Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.241

ISSN: 2582 – 7146

Curr. Rese. Agri. Far. (2024) *5*(6), 31-47

Current Research in Agriculture and Farming

Review Article

Peer-Reviewed, Refereed, Open Access Journal

Innovative Food Solutions for a Sustainable Future: Design and Technology

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Received: 15.10.2024 | Revised: 17.12.2024 | Accepted: 24.12.2024

ABSTRACT

The escalating global population, resource depletion, and climate change underscore the urgency of sustainable food systems. This review explores innovative solutions in food production, processing, and packaging to address food security challenges while minimizing environmental impact. Advances such as Agriculture 4.0, leveraging IoT, robotics, and precision agriculture, enhance resource efficiency and productivity. New Plant Breeding Techniques (NPBTs) and non-thermal processing methods ensure higher yields, nutrient preservation, and safety with reduced environmental footprints. Sustainable packaging solutions, including biodegradable and edible materials, contribute to waste reduction and circular economy goals. Despite cultural and technical adoption barriers, these innovations align with the United Nations Sustainable Development Goals, offering a pathway to equitable, resilient, and sustainable food systems. Enhanced investment, research, and policies are imperative for maximizing these technologies' potential and ensuring a secure food future.

Keywords: *Innovative Food, Food Security, Food Technology, Food Science*

INTRODUCTION

Sustainability is vital for advancing social, technical, and economic development, focusing on creating a circular economy and continuously fulfilling societal needs (Qureshi et al., 2019). In developed nations, consumer demands for healthy food that is safe to eat, nutritious, and pleasing to the senses is continuously rising (Loveday, 2019). For the growing population, sustainability provides a practical approach which ensures a reliable supply of the food that is safe, wholesome, and nourishing (Mak, Xiong, Tsang, Iris, & Poon, 2020).

Cite this article: Noor, S., Sajjad, S., Ahmad, M., Maryam, T., Rehman, U., Raza, H., Tariq, K., Ali, M., Bilal, M. (2024). Innovative Food Solutions for a Sustainable Future: Design and Technology, *Curr. Rese. Agri. Far.* *5*(6), 31-47. doi: http://dx.doi.org/10.18782/2582-7146.241

With increasing global population, there will likely be a greater need for food. The UN estimates that by 2050, the world's population will rise by 50% reaching 9.5 billion people (Henchion, Hayes, Mullen, Fenelon, & Tiwari, 2017). The Food and Agriculture Organization (FAO) believes that the agricultural production will need to expand by 70–70% by that time in order to fulfill demand. To fulfill those requirements, there is an increasing need to rethink and redesign our food systems to ensure they are sustainable, equitable, and resilient (McClements et al., 2021).

Food systems (FS) involve everyone and all the activities connected to producing, processing, distributing, consuming, and disposing of food, whether it comes from farming, forestry, or fishing, and include the economic, social, and natural environments around them (FAO, 2018).

A sustainable food system (SFS) ensures that everyone has access to food security and nutritional stability while preserving the resources without compromising the ability of future generations to meet their own needs. This means it is economically profitable, benefits society widely, and has beneficial or neutral impact on the environment (FAO, 2018).

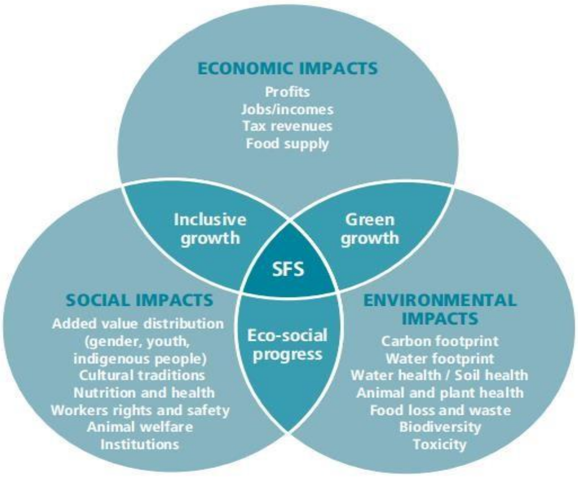
Certain food processing technologies contribute to environmental pollution and emit greenhouse gases as these rely on non-renewable resources of fossil fuels (Rahimifard et al., 2017). Current food systems encounter several sustainability challenges, including environmental issues like climate change, waste management, and practices that contribute to environmental degradation (Herrero et al., 2021). Moreover the issues regarding the accessibility and reliability of food's safety, quality and supple are also encountered (Picart-Palmade, Cunault, Chevalier-Lucia, Belleville, & Marchesseau, 2019).

