FOOD SCIENCE AND TECHNOLOGY

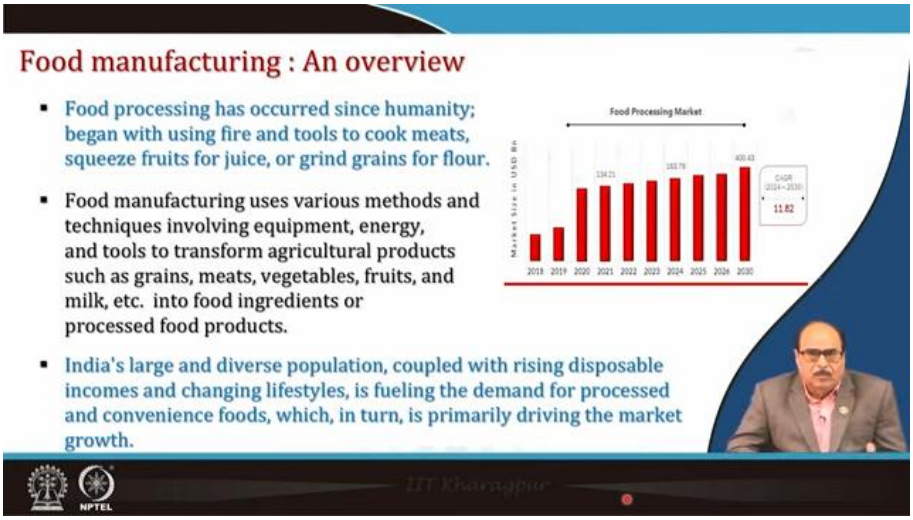
Lecture51

Lecture 51: Concepts in Food Manufacturing and Industry 4.0

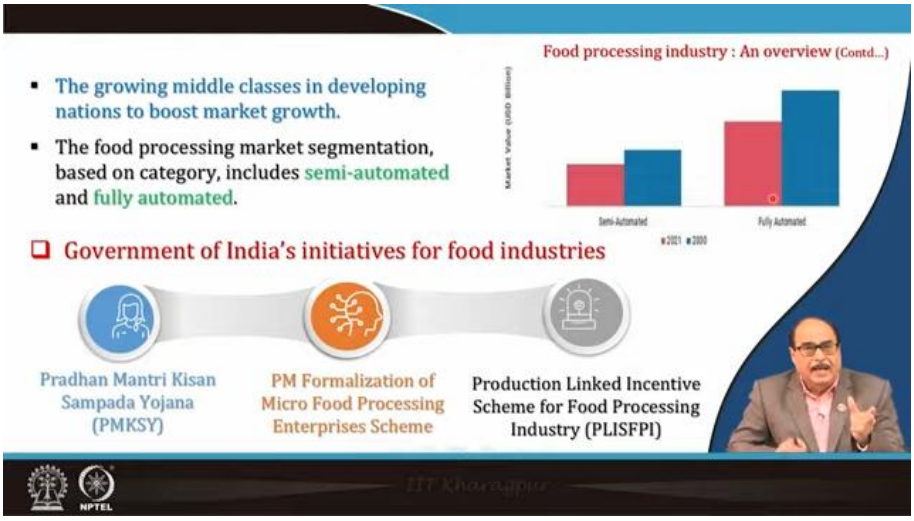
Hello everyone, namaste. Now, we are in the eleventh module of this course. So, the next five classes of this module will be devoted to food manufacturing and Industry 4.0.

In today's class, lecture number 51, we will talk about concepts in food manufacturing and Industry 4.0. We will discuss the various stages of the food industry and its evolution, and

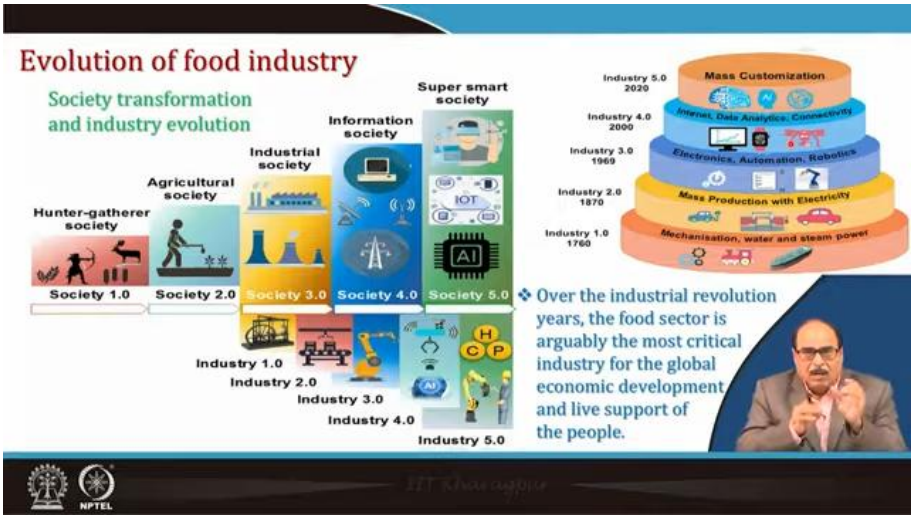
the current challenges in food manufacturing. Good manufacturing practices in the food industry 4.0, and we will also take a few case studies on IoT for real-time data collection and analysis.



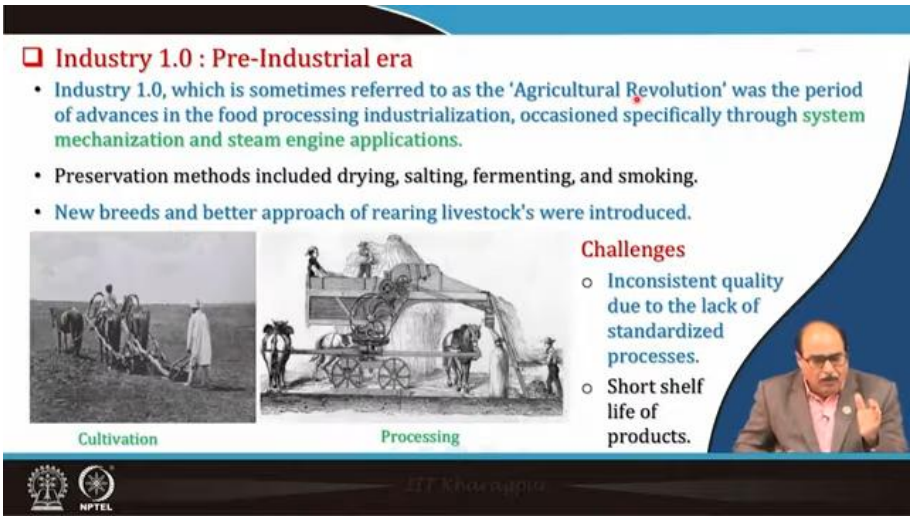
So, let us have an overview of food manufacturing. Earlier, we talked about food processing, the food processing industry, etcetera. And you know that food processing has existed since humanity began. It began with using fire and tools to cook meat, squeeze fruits for juices, or grind grains to make flour, etc. Food manufacturing uses various methods and techniques involving equipment, energy, and tools to transform agricultural products such as grains, meats, vegetables, and fruits. Milk and so on are used in various types of food ingredients or processed food products. Like the material which is consumed or which is produced at the farm gate, it may not be suitable for consumption. So, that is the job of the food industry; it converts those materials either in the form of ingredients to be used in the manufacturing of other products or directly to the end product, which is used by the consumer. India's large and diverse population, coupled with rising disposable income and changing lifestyles, is fueling the demand for processed and convenience foods, which in turn is primarily driving the market growth. You can look at this figure, which is taken from the literature, showing the food processing market, which shows the increase in the market in 2021. The food processing market was worth about 134.21 billion US dollars, and it increased in 2024 to 263.79 billion US dollars. And in 2030, it is expected to reach 400.43 billion US dollars. So, the expected growth, the CAGR, may be expected to be at 11.12 per cent from 2024 to 2030. So, the food processing industry is growing steadily.



