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REVIEW PAPER

Recent Insights on the Role of Various Food Processing Operations Towards the Development of Sustainable Food Systems

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Abstract
Chronic hunger and malnutrition will eventually result from the population's rapid growth. It is unlikely to succeed in tackling the rising challenges of delivering sustainable food for all people unless high attention is paid on the function of food processing to ensure the supply of stable food. It is impossible to overstate the importance of developing food processing and preservation technologies that can reduce food losses and wastage during surplus seasons. Therefore, sustainable food systems must be developed to provide healthy diets without damaging our world and its resources. The goal is to use various perspectives to confirm why food processing is crucial to future food supply. It is important to show the appropriate utilization of sustainability factors and effect assessments to construct for feeding the globe while staying within planetary limits. There has never been a better time to assure a plentiful food supply to feed the people than right now, when the population is expanding at a worrying rate. The sustainable food project seeks to move the food systems in a long-term, more equitable direction. Food processing, or the conversion of raw materials into functional, edible, and consumer acceptable food, is a critical link in the food value chain between consumption and production. This review looked at various existing and emerging food processing followed by preservation techniques. Food systems must also attempt to reduce food waste and losses, as well as the current and future impacts on the environment and society, to be sustainable.

Keywords Sustainable food supply · Food chain · Nutrition · Food processing · Preservation

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Introduction

The world around us is evolving at a dizzying speed. In this context of elaborating food consumption by an increasing population and changing dietary preferences, the global food system faces huge problems. A major problem is how to achieve expanding food requirements and provide nutritious foods to everyone for years to arrive without exhausting Earth's resources or breaching planetary limitations, which could disturb humanity's prospects [1]. Governments all across the globe dare to change our food management, but doing so will necessitate coherent, coordinated, and emerged action [2]. Food affects many aspects of our existence, with our health (nutrition), economy (employment), society (culture), and the environment. However, all rules that govern such fields are still formulated and executed in isolation. Government officials may share information about ongoing projects and, on occasion, create policies with joint goals. Rarely, however, will policies be emerged so that it is evident how every policy contributes to a larger goal, such as achieving sustainable food processing systems [3].

The emphasis is increasingly on approaching sustainable diets with low environmental effects and boosting population well-being today and in the future [4]. All components of the food supply pattern, starting from production to processing, packaging, and the storage with final delivery of food items to consumer should be considered by the food industry to make proficient use of available resources in every stage to provide nutritious nourishment for all time growing society with numerous variations [5]. Various preservation techniques are frequently used in food industries (Table 1). A variety of new farming and as well as processing methods with little negative effects on the environment can be applied in cities' controlled indoor environments. Techniques like hydroponics—where plants are grown in nutrient-rich solutions—aquaponics—where water and fish waste are used—and aeroponics—where nutrient-rich water is sprayed onto roots suspended in the air—are all promising. For instance, in New York and Chicago, hydroponic greenhouses on the rooftops of several buildings now produce fresh greens with reduced transit and storage distances for the local markets [67]. Figure 1 depicts the elements of sustainable food systems.

In this review paper, we have discussed that rapid population increase, urbanization, rising affluence, shifting consumer habits, and globalization, as well as climate change and the loss of natural resources, all must be taken into account while designing a food system and their challenges faced by consumers as well as industries. Many good things have come out of the advancements in food systems, particularly over the past three decades in developing nations. As the food industry has grown, these outcomes have included the increase of off-farm employment prospects as well as the expansion of food options beyond regional staples, satisfying customers' preferences for taste, form, and quality. Therefore, it is essential to have a better understanding of the workings of a variety of food systems to ensure that they evolve in a way that minimizes their negative effects and optimizes their good contributions.