A study done by The Global Burden of Disease in 2019 brings out a major global health issue: the rise of non-communicable diseases (NCDs) such as obesity, heart disease, and diabetes, which have emerged as the most significant causes of death and disability worldwide. The study also points out those poor diets played a major role, contributing to an estimated 8 million deaths globally. (Vos et al., 2020)

Established in 2015, one of the main focuses of Sustainable Development Goals (SDGs) of the United Nations' is achieving sustainable food system. The SDGs are designed by UN to tackle the current challenges with the aim of transforming the food and agriculture systems to eradicate hunger, enhance nutrition and ensure secure access to food by 2030 (FAO, 2018). Food systems are at the heart of many of the SDGs, particularly those related to ending hunger (SDG 2), promoting good health and well-being (SDG 3), and ensuring sustainable patterns of production and consumption (Weiland, Hickmann, Lederer, Marquardt, & Schwindenhammer, 2021).

The SDGs highlights the importance of adopting innovations in agricultural practices i.e. food production, processing, and distribution which are critical for creating stronger, healthier and sustainable food systems. By aligning the innovation in food system with the SDGs, we can create a future where food is produced and processed in such ways that are environmentally sustainable and also socially equitable and economically viable (Herrero et al., 2021).

"Sustainable Healthy Diets – Guiding Principles," were introduces by FAO and WHO in 2019 on World Food Day which outlines three core pillars of sustainability: social, economic, and environmental (Food, Nations, & Organization, 2019). According to FAO (FAO, 2014), a food system is sustainable if it is economically viable for everyone involved, fairly distributes benefits to all, including vulnerable groups, and supports social values like health, traditions, and good working conditions. It should also have negligible effect on the environment, protecting biodiversity, water, soil, and minimizing waste and pollution.



With growing concerns over rising global population, climate change, and resource depletion, building a food system that is sustainable and can offer healthier food options to everyone is urgently needed (McClements et al., 2021). Additionally, sustainable food systems need to tackle environmental issues, including lowering greenhouse gas emissions, conserving water, and protecting biodiversity.(Vos et al., 2020). This review will provide some of the sustainable food solutions that are available for better future.

The goal of sustainable agriculture is to produce enough food in a way that can fulfill current needs without putting at risk the capacity of future generations in fulfilling their own (Silveira & Amaral, 2022). Sustainable agricultural development improves resource efficiency, boosts resilience, and promotes social equity in agriculture ensuring access to adequate nourishment as well as food stability and security for all now and in the future (Legg, 2017).

Innovative Food Production Techniques Agriculture 4.0:

The agriculture industry has undergone several significant transformations over time. Initially, it shifted from traditional methods, also called Agriculture 1.0 to mechanization, which introduced machinery and steam power knows as Agriculture 2.0. This was followed by the bio-revolution, also known as the green revolution or Agriculture 3.0, characterized by major scientific advancements in genetics, fertilizers, and pesticides (Gyamfi, ElSayed, Kropczynski, Yakubu, & Elsayed, 2024).

Agriculture 4.0, also known as smart agriculture or smart farming, marks a major shift in the agricultural industry by utilizing advanced digital technologies (Gyamfi et al., 2024). It involves the adoption of new and innovative technologies within the agricultural sector (Da Silveira, Lermen, & Amaral, 2021) i.e. robotics, artificial intelligence as well as Internet of Things (IoT) sensors to improve farming operations. This approach not only modernizes agricultural practices but also promotes sustainability by optimizing resource use and reducing environmental impacts (Javaid, Haleem, Singh, & Suman, 2022).