The main reason is that it is the growing middle class in the developing nations, they are boosting the market growth. The food processing market segmentation, if you look at it, is based on the category, and that includes semi-automated and fully automated. And here also you see that if you look at the data of the 2021 to 2023, 2030 that is the semi-automated and the fully automated in the 2021 and 2030 and you will find a vast difference that is the fully automated is their value market value in the US dollar billion is much more in the fully automated sector than that in the ah semi-automated sector. In India, particularly the government of India, has taken several initiatives for the food industry, which has also given a boost to the food processing industry. A few major initiatives taken by the government of India include Pradhan Mantri Kisan Sampada Yojana, PM formalisation of micro food processing enterprise scheme, and production-linked incentives schemes for the food processing industry. And these schemes have definitely revolutionized the food processing sector in the country.

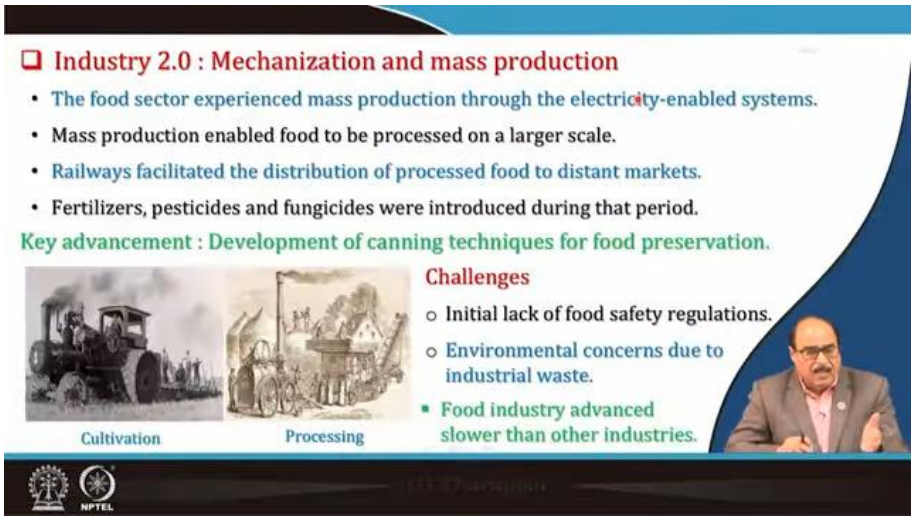


Now let us talk about the evolution of the food industry, how it evolved, and obviously, the evolution of the food industry, food processing is related to the evolution of society. In fact, when science developed, trade developed, market developed, and society transformation took place, which led to the evolution of industry. If you look at society 1.0, it was basically our ancestors; they were a hunter-gatherer society. Then, in society 2.0, it was the agricultural society. Society 3.0 was the industrial society, society 4.0 is the information society, and society 5.0 is the supermarket society or super smart society, you can say. Then, this is how society develops. Then, when the industrial society came, that is society 3.0, it also resulted in the evolution of the food processing industry, the food industry and then from here it comes industry 1.0, industry 2.0, industry 3.0, industry 4.0, and now we are talking about industry 5.0. So, this industry 1.0 started somewhere around 1760. During 1870 came industry 2.0, which focused on mass production with the use of electricity, etc. Industry 3.0 emerged around 1969 or so, and the main focus of this industry. Industry 3.0 was the use of electronics, automation, robotics, etc. Then, from the year 2000 onwards, it was the era of Industry 4.0, where the use of the internet, data analytics, connectivity, etc., started in the food industry. And finally, Industry 5.0, particularly from 2020 onwards, has a major focus towards Industry 5.0, meaning here the mass customisation, or you can say that is the process, etcetera. So, you can very well see here over the industrial revolution years, the food sector is arguably the most critical industry for global economic development and the life support of the people.

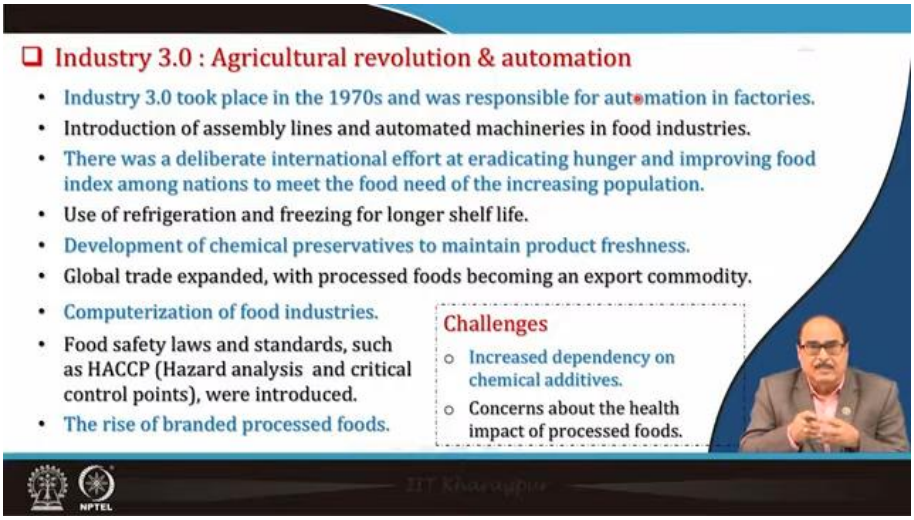


We will elaborate a little bit on the various revolutions of the food processing industry, various stages like Industry 1.0, the pre-industrial era. So, this Industry 1.0, which is sometimes also referred to as the agricultural revolution, was the period of advances in food processing industrialization. It was occasioned specifically through system

mechanisation and steam engine applications, and during this era, the preservation methods included drying, salting, fermenting, and smoking. New breeds and better approaches to rearing livestock were introduced in this era. However, this had certain challenges; the challenge was the inconsistent quality due to the lack of standardized processes, and the materials which were processed generally had a short shelf life.

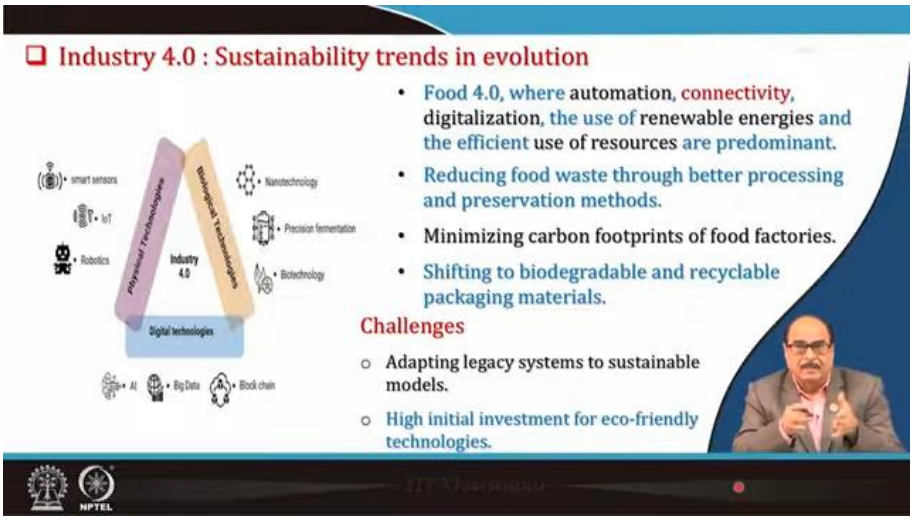


Then these challenges were tried to be overcome in Industry 2.0, which was the mechanisation and mass production, enabling food to be prepared on a larger scale, particularly using electricity-enabled systems. Railways facilitated the distribution of processed food to distant markets. They also transported ingredients to the food processing industry, etcetera. Fertilizers, pesticides, and fungicides were introduced during this period. So, the key advancement seen in this Industry 2.0 was the development of canning techniques for food preservation. However, while there were some developments, there were still certain challenges, such as the initial lack of food safety regulations. There were environmental concerns due to industrial waste generation, and the food industry advanced more slowly than other industries.