Table 1 Frequently used food preservation techniques

S. No	Preservation technique	Definition	Methodology	References
1	Thermal treatment	The technique has been well-proven in various food industries for many years, from bakery and dairy to fruits and vegetables	Foods are heated to a temperature of 75 to 90 °C or more, with a holding duration of 25–30 s. Pasteurization and heat treatment of maize had a significant effect on digestibility, flavor, glycemic index, aroma, color, and sensory aspects of apple juice beverage	[78–82]
2	Ultrasound	The efficient technique was chosen due to its ease of use and inexpensive cost as compared to more modern devices. Ultrasound's versatility is demonstrated by its use in a variety of industries, including medical, healthcare, and the food business	Ultrasonic radiation passes through the target solution in this process. This motion disrupts the solid particles in the solution, causing them to break apart and diffuse into the solvent. It should be mentioned that the technique's intensity should remain constant. Ultrasound treatment involves the use of high-intensity, high-frequency sound waves that are transmitted through food	[83]
3	Ozone treatment	The demand for organic goods has risen quickly in response to consumer expectations for healthier meals and a more sustainable lifestyle. Consumers are looking for a functional food that is free of additives and preservatives and has a long shelf life. As a result, ozone therapy technology has gained popularity in recent years. Because of its various features and fast decomposition, ozone was chosen. In simple terms, ozone is an oxygen allotrope. When oxygen divides into a single oxygen or nascent oxygen in presence of light or ultraviolent radiation, the molecule is produced	When compared to chemical preservatives such as chlorine (1.35 V), hydrogen peroxide (1.78 V), and hypochlorous acid (1.79 V), the compound decomposes swiftly into oxygen molecules and has a high oxidation potential (2.07 V), making it an effective antibacterial and antiviral agent. Aside from that, ozone eliminates the need to keep hazardous substances because the gas may be created instantaneously	[84–86]
4	Pulse electric field	A more advanced pre-drying technique for meals that requires less time in the oven. The method gained popularity due to its continuous operation and low electric field requirements (1–5 kV/cm). As it operates at a low temperature of 40 °C, the approach may be used as an alternative for thermal drying and can improve food drying	The pulse electric field methodology is inserting the food (milk, fruit, vegetable, or any fluids) between two electrodes, then applying high voltage (50 kV/cm) pulse for brief time intervals. A mixture of electroporation and electro permeabilization is used in this technique	[87, 88]

Table 1 (continued)

S. No	Preservation technique	Definition	Methodology	References
5	Freezing	To preserve the sensory features and nutritional qualities of green vegetables, spices, and milk products, cooling and freezing techniques have been widely used	Air blast, cryogenic, direct contact, and immersion freezing are commonly used freezing techniques, whereas innovative approaches include high pressure freezing, ultrasound assisted freezing, electromagnetic disturbance freezing, and dehydration freezing. The process of cooling and freezing is mostly based on heat transfer. During cooling, heat energy is transferred from the food and packaging container to the surrounding environment, leading to the cooling agreement	[89, 90]

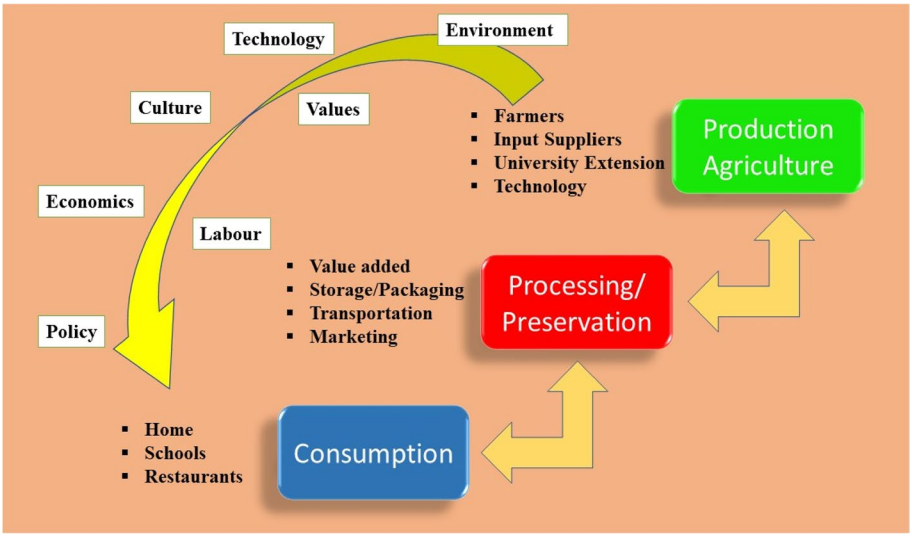

Fig. 1 Elements of sustainable food system

Implementation Methods for the Waste to Energy Supply Chain

Various Obstacle to Be Overcome

When implementing the WTE supply chain, obstacles from the areas of technology, finance, institution, and regulation may be encountered. These hurdles are difficult to distinguish from one another since policy instruments sometimes address multiple barriers at once. This is particularly true for institutional and financial obstacles because of how frequently they are linked [99]. Technology barriers, particularly in the individual plants or district energy industries, take the form of selecting the most eco-friendly and efficient type of technology, whereas financial barriers occasionally take the form of erroneous electricity prices, expensive grid interconnection fees, and high capital startup costs and the trained labors play important role in setting up. The major obstacles of developing effective policies and allocating government authority include the national vision (policy), aim (strategy), objective (program), target (project), and indicator (plan) being unclear. The usage of the best technology should always be emphasized by policymakers in order to assure environmental safety and facility effectiveness and effciency [98].