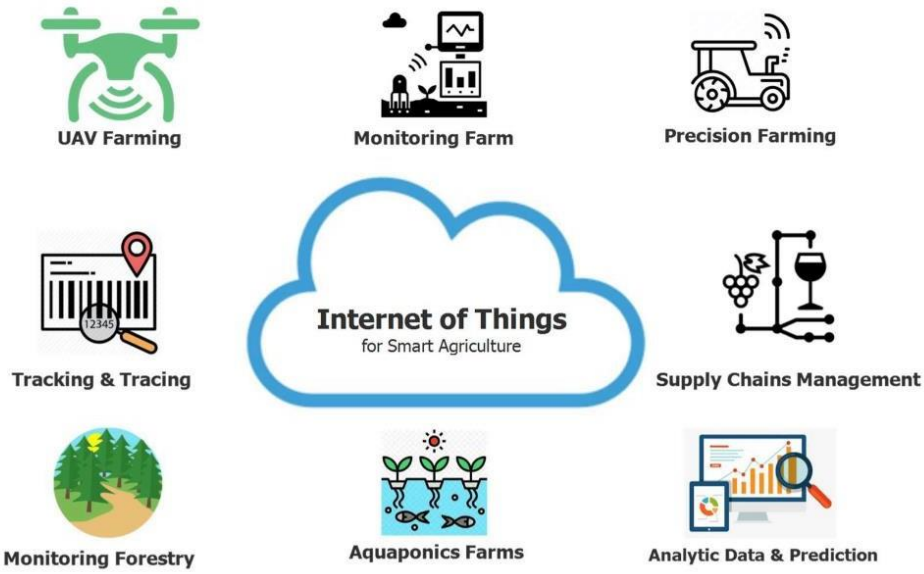
Internet of Things (IoT):

The Internet of Things is a network of interconnected objects including machines, software, sensors, devices, and people that are communicating and exchanging information over the internet to create a seamless link between the physical and virtual worlds (Elijah, Rahman, Orikumhi, Leow, & Hindia, 2018). IoT applications have transformed everyday objects into "smart things" such as smart homes, smart cities, self-driving cars, healthcare, supply chain management, and environmental monitoring (Dadhaneeya, Nema, & Arora, 2023).

Role of IoT in Smart Agriculture and Poultry Farming:

IoT technology is being used by the industries worldwide to improve agriculture and poultry farming, making them more intelligent, effective, and productive (Vinueza-Naranjo et al., 2021). For instance, IoT sensors installed in fields, machinery, and livestock provide real-time data on major factors like soil moisture, levels of nutrient, plant health, and animal welfare (Chataut, Phoummalayvane, & Akl, 2023).

The following figure shows the IoT applications for smart agriculture.



Efficient Irrigation Management:

IoT sensors embedded in farmland soil can measure moisture levels, allowing for the development of efficient water management systems (Placidi, Gasperini, Grassi, Cecconi, & Scorzoni, 2020). These systems activate sprinklers only when necessary, conserving water and enhancing efficiency (Chataut et al., 2023). This information is essential for remote monitoring and making timely adjustments. By transmitting data through IoT, farmers can oversee their operations from a distance and react promptly.

Automated Poultry Farming:

IoT is also revolutionizing poultry farming. For example, the Poultry Management System developed by (Batuto, Dejeron, Cruz, & Samonte, 2020) utilizes IoT to automate feeding and watering processes. An Android application was designed to schedule chicken feedings, while sensors detect empty containers and trigger notifications for refills, ensuring a continuous supply of food and water.

Cisco predicts that over 500 billion IoT devices will be connected to the internet by 2030 (Zikria, Ali, Afzal, & Kim, 2021). The integration of IoT and big data is set to revolutionize smart agriculture, boosting both efficiency and productivity in the industry (Quy et al., 2022).

Robotics and Automation:

Conventional operations like harvesting, weeding, and sorting are gradually being handled by robots, which lowers human costs and increases productivity. In the upcoming years, there will be more usage of agri-robots in the fields (Farooq, Riaz, Abid, Abid, & Naeem, 2019). It makes modern technology available to farmers. In addition, automated systems can handle harvesting, weed control, precision seeding (R Shamshiri et al., 2018), which lower the need for human involvement and improve process accuracy.

Achieving Cost-Effectiveness in Robotic Harvesting:

Despite the advancements in agricultural automation, millions of fruits and vegetables are still gathered by hand in open fields each year. (R Shamshiri et al., 2018). Fruit yields need to rise in order to make robotic harvesting cost-effective and to balance the higher costs of automation. According to (Hemming et al., 2014) almost 1.9 million tons of sweet peppers are produced annually in Europe. Current technology, with an average picking time of 94 seconds per fruit, only achieves a success rate of 33%, despite the fact that the ideal automated harvesting time per fruit is 6 seconds.