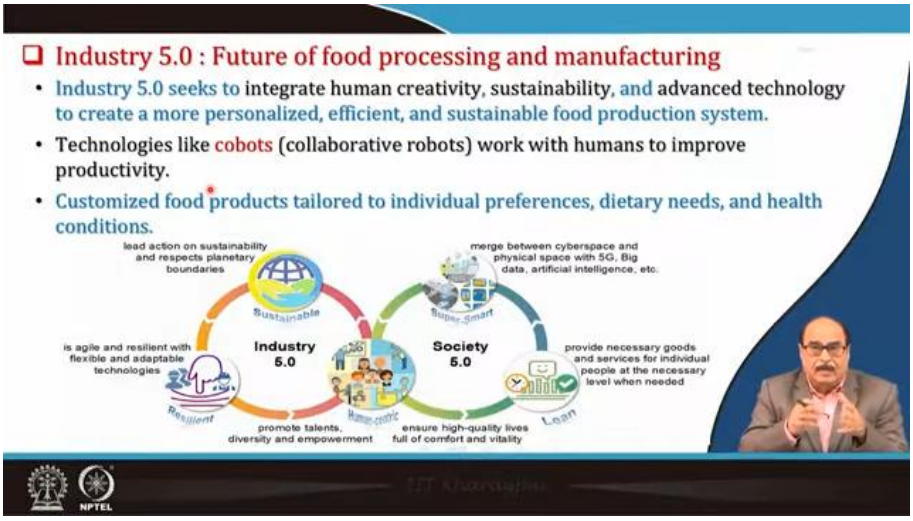
So, again, this led to the evolution of Industry 3.0, which was mainly focused on the agricultural revolution and automation. It took place around the 1970s, as I mentioned earlier, and it was responsible for automation in factories. The introduction of assembly lines and automated machinery in food industries began during this Industry 3.0 period. There was a deliberate international effort to eradicate hunger and improve the food index among nations to meet the food needs of the increasing population. And therefore, in this era, the use of refrigeration and freezing for getting better quality products or for longer shelf life was introduced. Development of chemical preservatives to maintain the freshness of products also started during this era. global trade expanded with the processed food becoming an export commodity. Computerisation of the food industry has started, which is the use of computers. And food safety laws and standards like HACCP, like hazard analysis and critical control points, etc., were introduced, and the rise of the branded products, branded food products, and many branded industries came. They established that they started producing and marketing branded food products. So, during this Industry 3.0 again. So, every development comes with certain opportunities and certain challenges. So, the challenges in the Industry 3.0 era were increased dependency on chemical additives. And also the concerns about the health impact of processed foods because of the use of chemicals and other things, which have resulted in certain health concerns.

So, these challenges were possibly taken care of in the industry 4.0 and which focus of this era was mainly on sustainability trends in evolution. Here, that is the automation connectivity and digitalisation that is the food industry. So, the use of renewable energy and the efficient use of resources are prominent. There is the automation, connectivity, digitalization, the use of renewable energy and efficient use of resources are predominant.

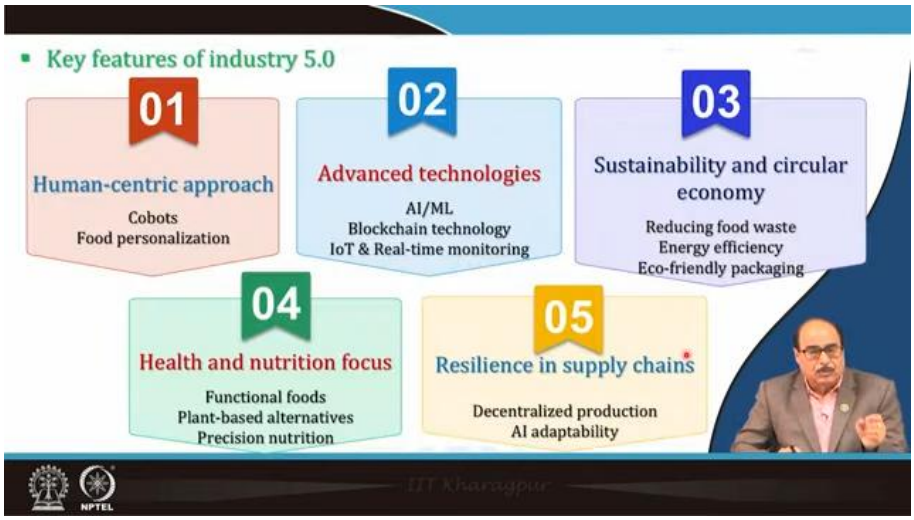


Reducing food waste through better processing and preservation methods is the focus of the food industry 4.0. Minimising the carbon footprint of the food industry is another major concern. Shifting to biodegradable and renewable packaging materials or recyclable packaging materials is a trend in Industry 4.0. So, there are physical technologies like a smart sensor, IOT, robotics, or biological technologies like nanotechnology, precision fermentation, biotechnology, or digital technologies like artificial intelligence, big data and blockchain that have become significant and their use has become more prominent in Industry 4.0. And as I told you, the major focus is sustainability in the food system. That is the sustainability when we talk about using these advanced physical, biological, and biotechnological means, or digitalisation means that is, you result in the reduction of food waste. As well as a reduction in the energy consumption, which boosts the food quality, safety and traceability, smart factories, farms, or the development of novel and healthier foods. These were the major focuses in this Industry 4.0 era. However, again, there were challenges in this sector as well, like adopting legacy systems to sustainable models and high initial investment for eco-friendly technologies because you are putting in use of high-end techniques and equipment. So, obviously, it resulted in high capital investment.

Now, these are the things we are talking about, let us briefly say about Industry 5.0, which is the future of food processing and manufacturing, Industry 5.0. seeks to integrate human creativity, sustainability, and advanced technologies to create a more personalized, efficient, and sustainable food production system. Technologies like cobots, that is, the collaborative robots, work with humans to improve productivity in Industry 5.0. Customised food products tailored to individual preferences and dietary needs, and health

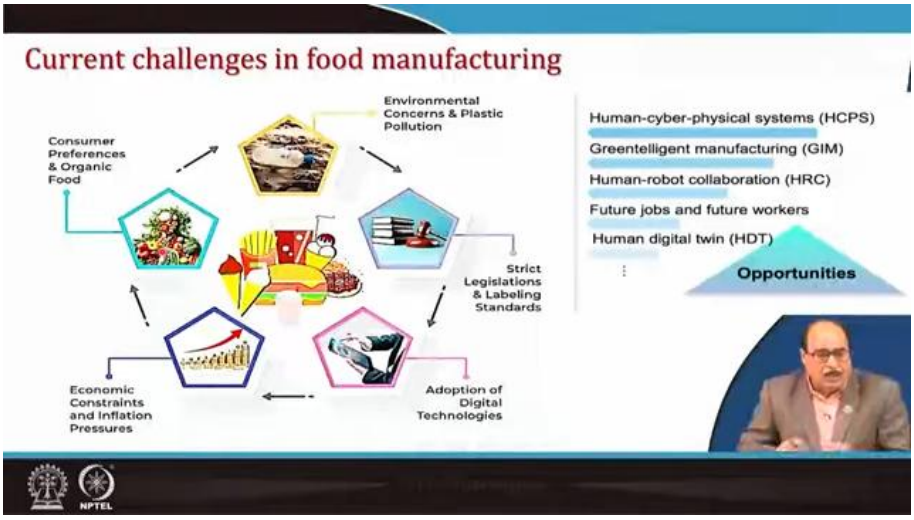


conditions are going to remain the focus area in Industry 5.0. So, if you again have a comparison between Industry 5.0 and society 5.0, here in Industry 5.0, that is the sustainable approach. More sustainable systems, like leading action on sustainability and planetary boundaries. Then, resilient systems like this industry are agile and resilient with flexible and adaptable technologies, and finally, it is human-centric, promoting talent diversity and empowerment. The same will help society like a super-smart society that merges between cyberspace and physical space with 5G, big data, artificial intelligence, etcetera. It provides necessary goods and services for individual people at the necessary level when needed and ensures a high-quality life, full comfort, and viability, which is a human-centric approach.