Economical Raise Policies

The main strategy put forth by GGND is to implement a "feed-in tariffs" (FITs) program to provide international price supports in order to boost the supply of renewable energy while lowering its cost. Utilities are compelled by a national FIT to purchase renewable energy at a fixed price above market rates. It forces electric providers to pay more for renewable energy for a set amount of time in a neighboring service region. More than 14% of

Germany's electricity now comes from renewable sources, making it one of the nations with the best success in implementing FITs globally. Spreading the cost of power grid connectivity and metering among all electricity users and gradually lowering the rate over time, a FIT pays these costs [98].

Government Accountability and the Policy Formulation

The issues that are unique to the field for which guidelines are being written must be known by policymakers. It is crucial to understand that the energy demands, local environments, local economies, and environmental protection regulations of various towns around the world will vary. To ensure compatibility and project viability, it is crucial to implement the proper policy measures. Sometimes, a policy only needs to remove a few small local obstacles rather than implementing significant, domineering financial structures. For instance, a successful strategic decision-making process for the WTE supply chain should consider the following: (1) supply and demand contracts; (2) network configuration, such as sourcing, location and capacity of energy production facilities; (3) assuring sustainability [100].

Different Types of Processing Methods

Numerous methods have been employed in the food processing industries; however, the researcher is working on developing new processing methods that will minimize the nutritional loss during processing and production costs and should be user-friendly to operate. Nowadays, there are different types of processing techniques but researchers divided the processing techniques into two categories thermal and non-thermal processing methods [6]. However, in non-thermal processing, there is no external heat provided in the processing system. Thermal processing procedures entail the inclusion of external heat in the processing system. Traditionally thermal processing methods are broadly employed in the food processing sector but as they are consuming high energy and decrease the nutritional, sensorial, and photochemical content, especially those that are heat-sensitive, make the shift towards nonthermal processing methods. Minimal processed and fewer additives mixed food treated with non-thermal processing has gained the interest of the consumer because of their enhanced quality with health beneficial properties [7]. Some of the novel processing methods that are employed in food industries for the processing of various food constituents involve high-pressure processing, high-pressure carbon dioxide, high hydrostatic processing, ionizing, microwave, ultraviolet, magnetic field, pulsed electric field, ultrasonic, high electric discharge, etc. are employed widely for the processing of various food products [8]. These novel processing methods are creating a huge demand with increases the chances of product innovation for better product quality and leads to develop more consumer-oriented food products [9]. In food processing, the researcher is working on the development of new techniques that are known for higher efficiency in terms of product processing, productivity, quality, safety, shelf life, and healthier diverse food products that will surely benefit a healthier food system and have sustainability too for the uncontrolled growth of populations [10]. The safety of food products with high production while processing, however, is a major worry, and in recent decades, advancements in the food processing procedures have been documented that exhibit superior quality without affecting the phytochemicals in comparison to the traditional processing. The major challenge for a healthier food system is the unpredicted growth of populations, globalization, and other factors like the environment, user-friendly techniques with matched consumer

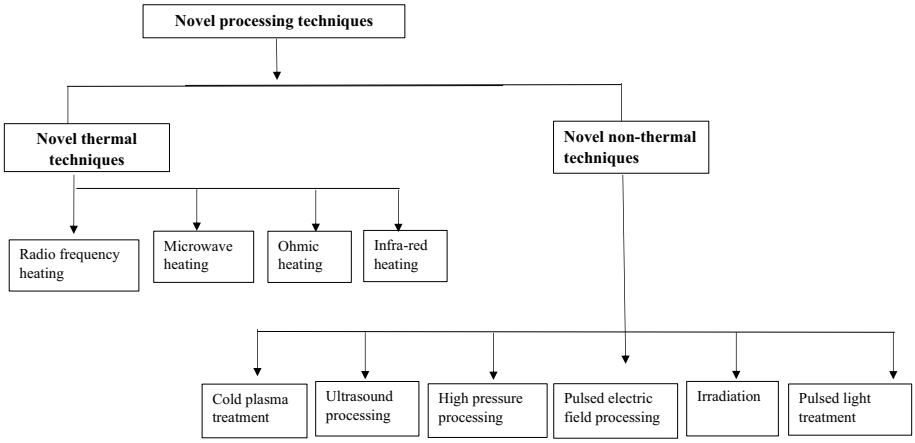

Fig. 2 Novel processing methods employed in the food industry (Barbhuiya et al., 2021)

specification has to be taken care of while processing the food products [11]. In Fig. 2, many thermal techniques were reported that are used for the processing of various food products but the continuous improvement has been done to them so that they can achieve maximum efficiency in delivering the food product with better quality [10]. However, apart from the nutritional, phytochemical processing, and product quality, there are other factors like food laws, market influence, and technological and commerciality of the techniques, and the product related to the specific technique is very important while adopting the processing techniques in the food industries [10]. Many techniques are used in food processing industries but the most current and updated techniques which are mainly employed in the food processing industries were mentioned below.