Robotic harvesting technology should be explored as an alternative solution to overcome labor shortages and reduce the costs associated with timely manual harvesting (Maffezzoli, Ardolino, Bacchetti, Perona, & Renga, 2022).

Examples of Agriculture 4.0

Computer Vision and Disease Control:

Computer vision enables devices and machines to collect and interpret data from pictures and videos. In agriculture, it offers innovative solutions by delivering real-time data on automating labor-intensive processes, health of crops, and maximize resource utilization (Chouhan, Singh, & Jain, 2024).

Impact of Pests and Diseases on Crop Yields:

Computer version and robotics are helpful in controlling diseases in plants. According to an estimate by FAO up to 40% of annual crop yield losses worldwide are caused by pests.

Annually, losses from plant diseases exceed $220 billion, and at least $70 billion economic damage is caused by invasive insects (Food & Agriculture Organization of the United Nations, 2021).

Autonomous Robots for Disease Detection:

Camera equipped autonomous robots with sensors capture detailed field data. Computer vision analyzes this to detect diseases, monitor crop health, and guide targeted treatments, minimizing pesticide use and environmental impact (Anand, Madhusudan, & Bhalekar, 2024).

Applications of Computer Vision in Agriculture:

According to (Chouhan et al., 2024), computer vision is transforming various aspects of agriculture, including:

- Improved Crop Monitoring and Management: Enhanced surveillance techniques for early disease detection and prevention.
- Livestock Tracking: Automated monitoring of livestock health and behavior.
- Advanced Irrigation Control System: Optimized water usage determined by real-time analysis of soil and plant conditions.
- Predicting Yields: Data-driven forecasting models for better yield predictions.
- Tracking Food Origins: Ensuring food safety and quality through accurate traceability.

Advances in robotics and computer vision have opened new opportunities for disease management in agriculture. These technologies can analyze visual data to detect and characterize disease symptoms in crops effectively (Anand et al., 2024).

Benefits and Potential of Smart Agriculture 4.0:

According to (Priyadarshan, Penna, Jain, & Al-Khayri, 2024), Smart agriculture offers numerous benefits across several critical areas, enhancing efficiency, sustainability, and productivity in farming practices:

Resource Efficiency:

Smart agriculture minimizes the consumption of water, energy, and materials in farming. For instance, (Javaid et al., 2022) highlight the use of sensors for monitoring soil conditions, nutrient content, and levels of water, contributing to more efficient resource use. Analyzing the suitability of the land before cultivating crops enables farmers to maximize productivity and raise yield (Villa-Henriksen, Edwards, Pesonen, Green, & Sørensen, 2020).

Crop Management:

Agriculture 4.0 helps in crop management and monitoring as it focuses on tracking plant growth and health. Digital and technological advancements play a key role in this field, as they gather and analyze data to keep a close watch on crops (Partel, Kakarla, & Ampatzidis, 2019). This helps with planning and optimizing production plans as well as enabling timely responses to diseases or any type of risk.

Controlled Environment Agriculture:

Growing crops in protected environments is a vast application area known as greenhouse cultivation, or indoor farming (Shamshiri et al., 2018). By enhancing control over factors including soil, water, and fertilizers, this approach maximizes resource efficiency, raises crop yields and boost productivity. (D. C. Rose & J. Chilvers, 2018) suggest that smart agriculture can greatly benefit sustainability by enhancing the efficiency and productivity of food production and providing potential environmental and social advantages.

Precision Agriculture:

Precision agriculture makes more accurate decisions and focuses on targeted resource allocation possible by utilizing artificial intelligence (AI) and data analytics. According to (Medel-Jiménez, Krexner, Gronauer, & Kral, 2024), these technologies can significantly enhance the environmental sustainability of farming, addressing issues such as soil health, air and water pollution, and climate change.

Empowering Farmers:

Access to real-time data and decision-making tools allows farmers to make informed choices, enhance their economic situation, and adapt to changing environments. A study by (Eastwood, Ayre, Nettle, & Rue, 2019) emphasizes that digital tools and platforms help to narrow down the knowledge gap between farming communities and specialists, promoting better agricultural practices.