So, the key features of the food industry 5.0 are likely to be, as I told you earlier, that is, one, it will be a human-centric approach, that is, the use of more and more cobots or food personalisation. There will be the use of advanced technologies like AI or machine

learning, artificial intelligence, machine learning, like blockchain technology, the Internet of Things, and real-time monitoring. Then, sustainability and a circular economy, like reducing food waste, having better energy efficiency and eco-friendly packaging. The other major key feature of the industry 5.0 will be the more important and health and nutritional focus that is the development of automated production of functional foods, plant-based alternatives, precision nutrition and so on and resilience in the supply chain, like decentralised production and AI adaptability. So, these are likely to remain the key focus or key feature area of the Industry 5.0.

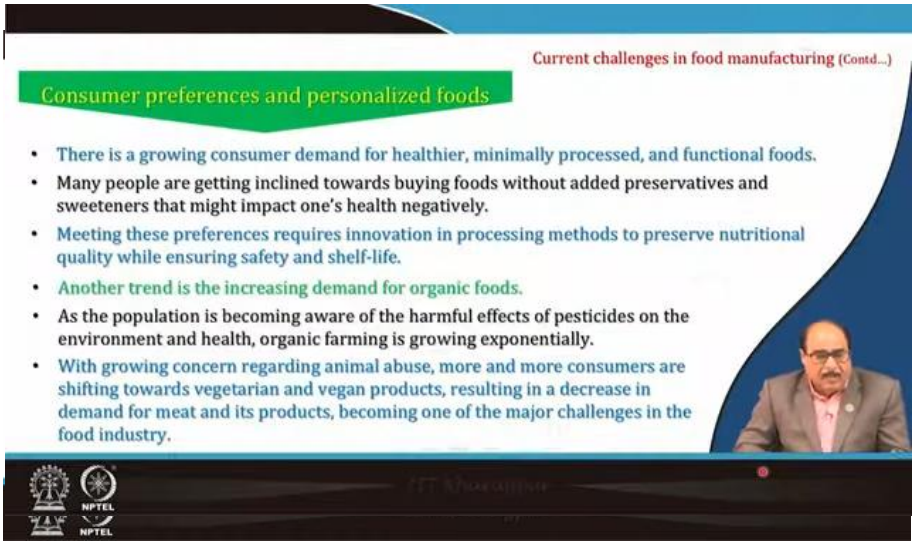


Now, let us briefly talk about current challenges in food manufacturing. Obviously, there are environmental concerns, use of plastic pollution, etc., increasing use of how to have sustainability, how to reduce this environmental carbon footprint and all those things. Strict legislation and labelling standards are now being enforced by several countries. So, this is again their compliance, their use, etc., becomes again a challenge in some countries with digital technologies. economic constraints and inflation pressure, you know the inflation is rising day by day or every year in almost all countries. So, that again put the economic constraint and the food industry and finally, the consumer preferences and organic foods, etc., the consumer has become more personalised in their requirements, etc. So, that again becomes a major challenge area.

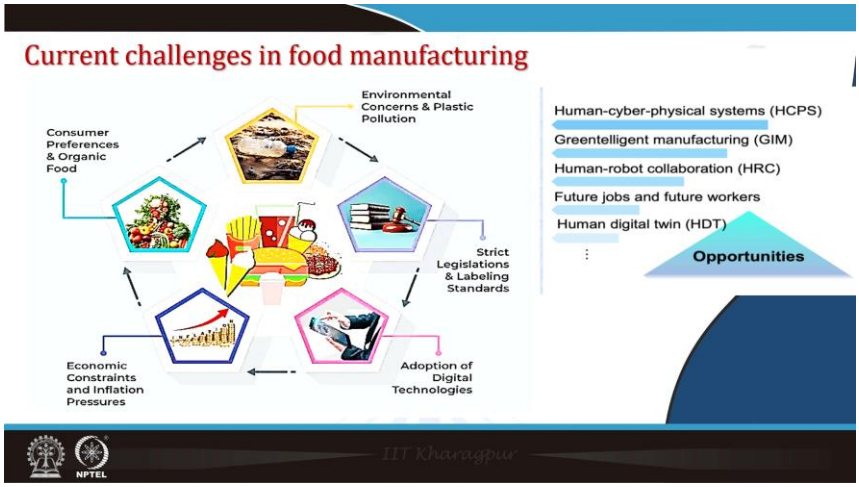
So, I think, as I told you, every challenge comes with some opportunities. So, there are ample opportunities also in the food processing sector now in the food manufacturing, particularly because of the availability of advanced tools, systems, and technologies like we have now human digital twins, SDT, future jobs and future workers, human robot collaboration. Green intelligent manufacturing like which is called popularly gym or

human cyber physical system SCPS. So, these advanced technologies provide opportunities in the food processing and food industry sectors.

So, let us elaborate a little bit on the current challenges, like sustainability in food manufacturing. Obviously, food processing operations contribute significantly to environmental degradation through waste generation and pollution of air and water resources, and that is a well-known fact. So, now, the major aim is to reduce the generation of waste and pollution of air, water, etc., with the rising awareness of eco-friendliness. Excessive consumption and inappropriate disposal of plastics have come up in some of the major issues faced by the food and beverage companies today. In the year 2023, a reputed food processing company, a brand of food processing company, an international company, announced the use of a US dollar 8.7 million investment in a facility in the UK for handling hard-to-recycle plastics. Even some other brands have, in recent years, confirmed the use of recycled plastics. or flexible packaging to replace most of their plastic usage. And these challenges will further rise when more countries make guidelines to mitigate pollution. So, this is a major challenge and obviously, it is a big one, as I told you, some industries came forward, and even the focus is there. Meet the challenges, how to overcome the challenges and make the food processing industry a sustainable business model.