Novel Thermal Processing Methods

One of the novel approaches to preserve food is heat or thermal treatment. A previous investigation also revealed 5 different varieties of rice that, when subjected to hydrothermal treatment, produced outcomes comparable to market rice grade [12]. Food heating reduces the presence of pathogens. Significant research has discovered nutrient losses, energy waste, flavor changes, and food matrix damage, though. Researchers found post-treatment variations in the physico-chemical characteristics, antioxidant activity, and nutritional differences between light and dark honey [13]. Some novel techniques are explained below.

Radiofrequency Heating Processing

Radiofrequency heating is a novel thermal processing technique, also known as dielectric heating. In this technique, a radio frequency generator plays a crucial role by generating the alternating electric field to heat the dielectric materials [14]. The dielectric energy causes the vibration in the water molecules which is present in the sample, and this vibration produces the heat inside the sample causing to inactive the microorganism and enhanced the shelf life of the sample. The dielectric field of the food samples is depending upon many factors like moisture content, viscosity, soluble solids, phytochemical composition, pH, and other factors [15]. This processing technique is used in the industries but in batch

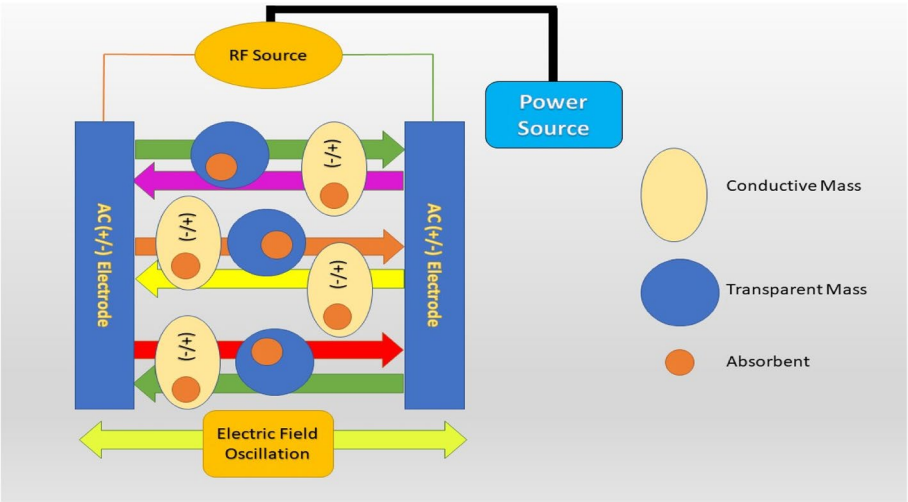

Fig. 3 Schematic representation of radio frequency heating

processes, not in the continuous process but still, a researcher reported that this technique is one of the best and most promising future in the food applications like baking, cereal processing, etc. [10]. Radio frequency functioning between two electrodes is represented schematically in Fig. 3 [16].

Microwave Heating Processing

Microwave heating is the thermal processing technique, which uses electromagnetic radiation in the range of 1–100 GHz for the heating of food samples. This technique gains popularity because of its high efficiency in achieving heating rates in a short time, uniform heating, and low maintenance with safe handling [17]. In microwave heating, the electromagnetic wave will oscillate in the most effective frequency range of 0.915 and 0.245 GHz, and absorption of energy is dependent upon the dielectric and magnetic properties of food materials. In industries, microwave heating is broadly employed in numerous food applications because it is a user-friendly technique, rapid and uniform energy transfer, safe, and economical with good productivity [18]. Apart from the processing of food products, this technique is used for thawing, reheating, defrosting, etc. However, researchers are modifying or developing the new hybrid processing techniques by incorporating microwaves such as in drying and exploring commercial large-scale food applications [10].

Ohmic Heating Processing

Ohmic heating is an advanced thermal processing technique where current is passed via sample due to the resistance of the food sample. It is also called as electro-heating or joule heating [19]. Ohmic heating is known for uniform heating with better quality without affecting nutritional components of food products and has better penetration powder in comparison to microwave heating [19]. Ohmic heating is used for wide applications like thawing, evaporating, blanching, extraction, dehydration, fermentation, pasteurization, sterilization, etc. It causes mild thermal cellular damage at the cellular level and can

inactivate the spoilage of microorganisms, ultimately extending the food constituents' shelf life. In scientific literature, it was reported that ohmic heating has a better future in food processing industries and is known for delivering healthy and processed safe food products [20].