Protected Agriculture:

4.0 technologies improve protected agriculture, which grows crops in controlled surroundings like greenhouses. By using fewer agrochemicals, such as fungicides, herbicides, and insecticides (Hamuda, Glavin, & Jones, 2016), farming expenses and environmental contamination are decreased. This strategy increases productivity while promoting sustainable and effective agriculture practices by encouraging the optimum growing conditions for crops and protecting them from harsh environments and pests (Maffezzoli et al., 2022).

Challenges to the Implementation of Smart Agriculture:

Agriculture 4.0 encounter multiple interrelated challenges that impact the acceptance of new developing and emerging technologies (D. Rose & J. Chilvers, 2018). Due to the complexities of the agricultural ecosystem, which is currently undergoing a transformation, the growth of agriculture 4.0 often falls short of its full potential (Giua, Materia, & Camanzi, 2022). Key barriers in production and farm to market chain include data reliability concerns, insufficient rural connectivity, technological complexity, and a shortage of lack of digital skills or trained labor (Da Silveira et al., 2021).

A study by (Da Silveira, Da Silva, Machado, Barbedo, & Amaral, 2023) involving farmers in southern Brazil identified several key barriers in adopting smart farming practices. The primary issues reported include a lack of infrastructure, limited access to farmer-friendly solutions, a need for more research and development (R&D) and innovative business models, varying levels of risk across different age groups, and insufficient data accuracy on rural environments.

New Plant Breeding Techniques:

New Plant Breeding Technologies (NPBTs), which mainly includes genetically engineered and gene-modified crops, are essential for improving food security and encouraging sustainable agricultural growth (Zilberman, Holland, & Trilnick, 2018). By increasing food production and decreasing environmental effect, these technologies have great potential in achieving Sustainable Development Goal 2, which is "zero hunger and improved nutrition" (Springmann et al., 2018). With over 800 million people experiencing chronic hunger and 2 billion are micronutrient deficient, there is a pressing need for transformative changes in global food systems (Qaim, 2020).

Biofortification and Genetically Modified Crops:

According to FAO, Global rice production was predicted to have reached 741 million tons in 2016. Biofortification is done to increase micronutrients content. Staple food crops were fortified with zinc, iron and vitamin A which are the most limiting in diets (Bouis & Saltzman, 2017). High zinc rice, high iron beans and vitamin A enriched maize were introduced and more than 3 million people are eating these biofortified crops (Zhao, Lin, & Chen, 2020).

Additionally, smallholder farmers' adoption of genetically modified (GM) crops resulted in increased production, reduced use of pesticide, poverty alleviation, and also improved food security (Qaim, 2016). According to a study, verities of certain genetically modified crops including maize, soybean, and cotton produced 20%, 15% and 7% higher yields compared to non-GMO verities respectively (Yali, 2022). Through African seed companies, the Water Efficient Maize for Africa (WEMA) project is creating varieties of drought-tolerant maize for farmers (Oikeh et al., 2014).

Advances in Gene Editing: CRISPR/Cas9 and Crop Improvement:

Gene modification techniques, such as CRISPR-Cas9, ensures accurate and efficient alterations to crop genomes (Gaillochet, Develtere, & Jacobs, 2021). The CRISPR/Cas9 system relies on Cas9 enzyme, which cleaves DNA under the guidance of RNA. Plant breeding can be accelerated by precisely and effectively modifying genes through system optimization (Liu et al., 2022).

Case Studies: CRISPR/Cas9 in Barley and Tomato for Disease Resistance:

According to (Borrelli, Brambilla, Rogowsky, Marocco, & Lanubile, 2018), barley was modified to improve its resistant against powdery mildew, a common fungal disease that affects crops using CRISPR-Cas9. The MLO (Mildew Locus O) gene in barley and MLO1 in tomato (Pu Yan et al., 2018), which makes plant more susceptible to powdery mildew, was targeted using CRISPR/Cas tool in which Cas protein cut the DNA at the location of the MLO gene. The result shows improved resistance in barley and tomato to powdery mildew (Liu et al., 2022).

Benefits of New Plant Breeding Techniques:

These advancements can enhance crops' resistance to insects and other diseases reducing the needs of pesticide spray (Bailey-Serres, Parker, Ainsworth, Oldroyd, & Schroeder, 2019), increase their tolerance to extreme heat and drough, which is essential for adapting to climate change (Eshed & Lippman, 2019). Moreover, the affordability of these technologies makes them accessible for use in underutilized crops like pulses and local vegetables, further supporting global food security (Qaim, 2020; Zaidi et al., 2019).