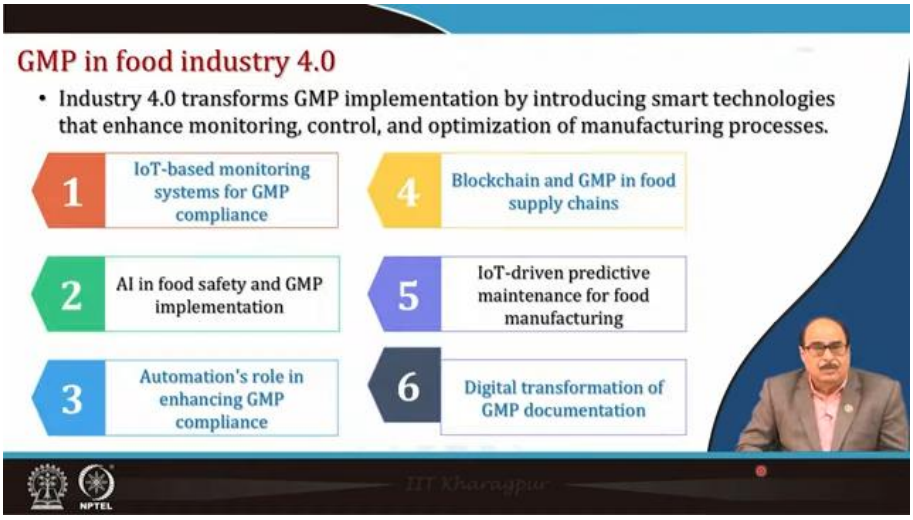
Then legislation and food safety issues, that is, you know, the food products are strictly regulated. There are various regulating agencies like the USFDA, FSSAI in India, and the EPA, which is the Environmental Protection Agency. European Union, etc., for different aspects like labelling, hygiene, safety, documentation, and so on. All these issues are now strictly regulated in food. However, due to the introduction of new processing technologies and changes in the raw material production, etc., these have made it a significant challenge to ensure food products meet safety standards. And even still, in many countries, there are no well-defined regulatory standards for the newer technologies or for the newer products, etc. So, maintaining compliance requires continuous monitoring and adaptation of evolving regulations. Organisations are continuously working to enhance their legislative powers to mitigate the risk of disease or contamination from food products. Recent studies have linked diets high in ultra-processed foods. They result in increased risk of illness such as cancer, heart disease, obesity, depression, etc. So, that again that is the strict regulations need to be put in force to take care of these things. So, the role of food labelling lies not just in the identification of products, but also in delivering vital information to consumers. That is, you eat this food, this is safe, this is properly processed, it is not ultra processed, it has the necessary quality and safety attributes and so on. So, the consumer, when they see the label, they become yes that they become more and more they feel safer that if I use this food, I will not fall into any problem, etc., and that becomes the role of the regulatory agencies.



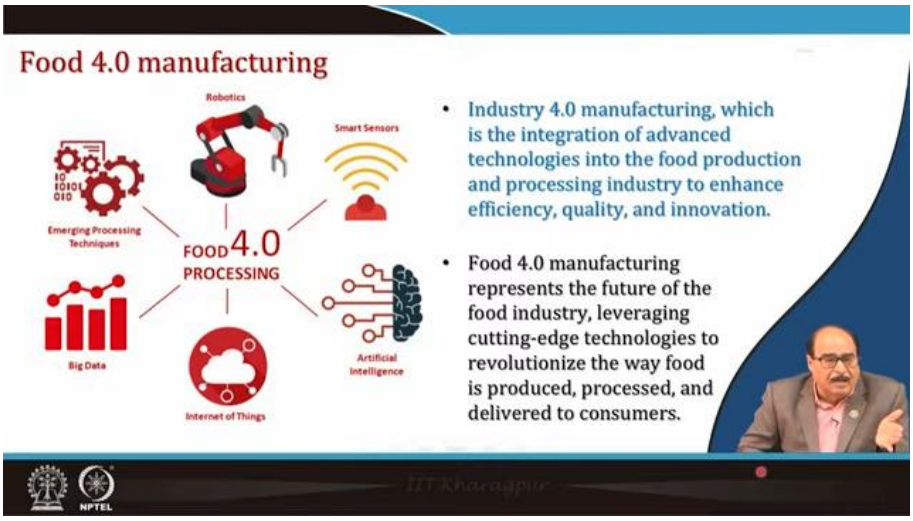
Then another challenge is that, as I told you earlier, it is also consumer preferences and personalised foods. Now, there is a growing concern that people are living in the information technology era, and they are more and more aware of what they need and what they should take. So, there is a demand for healthier, minimally processed and functional food, health foods, etc. Many people are getting Inclined towards buying foods without added preservatives and sweeteners that might impact one's health negatively. So, meeting these preferences requires innovation in processing methods to preserve nutritional quality while ensuring safety and shelf life, and the trend is increasing demand for organic foods. As the population is becoming aware of the harmful effects of pesticides on the environment and health, organic farming is growing exponentially. So, with the growing concern regarding animal abuse, more and more consumers are shifting towards vegetarianism and they are shifting towards vegan products, and this has resulted in a decrease in the demand for meat and its products, which is again an area of concern or major challenge in the food processing industry.

Supply chain disruptions can again result in significant losses during post-harvest processing due to factors like pests, microorganisms and inadequate handling. These losses not only affect the economic outcome but also pose challenges to the food industry and resource optimisation. Events such as pandemics, climate change, and geopolitical tensions can disrupt supply chains, affecting the availability and cost of raw materials and finished products. Building resilient supply chains is essential to mitigate these risks. Technologies such as supply chain analytics allow stakeholders to examine tremendous volumes of data, culminating in actionable business intelligence. So, forecasting demand, managing inventory, and improving the end-to-end efficiency of supply chain operations become possible by these means.

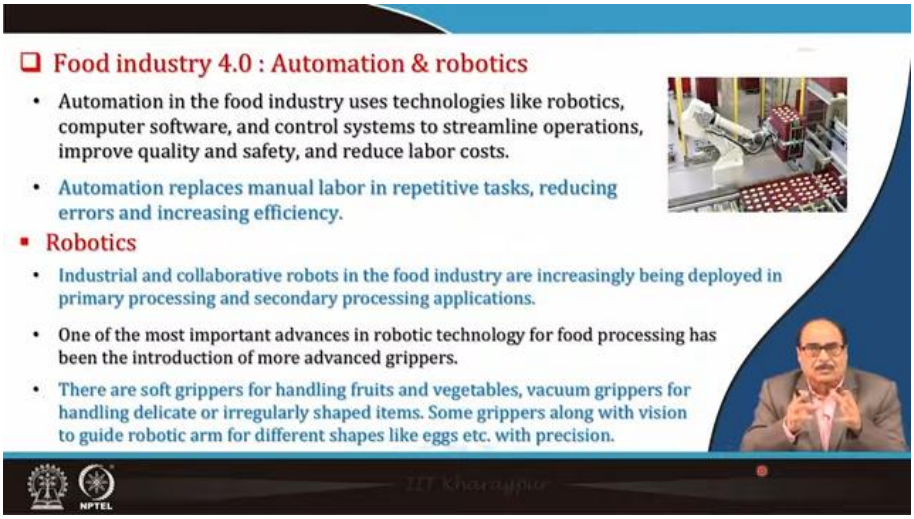
Then, the adoption of various new technologies again sometimes poses a challenge. The integration of advanced technologies such as automation, data analytics, and IoT services, collectively known as Industry 4.0, presents both opportunities as well as challenges. While these technologies can enhance efficiency and product quality, their implementation requires significant investment and a skilled workforce. The increasing resilience and digital technologies lead to the generation of vast amounts of data. Effectively managing and utilising this data for decision-making and process optimisation is a significant challenge for the food industry. That is the digital transformation challenge. If you say that the major thing is adopting AI-powered tools with existing systems, the cost of sourcing data, and digital expertise, and the risk of cyberattacks, which has particularly increased. These cyberattack risks have increased nowadays, along with the use of data for personalised marketing.



So, with this, now let us briefly talk about GMP in the Food Industry 4.0. Earlier, we discussed what good manufacturing practices are, what HACCP is, etc. So, Industry 4.0 transforms GMP implementation by introducing smart technologies that enhance monitoring, control, and optimisation of manufacturing processes. Like IoT-based monitoring systems for GMP compliance, the use of artificial intelligence in food safety and good manufacturing practices implementation, the role of automation in enhancing GMP compliance, and blockchain technology in GMP for the food supply chain. The use of IoT-driven predictive maintenance for food manufacturing or the digital transformation of GMP documentation. So, basically, the use of smart systems and smart technology for GMP operations.