Infra-red Heating Processing

Infra-red heating is also a novel thermal processing technique that uses electromagnetic radiation to heat the food sample. It is an indirect method to heat the food samples where electromagnetic energy penetrated the food sample and is absorbed in the sample in the form of radiation. The absorbed energy is converted into heat using convection and conduction mode, and absorbed energy is dependent upon the food material characteristics, especially food color [10]. The spectral range for infrared radiation was categorized into three categories, namely, near-infrared (700–1400 nm), mid-infrared region (1400–300 nm), and far-infrared region (3000–10,000 nm), though this infrared region lies between the ultraviolet and microwave energy regions [21]. It is known for processing the food sample with low processing cost and time and is very consumer-friendly, economic, safe, and known for high its high productivity [22]. Though the technology has very merited over the traditional processing techniques, the demerit of this is that it can penetrate the food sample up to a certain limit (a few millimeters); therefore, this technology has not been explored. But field investigators are exploring many ways in which this technology can be modified and used in the food processing sector to develop novel or highly efficient food systems [10].

Novel Non-Thermal Processing Methods

High-Pressure Processing

It is a non-thermal processing method, it is a cold sterilization process where the food samples were placed inside a vessel and a high isocratic pressure of 300–600 MPa was maintained inside the vessel, and processing time and pressure depend upon food materials and targeted microorganism [23]. Due to increased pressure, the temperature of the food sample will rise and hence the processing of the food sample was achieved. It is a very convenient method to stretch the shelf life of food products without affecting the freshness of the food samples. In scientific literature, it was reported that pressure in the range of 500–700 MPa was able to inactivate the *Clostridium botulinum* microorganism [24]. High-pressure processing is widely involved in the food processing industry to preserve various samples of food like carrot, cauliflower, crab, meat, etc. [23]. Some potential benefits of high-pressure processing method have been represented in Fig. 4 [25].

Pulse Light Processing

Pulse light is the processing method that is used to decontaminate the surface of the food sample. It is a non-thermal processing method which uses short pulses (100 ns to 1 ms) or ultraviolet pulses with high intensity, visible, near-infrared region to inactivate or kill the spoilage microorganism [26]. It was generally used for the processing of fruit juice, vegetable, and meat processing industries. A group of researchers studied the combination of the pulse light and showed that on average, it was composed of 54% UV light, 26% visible, and 20% infrared radiations. It is also comprised of high voltage of up to 70 kV/cm accumulating in a capacitor and discharges in the variation of short pulses via xenon-light source

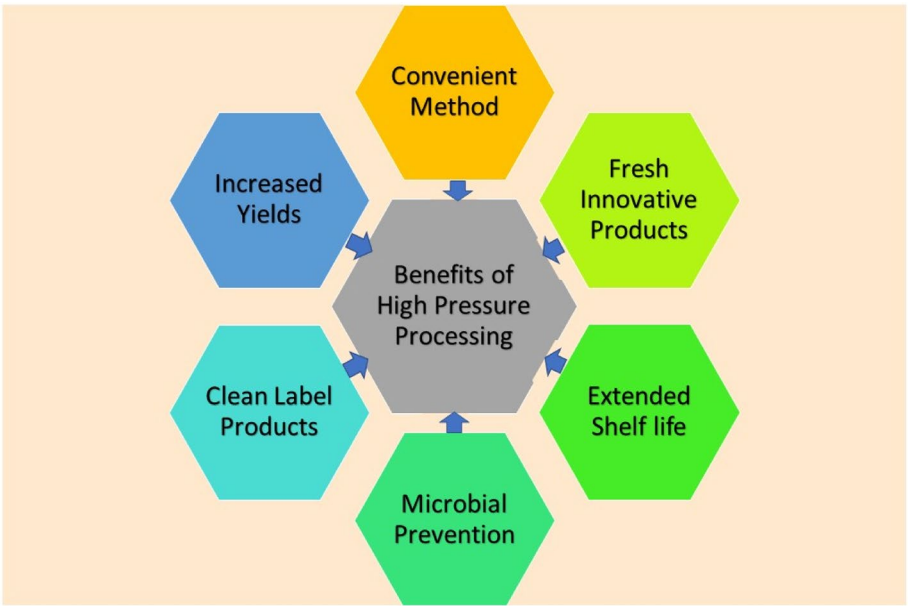

Fig. 4 Potential benefits of high-pressure processing method

and food samples are kept in between the two electrodes [27]. This technique is found in the outstanding non-thermal processing techniques to enhance the shelf life of foods like apples, cheese, and many other food products [23].

Cold Plasma Processing

One non-thermal processing method that makes use of the fourth state of matter that is plasma or the quasi-neutral gas containing atoms, molecules, or ions in the excited state is called cold plasma. Plasma is produced at room temperature and it kills the microorganism present in the food sample with maintaining the equality of the food product. It is a combination of noble gases like argon and helium and or combining various other gases in a specific ratio that was acceptable in the plasma [28]. It is an upcoming non-thermal technology that has very good industrial application used for the preservation and processing of various vegetables and fruits with an excellent ability to inactivate the spoilage microorganism [29]. There are several potential benefits of cold plasma technology as shown in Fig. 5.