Non-Thermal Technologies:

Consumers' demands are continuously growing for nutritious and tasty food which has pushed producers to innovate and develop techniques that give a "fresh-like" taste to food and has high nutritional value (Troy, Ojha, Kerry, & Tiwari, 2016). The innovative non-thermal processing methods that are being explored by food industries include ultrasound (US) processing, pulsed electric field (PEF), supercritical fluid extraction (SCF), high hydrostatic pressure (HPP), and ultraviolet radiation. These technologies help maintain food safety as well as quality, lower nutrient loss, and use energy more efficiently than traditional thermal processing (Manzoor et al., 2019).

Conventional technologies often lead to off-flavors from chemical reactions, nutrient fluctuations, and in result food quality is decreased, which drives the adoption of non-thermal technologies (Mújica-Paz, Valdez-Fragoso, Samson, Welti-Chanes, & Torres, 2011). European countries aim to reduce food waste by nearly 30% by 2025 and 50% by 2030 (Laaninen, 2020). After extensive research, it was shown that high-pressure processing (HPP) and pulsed electric fields (PEFs) could successfully ensure food safety, which led to their successful commercialization (Režek Jambrak, Vukušić, Donsi, Paniwnyk, & Djekic, 2018).

PEF:

Pulsed Electrical Filed technology uses short bursts of electric pulses for few seconds (1–100 μs) to induce structural changes and rapidly disrupt cell membranes, either temporarily or permanently, based on the intensity and exposure. This process is known as electroporation (Hernández-Hernández, Moreno-Vilet, & Villanueva-Rodríguez, 2019).

PEF is an eco-friendly and is considered an cost-effective technology for eliminating microbes and enhancing mass transfer and safety of the food products (Zhang, Wang, Zeng, Han, & Brennan, 2019). PEF supports sustainable food processing and offers economic benefits to the food sector while maintaining product safety and quality (Picart-Palmade et al., 2019). PEF treatment maintains the nutritional value of the product (Pallarés et al., 2020), is more effective for pasteurization of liquid foods and decrease food toxins/pathogens increasing food safety.

For liquid food preservation, the US Food and Drug Administration (FDA) mandates a 5-log reduction in microbial levels (Režek Jambrak et al., 2018). PEF have been extensively tested to achieve this 5-log reduction in microbes and enzymes across different samples of food. Coconut milk was given treatment of 30KV cm-1 and 5.5 log reduction for bacteria was achieved. Similarly milk was treated to reduce E.coli and was given treatment of 35 kV cm- 1 for 2 μs at 200Hz. The result shows 6 log reduction (Arshad et al., 2021).

Hydroxy Methyl Furfural (HMF) is produced during thermal food processing through the Millard reaction; reaction between amino and carbonyl compounds, which is potentially carcinogenic for humans (Khaneghah et al., 2020). The effect of PEF treatment (10 kV/cm) on HMF formation in tomato, strawberry, and watermelon juices showed a reduction of 7%, 40%, and 80%, respectively, compared to thermal treatment (Arshad et al., 2021). Similarly, HMF formation in date juice decreased by 12% (Mtaoua et al., 2016).

PEF processing offers numerous benefits like conserving energy and water, enhanced reliability, higher quality products, greater efficiency, and reduced environmental impact. PEF pasteurization is requires less energy compares to conventional treatment which in results reduce

CO_2 emission (Wiktor et al., 2020). PEF also help in reduction of food waste by improving the extraction process of natural extracts. The recovery of polyphenols doubled, and anthocyanins increased by 55% from grape pomace by using an electric field strength of 13.3 kV/cm (Arshad et al., 2021). This in result provides environmental as well as economical sustainability.

HPP:

High Pressure Processing (HPP) also known as High Hydrostatic Pressure involves subjecting liquid or solid foods to elevated pressures of 400-600 MPa at low or mild temperatures (below 45°C) using a liquid as the pressure medium, usually water (Muntean et al., 2016). This cold pasteurization process evenly applies pressure to both the food's interior and surface, extending shelf life while preserving sensory and nutritional qualities (Hernández-Hernández et al., 2019).