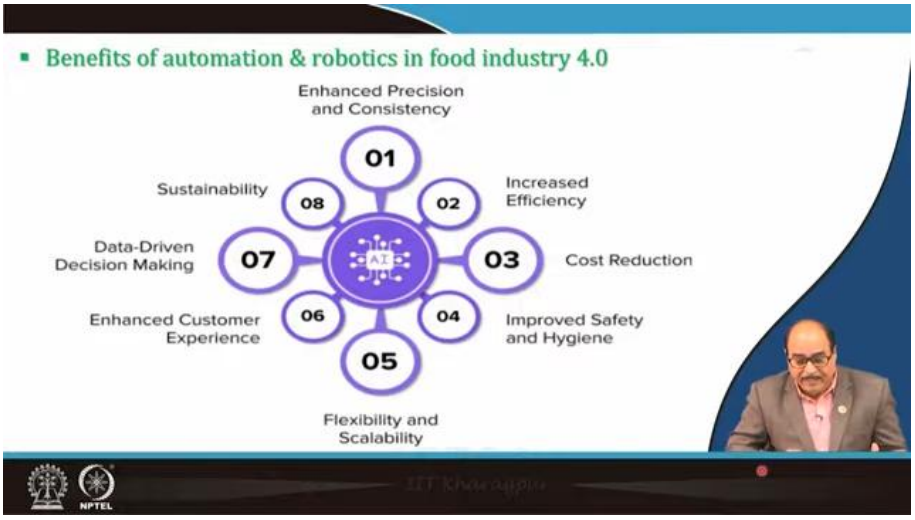


So, Food 4.0 manufacturing, again, as I told you, uses robotics, smart sensors, artificial intelligence, the Internet of Things, big data, and emerging processing technologies. Basically, you can say that it is the integration of advanced technologies into the food production and processing industry that enhances efficiency, quality, and innovation. Food 4.0 manufacturing represents the future of the food industry, leveraging cutting-edge technologies to revolutionise how food is produced, processed, and delivered to consumers.

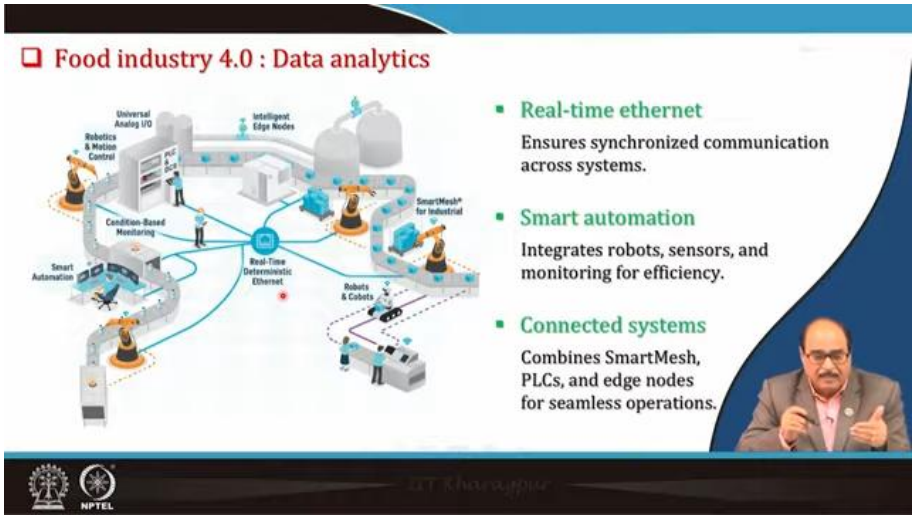


So, there are key aspects of Food Industry 4.0, which are, number one, automation and robotics. So, automation in the food industry uses technologies like robotics, computer software, and control systems to streamline operations, improve quality and safety, and reduce labour costs. Automation replaces manual labour in repetitive tasks, reducing errors and increasing efficiency. And robotics now robotics has come in a big way the use of robotics in various food sectors, in food processing, in manufacturing, in the supply chain,

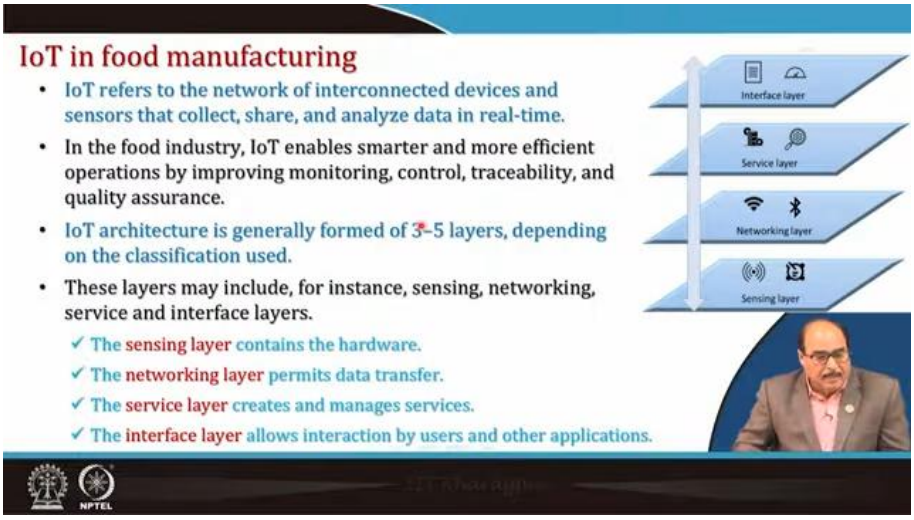
in handling, and also that industrial and collaborative robots in the food industry are increasingly being developed or deployed in primary processing as well as in secondary processing, in packaging, in handling, and other operations. And one of the most important advances in robotics technology for food processing has been the introduction of more advanced grippers. There are these grippers, which are equipped with sensors. There are now soft grippers for handling fruits and vegetables, and vacuum grippers for handling delicate and irregularly shaped items. Even some grippers, along with vision systems, have the capability to guide robotic arms for different shapes, like eggs, etc., with precision. These advancements in robotics technologies have increased their use in the food processing industry.



So, obviously, the benefits of automation and robotics in the food industry include enhanced precision and consistency, increased efficiency, cost reduction, improved safety and hygiene, flexibility and scalability, enhanced customer experience, data-driven decision making, and finally, sustainability in the food industry.

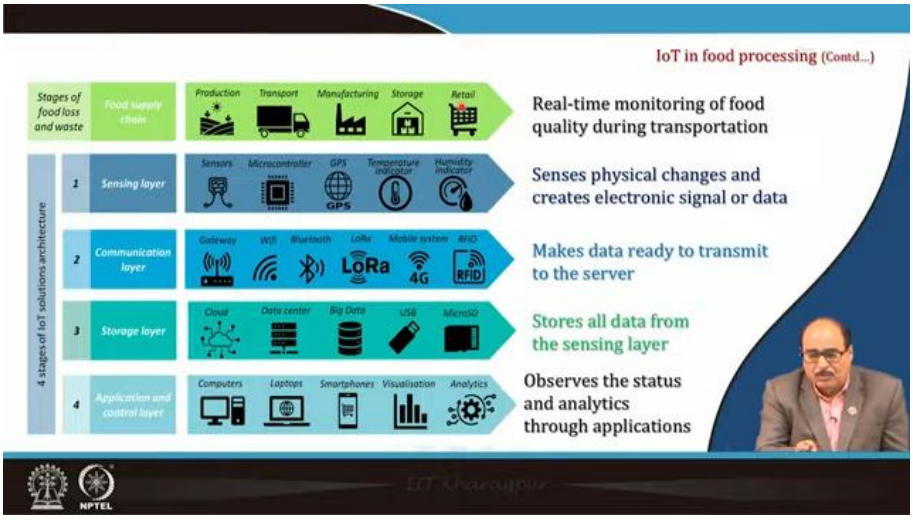


So, another major aspect of Food Industry 4.0 is data analytics, which is basically the use of real-time Ethernet. Real-time Ethernet ensures synchronized communication across the various systems present in the industry. Smart automation integrates robots, sensors, and monitoring for efficiency in the production system, efficiency in the communication system, and finally, connected systems. Like, it combines the smart mesh PLCs and edge nodes for seamless operations. So, that is the role of data analytics, etc.