Irradiation Processing

In irradiation, ionizing radiation is used for the processing of the food sample. The ionizing radiation kills or inhibits the spoilage, pathogenic microorganisms present in the food sample. In this process, then, food is treated with X-rays and an accelerated electron beam with the help of an electron machine accelerator or gamma rays. The two most common isotopes used for food irradiation were ^{60}Co and ^{137}Cs [23]. These ionizing radiations cause the destruction of the water molecules which is present in the food sample and leads to the production of free radicals (-OH). These free radicals help in inactivating the DNA of the

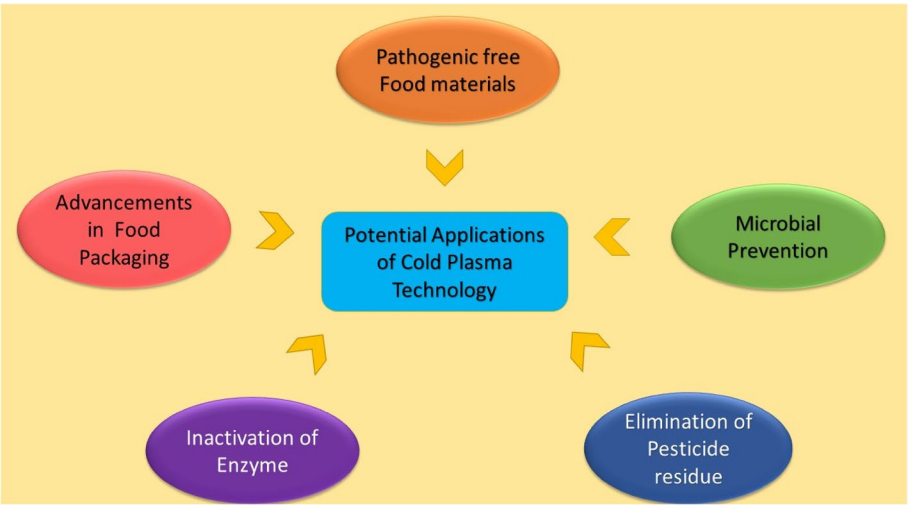

Fig. 5 Potential benefits of cold plasma technology in food processing

microorganism and hence preserve the treated food sample. The unit of irradiation is measured in the Gray (Gy) and different levels of dosses have been set up for the different levels of the food products, for example, irradiation dose of 1 to 30 kg was used for the treatment of mushroom and a dose of more than 15 kg was for ready to eat products and doses in the range of 10–50 kGy were reported for the food for low moisture content [30].

Ultrasound Processing

Ultrasound is the non-thermal processing technique that uses the sound wave of frequency above 20 kHz, which is above the frequency of normal hearing waves. The ultrasound is divided into three categories which mainly depend upon the frequency of the ultrasound, namely, diagnostic ultrasound (1–500 MHz), frequency ultrasound (100 kHz–1 MHz), and power ultrasound (20–100 kHz) [31]. These longitudinal waves generate vibration in the sample matrix and due to compression and rarefaction cycles, the pressure and temperature of the sample were increased. The generation and collapsing of cavitation bubbles cause variation in food structure by breaking the weak intramolecular interactions and increasing the mass transfer [23]. Ultrasound is used for various purposes in the food industries like thawing, drying, brining, pickling, degassing, and defoaming of various food products [32].

Pulse Electric Field

Pulse electric field is a non-thermal processing technique, which uses high voltage short electricity in the range of 20–80 kV/for a short fraction of time (seconds) and the food sample is kept between the two electrodes and current is passed via electrodes. The capacitor plays important role in the pulse electric field, which stores the electric energy and released the energy in short pulses to avoid the heating of the sample. The pulses electric field provides the food sample with better quality without affecting the nutritional content of the food samples [33]. These electric fields when applied to the food sample cause the temporary pores on the surface through electroporation and inactivates the spoilage

or pathogenic microorganism present in the sample. This technology is a continuous process and is very widely employed and suitable for the food beverage industries like soups, juices, eggs, dairy, etc. [34].

Supply Chain of Processed Foods (in Terms of Preservation and Processing)

In the long history of humanity, cooking is believed to have been the first form of food processing. Salting, drying, and fermenting were some of the earliest processing techniques used by prehistoric communities. Fermentation products such as cheese, wine, bread, and beer were well-known in Greece. Olive oil and salted olives are in the same category. Christ blessed wheat, oil, and wine and they became essential components of the Divine Liturgy. People have never stopped searching for better and more productive methods to transform perishable food products into long-lasting, nutritious, enjoyable, and nourishing food. Traditional food products and regional consumption methods got embedded in the culture of every ethnic group as a result [35].