In meat industry, HPP is used for processing of different meat products and seafood. The pressure of 175 – 600 MPa for 3-5 minutes showed minimal effect on nutrients and sensory attributes were retained (Bolumar et al., 2020). Studies on HPP at 100–500 MPa for 10 minutes revealed that 400 MPa treatment resulted in increased total phenolic content and higher antioxidant activity in strawberries, while also preserving vitamin C levels (Nuñez-Mancilla, Pérez-Won, Uribe, Vega-Gálvez, & Di Scala, 2013).

HPP provide food safety by reducing food contaminants and toxins at pressure 30 to 500 MPa, 30–50 _C (Avsaroglu, Bozoglu, Alpas, Largeteau, & Demazeau, 2015). Pressure treatment at 300 MPa for 3 min contributes to reduction of food waste generated during food processing which provides Environmental sustainability (Casquete et al., 2015).

HPP is used to lower the amount of L. monocytogenes by approximately 0.91 log10 colony- forming units (cfu)/g at 600 MPa across various food products including cheese, fruit juices, guacamole, seafood and meat products (Nabi et al., 2021). Carotenoids found in pumpkin can degrade with intense thermal treatments. HPP helps minimize color and carotenoids losses in pumpkins and preserves carotenoid content in various vegetables and foods.

HPP is more eco-friendly than conventional thermal processes, as it consumes less energy and lowers the amount of CO_2 emissions (Cacace, Bottani, Rizzi, & Vignali, 2020). HPP is an environment friendly technology that offers sustainable food solutions without degrading quality and safety of food, benefiting the food sector economically. Additionally, it is a natural procedure that encourages clean labeling of food products (Nabi et al., 2021).

Innovative Packaging Solutions for Food:

Packaging of food is the final stage of food processing before it enters the market. Food packages are passive barriers that help keep food safe from environmental damage and enhance its shelf life (Drago, Campardelli, Pettinato, & Perego, 2020). Various terms like "active," "interactive," "smart," "clever," and "intelligent" describe innovative packaging technologies. Intelligent and active packaging often work together to create "smart" packaging (Vanderroost, Ragaert, Devlieghere, & De Meulenaer, 2014).

Conventional packaging leads to environment damage as materials like plastics end up in landfills or in oceans and are not decomposed easily (Petkoska, Daniloski, D'Cunha, Naumovski, & Broach, 2021). To achieve sustainable future regarding food system, packaging should also be upgraded.

Edible Packaging:

Compared to traditional plastic packaging, edible packaging presents an innovative and sustainable alternative that can significantly reduce waste leading to a more sustainable future (Petkoska et al., 2021). By reducing wastes from plastic and encouraging the use of renewable materials, edible packaging contributes in achieving the Sustainable Development Goals (SDGs) of the UN, especially those regarding responsible consumption and production (SDG 12) and life below water (SDG 14) (Weiland et al., 2021).

Edible packaging, made from natural, biodegradable materials, offers a promising solution to the plastic waste problem. These materials are derived from renewable resources such as seaweed, starch, and proteins (Pooja Saklani, 2019). This reduces the need for disposal and minimizes environmental impact. It also contributes to better nutrition value as edible packaging can be enriched with nutrients which also improves the product's shelf life (Petkoska et al., 2021).

An edible coating was made from cornstarch and mint extract which was applied to cucumber, when stored at temperatures 25°C and 10°C, it resulted in enhancement of shelf life and quality (Raghav & Saini, 2018). Similarly, a rice starch based edible coating was applied to banana fruit after harvesting. The coating was blended with sucrose ester and resulted in slowing down the ethylene formation, lowering the respiration rate, and increasing the shortage life for 12 day (Thakur et al., 2019).

Smart Labels:

Smart labels, also known as electronic labels, are now being used to provide information electronically through smart phones. Moving towards smarts labels is more sustainable option as it requires minimum to no paper at all (Kırca, 2022). QR codes are being used on food packages as labels and they provide quick access to information about the product's ingredients through smart phone (Atkinson, 2013). It is also called auto-ID technology. QR codes can be printed on posters or on food product package for advertising purpose (Rotsios et al., 2022). This increases the interaction between the consumer and the product. According to a survey, 57% scanned QR codes to get specific information about the product and 67% agreed that they make life easier (Scanova).

