, and nutritional value of food prior to purchase. It is anticipated the trend will grow as health conscious consumer's desire more personalized food options

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[77]. Concerns related to sustainability and the need to stop relying on conventional meat sources are creating new opportunities for AI driven food production. Alternative proteins such as plant-based meat, lab grown meat and insect based protein sources are using AI to play a key role in their development [78].

The resulting plant based meat alternatives closely mimic in texture and taste of traditional meat and they're designed by machine learning algorithms that analyze ingredient compositions and optimize recipes for this purpose. AI is also being applied in cellular agriculture to conditionally identify the lab grown meat growth conditions that are doing efficiently and are cost effective to make them consistent and scalable [79]. With AI further perfecting these processes, it's presumed the cost of alternative proteins would drop and provide them to the mass market globally. Robotics and autonomous systems will be largely relied on in the future of AI driven food manufacturing.

AI robots will begin to take on more complex tasks such as food preparation, cooking, packaging, etc. and decrease human intervention and increase efficiency. Already, robotic chefs that serve up gourmet meals with the precision and consistency of robotic chefs are being developed. In smart food factories, the AI powered robotic arms with next generation sensors will be responsible for handling the gentle food items thereby reducing waste as possible and increasing quality as much as possible. While fully automated kitchens and food processing plants are a way off, the fact that robotics technology continues to improve means that they may be the future of food production [80].

A key area where AI is still going to play a role in supply chain optimization. Predictive analytics powered by AI will make demand forecasting more precise and will eliminate overproduction, and food waste in that regard will be minimized. The future innovation will lie in the bringing of AI onto block chain for food supply chain to have transparency and traceability back and forth. AI systems block chained will be providing real time insights into food sourcing, followed through every step of the production and distribution [81]. This will also assist consumers to assure of the authenticity and sustainability of their food products as well as compliance to the food safety norms. Additionally, choosing the most efficient delivery routes will cut down transportation costs and carbon footprints through AI – driven logistics optimization [82].

In the future, future AI driven food manufacturing will have to be majorly based on sustainability. AI

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will be instrumental in mitigating food waste, more effectively using resources and making energy more efficient. Smart sensors and AI algorithms will comb food production environments to determine the appropriate amount of energy, water and raw materials procurement that reduces waste [83]. Moreover, AI based precision agriculture helps in the sustainable production of food through optimizing crop conditions for optimum growth, reducing the use of pesticides, and ensuring better soil health. We'll be able to grow our food vertically in urban areas with AI controlled climate and grow things year round independent of farming methods we are used to [84].

The Internet of Things (IoT) and AI will determine the future of food safety. Food processing conditions will be continuously monitored using AI powered sensors which will detect the potential contaminants in real time. This will make these systems more effective at predicting and preempting the risk for contamination. Real time tracking of Food storage and transportation conditions will be possible through the AI driven IoT device [85]. A typical example here is smart packaging which has AI powered sensors, it can give real time updates of the temperatures, humidity and levels of spoilage during the food products in the supply chain. These innovations will result in safer, higher quality food products for the consumer [86].

3D food printing is one of the most futuristic AI applications for use in food manufacturing. With accurate ingredient compositions, pointed out food items could be customized by AI powered 3D printers and present new culinary experiences for one to try. The potential of this technology lies in the ability to greatly advance the way we produce food, especially in the healthcare industry where a nutritional solution is very personalized [87]. Besides, as another way to contribute to sustainability, the use of alternative ingredients, such as plant-based proteins and insect based flours, can be utilized to print out nutritious meals with minimum environmental impact utilizing AI-driven 3D food printing. With advancing technology, 3D food printing could, therefore, very well become the mainstream solution for customized and sustainable food production [88].

The sky's the limit with AI \u2014 powered manufacturing is the future of food. AI has huge potential to transform the food industry through hyper personalized nutrition, alternative protein development, autonomous food processing and block chain integrated supply chains. Key priorities of smart food factories will persist to be: sustainability, efficiency and food safety, which will continue to spur innovations in smart food factories [89]. Since AI technology evolves, food manufacturers should

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make use of it to be competitive and to respond to contemporary customers. Through the use of AI, the food industry can become more streamlined, waste less, provide higher quality food and design completely new food products that meet the expectations of a market that is only becoming larger faster.

CONCLUSION

Artificial Intelligence (AI) is being integrated into food production to revolutionize the industry and convert existing food factories into smart and data driven factories. AI systems are making food production more efficient, safer, and less wasteful, and are assisting in developing personalized nutrition and more sustainable food production. However, with further development of AI, the importance of it in the food manufacturing will become only stronger – thus determining the ways we produce and consume food in the next future. AI offers various benefits for food production, but there are still hurdles. To responsibly and efficiently deploy AI driven solutions, one faces high implementation costs, data privacy concerns, need for skilled professionals and ethical considerations, which also act as its hindrances. To enable workers to move into new roles, companies must spend on AI training and up skilling. Without it, AI becomes a competitor to human expertise, instead of partnering with it.

One of the most promising applications of AI in combating food safety is to assist in food safety. With food inspection faster and more accurate thanks to machine learning algorithms and computer vision systems, contamination risks are reduced and consumers get high quality products. AI powered predictive maintenance is reducing equipment failures and production downtime, resulting in a higher level of operational efficiency. Another important domain where AI has made strides is with respect to sustainability. AI driven systems are helping food manufacturers practice responsible consumption by optimizing food supply chains, reducing food waste and better management of resources. Alternative protein development like lab grown meat and plant based substitutes powered by AI, along with clever zoning and improved. Commercialization of food can dramatically reduce the environmental footprint of food production and provide consumers better ethical food choices.

In the near future, the advancement of robotics, block chain, IoT, and 3D food printing with artificial intelligence will lead the utilization of AI in food manufacturing. Personalized nutrition will grow

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and consumers will be able to personalize their diets by the health data and their preferences. Food production will become more efficient, reducing human error and utilize mass customization of food products by AI driven automation. With that, the regulatory frameworks must also catch up as the state of AI technology moves forward. Food production will need governments and industry leaders to act to jointly issue directive about how AI must be implemented in food production, ensuring transparency, fairness, and accountability. Also, ethical considerations, such as, data privacy, job displacement, and AI bias, must also be carefully managed to ensure the creation of a balanced and inclusive food manufacturing. AI is changing food production and creating an opportunity for unprecedented improvements in efficiency, safety and sustainability. Although challenges persist, proactive investment in AI technology, workforce development, and regulatory oversight promise to unlock AI's full potential for the food industry. With AI backed food manufacturing methods remaining advanced, they will be expected to fulfill the rising worldwide requirement for protected, nutritious, and maintainable nourishment items; characterizing the eventual fate of nourishment division for ages to come.

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