High-hydrostatic pressure (HHP) and high-intensity electric field pulses (HELP) are new technologies that rely on the active principle of dispersing instantly throughout the food component, irrespective of shape and size. As a result of these technologies, applications with low-temperature are available, which can help achieve reduced processing time durations and/or lower impacts on the process. Because the aforementioned technologies also require expensive equipment and must be used under certain conditions to meet hygienic levels, it is quite early to say which will triumph over the traditional, well-established approaches [36].

Food Supply Chain Sustainability Functions

The general food supply chain includes farming and post-harvest functions like processing, and market availability such as distribution, consumer handling (FSC), and retailing or catering. Agricultural and food logistics convey a big role in food supply chain management [37]. Figure 6 explains the various insights into the formation of a sustainable food supply chain system.

Supply Chain Network Structure

For food safety and quality and maintenance, a result-oriented and efficient supply chain network model is essential. As globalization requires more healthful and nutritious food, the present framework faces various challenges. To begin, a single distribution system, also known as a WMS, is utilized to build and develop a food supply chain network model. Mixed-integer linear programming structures are often used to determine optimal sites and distribution circle topologies, according to Manzini and Accorsi [38]. It is necessary to have a comprehensive and global organization. Second, within the context of a network structure, optimizations are always taken into account. Planning, scheduling, profit, and cost are all common considerations. The implications on the environment and long-term performance are not highlighted.

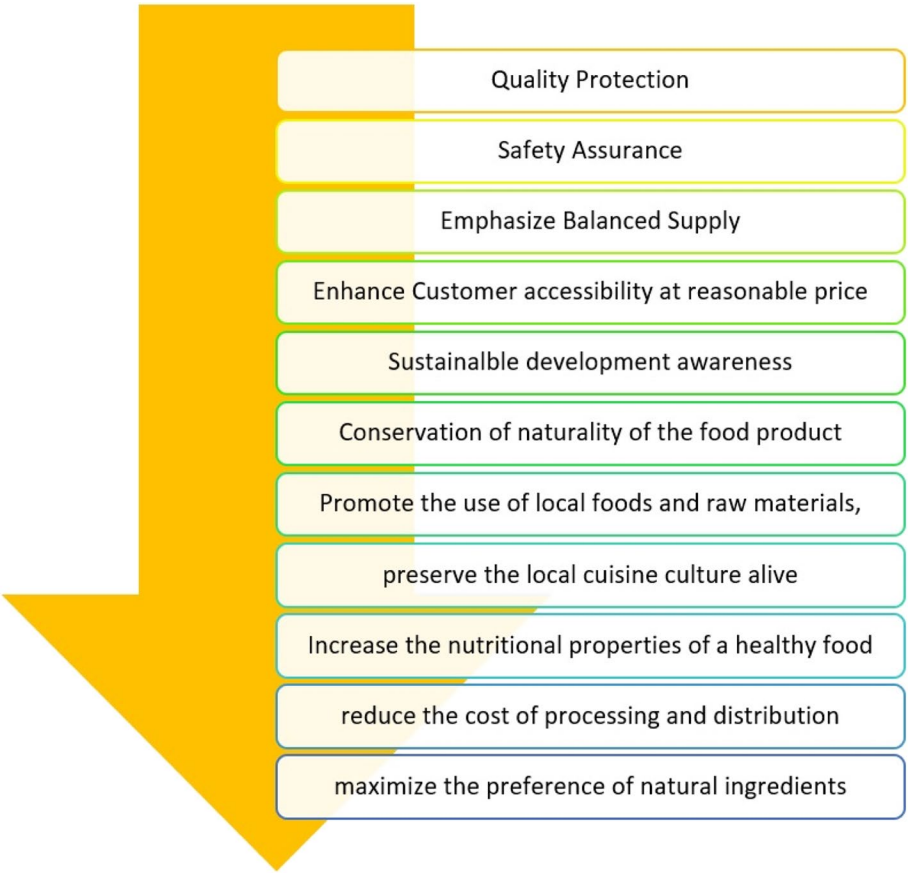

Fig. 6 Schematic representation of sustainable food supply chain system

Future Orientation of Sustainable Food Supply System

Food supply system that is sustainable implied on several factors that are discussed below. Reduced environmental impacts, improved food waste recycling, and increased facility sharing can all contribute to more sustainable food industry in the future. New approaches to expected development, as well as other industries such as production and the economy, are crucial for achieving sustainability, according to Irani and Sharif [39] and Lan and Zhong [40]. This design's ultimate purpose is to approach the global food chain at interdependent and optimal levels, allowing stakeholders to participate in closed-loop management and oversight. Newly optimized frameworks, effective supporting tools, enabling technologies, and integrated models will need to be investigated further to achieve this goal [41].