Active and Intelligent Packaging:

Active packaging is invented to intentionally expel or absorb materials into or from the packaged food or its surroundings (Baiguini, Colletta, & Rebella, 2011). Active packaging enables the packaging material to take an active action in providing improved food conservation over traditional packaging (Drago et al., 2020).

Intelligent and smart packaging improves communication with consumers by monitoring and sharing details about a product's status (Elkhattat & Medhat, 2022). The goal of intelligent packaging is to communicate product conditions throughout the supply chain. Since the package travels with the product, it can continuously relay information about the product's state (Drago et al., 2020).

Sensors and Indicators:

Time-Temperature indicators are used to make sure that the product is stored in proper conditions as they are sensitive to environmental changes. (Skinner, 2015). Some commercially available food active packages (Drago et al., 2020) and indicators include:

- Activ-FilmTM which act as moisture absorber and are used in fruits and vegetables. And it uses the films make up of Low-density polyethylene (LDPE).
- SANDRY® is used as Carbon dioxide absorber and is used in Fruit, coffee, fermented food available in the form of sachet.
- Fresh-Check® TTIs are produced by Temptime Corporation, USA. When the product is stored at high temperatures, the central circle on the oval-shaped label becomes darker.
- 3MTM MonitorMark® is self-adhesive pad. It contains a blue dyed fatty acid ester enclosed in a carrier substance.
- CoolVu Food® is used for dairy products and beverage and has an active zone which fades from silver to white. The higher storage temperature results in the faster fading.
- RipeSenseTM have developed these intelligent ripeness indicators. Indicator label that reads crisp, firm and juicy begins red, progresses to orange, and then turns yellow (Kırca, 2022).

CONCLUSION

In conclusion, achieving a sustainable global food system requires a comprehensive approach that involves innovative solutions to current problems and the use of advanced technology. A clear framework is provided by the Sustainable Development Goals (SDGs), emphasizing the importance of sustainable agriculture and innovative solutions to food security challenges. A major step toward more effective, productive, and environmentally friendly agriculture is represented by Agriculture 4.0, which uses data-driven techniques and IoT technologies, marks a transformative shift towards conventional agriculture practices. The vast applications of IoT in smart agriculture like automatic feeding, precision irrigation, and advanced data analysis illustrate the growing potential for innovation and increased productivity in the sector. Additionally, integrating computer vision and robotics presents potential solutions to conventional agricultural problems, enhancing efficiency, sustainability, and resilience against pests and diseases.

New Plant Breeding technologies (NPBTs) offer numerous benefits, including increased crop diversity, higher yield potentials, improved nutrient use efficiency, and a reduced reliance on agrochemicals. Genetically Modified (GM) crops have proven to increase the production and resistant against diseases. These technologies can lessen agriculture's environmental footprint by making crops more resilient to pests and diseases, thereby reducing the need for chemicals i.e. pesticides and fertilizers. Similarly, Non-thermal technologies are also playing a crucial role by maintaining food safety and quality while reducing energy consumption. These technologies kill microbes without damaging the nutritional profile maintaining the raw taste in the food, and enhancing the shelf life of the product. Non-thermal technologies are getting more and more attention as these are environment friendly and produces minimum to no waste and are labelled as green technologies.

With the advance era; the era of Internet of Things (IoT), the traditional paper labels are being replaced by smart labels. Meanwhile, new packaging innovations, including biodegradable and edible materials, support waste reduction as they are either eatable or biodegradable and encourage circular economic practices. While these advancements lay the groundwork for a more stable, stronger and sustainable food system, the need of continual optimization is necessary to ensure wider adoption and enhanced results. This involves informing people and farmers about latest technologies and their benefits, making the use of robotics more affordable, and expanding the use of sustainable packaging.

Although there are some cultural and ethical concerns about the acceptance of these new technologies, but together, these advancements facilitates the way for a resilient and sustainable food system that satisfy the present needs without compromising future generations' ability to fulfill theirs. Increased investment in research, technological advancement, and supportive policies will be vital to overcoming existing challenges and maximizing the potential of these technologies. By embracing these technologies and innovations, we can create a food supply that is not only sustainable and efficient but also equitable and accessible to all.

Acknowledgement:
I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding: NIL.

Conflict of Interest:
There is no such evidence of conflict of interest.

Author Contribution
All authors have participated in critically revising of the entire manuscript and approval of the final manuscript.

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