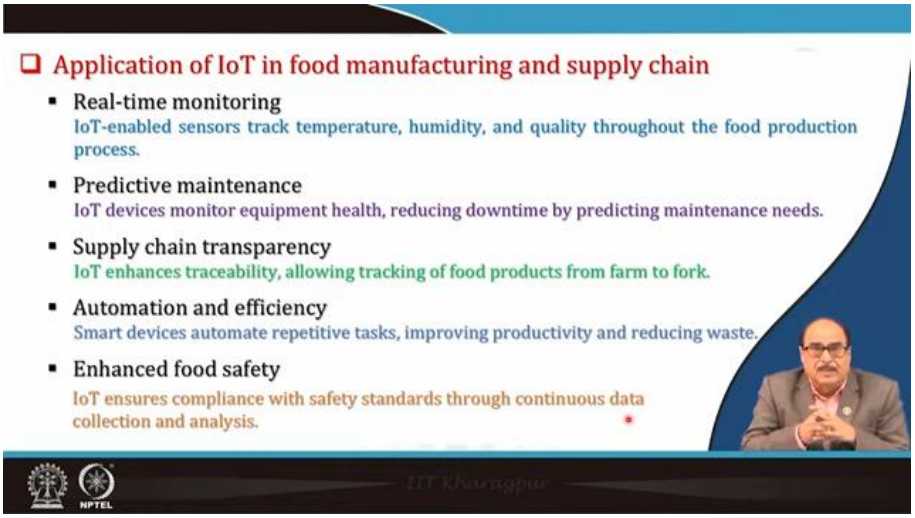


Then, let us briefly talk about the use of the Internet of Things (IoT) in food manufacturing. IoT basically refers to the network of interconnected devices and sensors that collect, share, and analyse data in real time. In the food industry, IoT enables smarter and more efficient operations by improving monitoring, control, traceability, and quality assurance. IoT

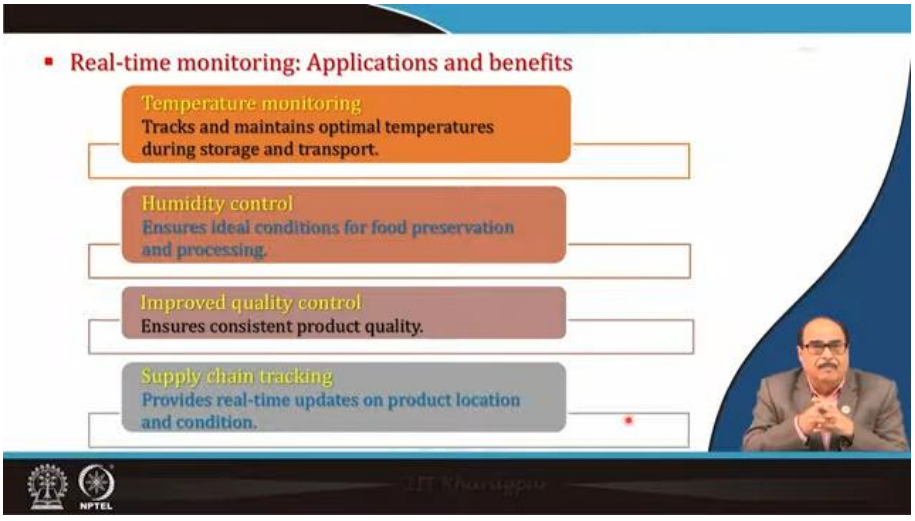
architecture is generally formed in 3 to 5 layers, depending upon the classification used, and these layers may include, for instance, the sensing layer, which contains the hardware; then the networking layer which permits data transfer; the service layer, which creates and manages the services; and finally, the interface layer, which allows interactions by users and other applications.



So, take the example, for instance, of various stages of food loss and wastage in the food supply chain, and the various stages are production, transport, manufacturing, storage, and retail. So, this IoT helps in collecting the real-time monitoring of food quality during transportation and at each and every stage. So, there are, as I told you, the sensing layers, meaning various sensors, a microcontroller, a GPS, a temperature indicator, humidity indicators, etc. They can be installed in various stages in the value chain in the whole supply chain system or in the operation system, and these sensors physically change and create the electronic signals of that data at the change, that is, if there is a change in a particular quality at the board. So, it converts into electronic signals, and then there is a communication layer, which may include RFID or a mobile system. Lora, Bluetooth, Wi-Fi other gateways etcetera that it makes data ready to transport the system that is earlier electronic data has been which has been created you know this make the that is this communication layer make the data ready to transmit to the server and then In the server there is a storage layer using micro SD, USB, big data, data center or even cloud storage means it stores the all the data which has been communicated from the sensing layer which has got from the sensing layer and finally, the application ends control layer, it observes the status and analyzes analytics through the applications so, that is how it does.

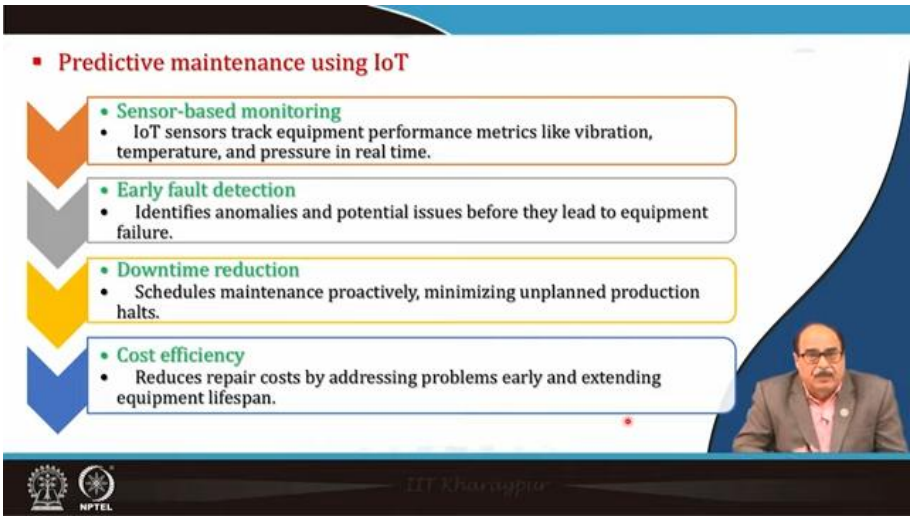


So, obviously, the application of internet of things in the food manufacturing and supply chain, they told you it may be used for real time monitoring that is the IoT enabled risk, stress, temperature, humidity, and quality throughout the food production, IoT devices monitor equipment health, reducing downtime by predicting maintenance needs. IoT enhances traceability, allowing tracking of food products from farm to fork. Smart devices automate repetitive tasks, improving production and reducing waste, therefore increasing automation and efficiency, and helping in achieving advanced, enhanced food safety. IoT ensures compliance with food safety standards through continuous data collection and analytics.



These are real-time monitoring applications in food processing, and benefits include temperature monitoring, which tracks and maintains optimal temperatures during storage

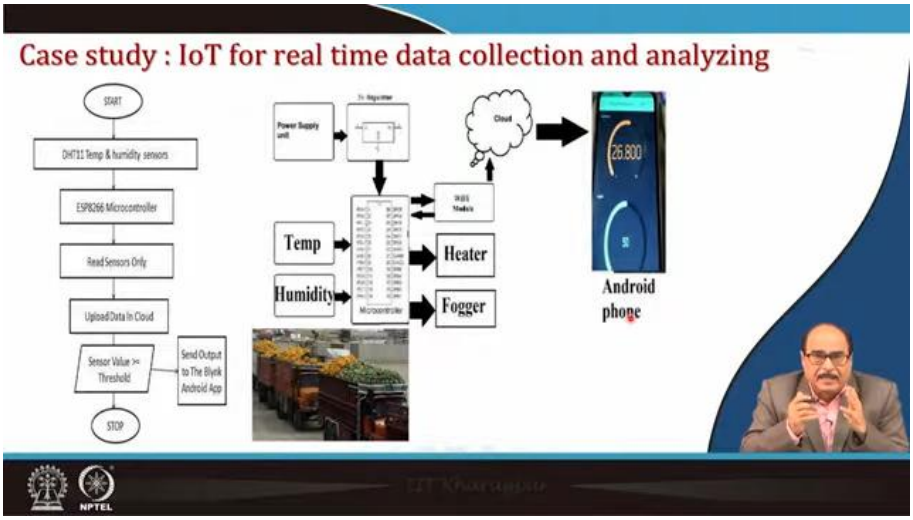
and transport or even during processing. Humidity control ensures ideal conditions for food preservation and processing. Improved quality control ensures consistent product quality, and supply chain tracking provides real-time updates on product location and condition.



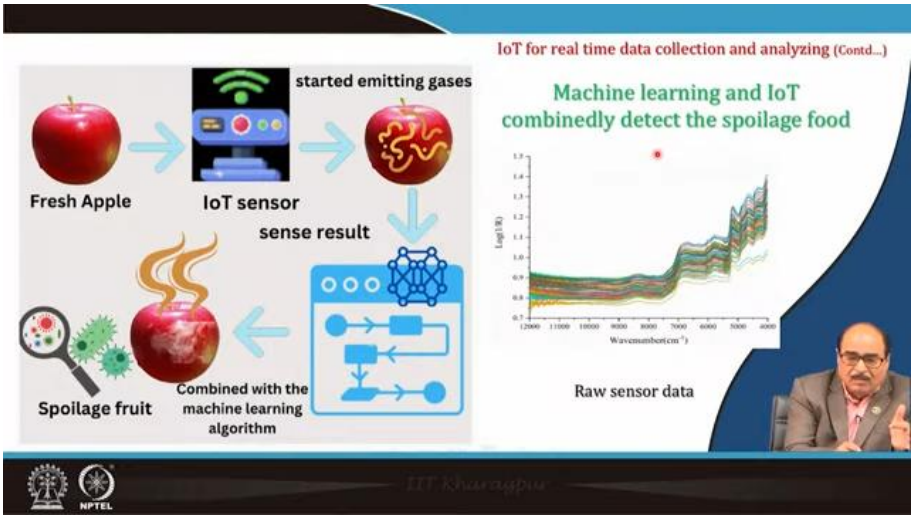
Then, predictive maintenance using IoT, as discussed, involves sensor-based monitoring. IoT sensors track equipment performance metrics like vibration, temperature, and pressure in real time. These IoT sensor identifies anomalies and potential issues before they lead to equipment failures. They schedule maintenance proactively and therefore minimise unplanned production halts and reduce repair costs by addressing problems early, extending equipment life, and therefore resulting in cost efficiency.

Quality control through the Internet of Things, you can see here that there are people in the literature who have worked on products like samosa, Indian products and their IoT-based food monitoring, its quality during production as well as during handling, etc. So, IoT

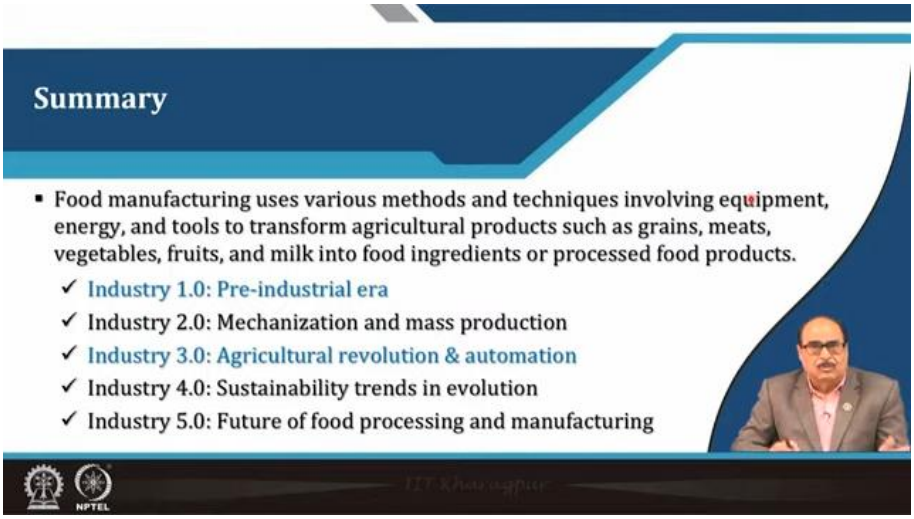
ensures consistent quality by monitoring critical control points in production. Its application includes tracking moisture levels in baked goods to ensure texture and shelf life, or checking contamination levels in raw material during processing. Its benefits are that it guarantees adherence to food quality standards as well as improves customer satisfaction by delivering a consistent product. You can produce a product in batches which is consistent in quality and consistent in nutritional value.



So, let us briefly take a case study that is IoT for real-time data collection analyzing and for any study, obviously, you have to have one algorithm that is in the Again you start there are like here in the term it is a fruits and vegetable storage and supply system handling system. So, here, there may be temperature and humidity sensors provided, which take the data of the temperature, humidity, etc., and send this data to the microcontroller. Then there are real read sensors only, and these sensors communicate and upload the data to the cloud, finally, and the sensor values the threshold and send the output to a blank or Android app. So, this is how it means you have your algorithm and then proper sensors and other things, different layers, and it uses sensors. The data is sent to the power supply through the power supply system, which sends data to the cloud storage, and finally, it is used to give the desired result.



Here again, you can see this, suppose there is a fresh apple. So, first you give the fresh apple, and then the IOT sensors, etc., will take the sensors and check the data. And then there is when there is or its quality deteriorates, then various gases, etc., are generated. So, these sensors the gas sensors etcetera this is those gases and this is sent to the further communicated to the processor where it is combined with the machine learning algorithm and finally, it senses and analyzes the data from these spectra, which are created inside it, and it confirms that the material is spoiled. It compares with the fresh one and detects that this is where machine learning and IoT combine to detect the spoilage of the food, and there are many such applications in the system.



So, finally, I will summarize this lecture by saying that food manufacturing uses various methods and techniques, and there are various operations involved, which we discussed

earlier. Obviously, the development and evolution of the food industry are entirely linked to how societies developed. The food industry has evolved, and now we are in Industry 4.0, which emphasizes sustainability in food production, food evolution, and Industry 5.0. It is the future of food processing and manufacturing. The main aim here is the development of a sustainable food production system, a circular economy with the use of smart technologies and novel processing. How can we deliver personalized nutrition or food for people with specific needs, specific data, and which meets the requirements of the people? It is good, high in quality, safe to consume, and delivered in the form in which the consumer likes it. So, that is here, but more so, that is done by the smart processing and automated processing. So, smart processing smart food processing is the future of the industry.

So, these are the references that were used in preparing this lecture.

Thank you very much for your patient hearing.