Effects of the Pandemic on Food Supply Pattern

The food supply chain uses two techniques for confirming food safety and quality. The first stage includes government-mandated conditions that are scrutinized. The second option is to use voluntary market legislation or international organizations to establish standards

[42]. Manual hygiene includes the wearing of protective equipment like masks, helmets, and gloves. In food processing industries, sanitation of surfaces and working surroundings, safe food handling or preparation or delivery, and social distance are all safety example practices that assure continuity in food flow at all levels. In the later phases of the food supply chain, protective measures are crucial because as the chain extends, more individuals are in danger [43].

Approach to Food Supply Chain

One third of all food was lost or discarded before the pandemic at various points along the food supply chain, involving postharvest management, production, processing, retailing, and consumption. This resulted in greater attention on food waste than ever before, in the era of the coronavirus. COVID-19 had a minimal effect on total food loss and waste formation, according to Aldaco et al. [44], but it did result in a 12% increase in food waste formation at household level. Food waste could be extracted and reintroduced into the food chain with bioactive components like phenols, pectin, flavonoids, carotenoids, glucosinolates, isothiocyanates, essential oils, and whey protein isolate. Functional components present in food can be used in preservatives, gelling agents, and nutritional supplements. Extracting, fractionating, and isolating bioactive compounds from food waste can be done using both traditional and new methods [45–47]. On the other hand, food waste generated during the production, processing, or consumption stages will demand extra collection and processing facilities.

Consumer Attitudes Towards Processed Food Products

Food plays important role in consumers life and is very necessary for life to exist physically. It refers to any material that is taken to give nutritional support to the body and is processed to generate energy for tissue growth. In terms of human beings, they are always fond of exquisite cuisine. People used to cook their meals, but now that food is scientifically processed and packed to increase the quality and retain its nutritional value of foods, one may see significant variation in consumer food habits. Due to changes in people's lifestyles, dual-income families, the effect of western culture, and expanding urbanization, they are more susceptible to packaged processed food today. The global processed food sector has changed dramatically, moving away from bulk processed goods and toward value-added consumer packaged meals. The food processing sector is estimated to be worth Rs 315,000 crores, including Rs 99,000 crores in value-added products, according to the Ministry of Food Processing. According to Rabo India Finance, India's processed food industry accounts will increase from Rs 11,500 billion to Rs 11,500 billion by 2014–2015. Processed food (cooked and packaged) is a type of value-added food that is simple and quick to make. Because they are readily available in every outlet, they are also known as convenience food. Consumer attitudes toward ready-to-eat in India, according to Goyal and Singh [48], suggest that young consumers mostly prefer ready-to-eat outlets for fun and pleasure, but they still believe that home food is better than ready-to-eat options [48]. The majority of Hubli and Dharwad residents bought food on impulse, and the majority of them were healthy and quality-aware. They discovered that people were well-informed about private food goods.

Swamy et al. [49] attempted to investigate the current buying habits of individual households when it came to market-ready food products. The best qualities, followed by retailer impact, quick availability, and convenience, are the essential elements that influence the brand preference of selected ready-to-eat foods. Rapid technical advances and changes in people's lifestyles, followed by comfortable usage, less time consumption, easy availability, and improved flavor, are the primary reasons for the expansion of market-ready food products, according to Pradeepa and Kavitha [50]. According to Kathuria and Gill [51], 70% of Indian families are nuclear, and women spend less time cooking. Due to the family's dual income, members of the household are more likely to purchase ready-to-eat food. The value of basic food ingredients manufacturing is expected to exceed Rs 60,000 crore. This sector is anticipated to be worth Rs 110,000 crore after primary, secondary, and tertiary processing. The key benefits that the food-processing industry delivers to the economy as a whole and individual businesses are reflected in this cost overrun. Food Processing industry has played a key role in the formulating the products for the diverse population and age group as per the requirement of advanced society and modern market trends. As a result of the government's awareness of the potential, condensed milk, ice cream, pasta, fish, and poultry preparations, meat, pectin, and yeast have all been exempted from excise duty [49].

Perception of Consumer

As a result of their general eating habits and behavior-perception, mostly during adolescence, the need for efficient nutritional education for young consumers has grown, and researchers investigated the relationship between young customers' food preferences and their nutritional awareness behavior in three environments [52]. The findings demonstrated that the apparent dominance of school, home, and social contact is somewhat overturned as young consumers develop an "independent" personality trait, especially throughout adolescence. According to the authors, many young consumers' food preferences and their preferences are mostly of the "fast food" variety, and as a result, their food eating habits may lead to the intake of junk food that possesses nutritionally deficient meals.

Consumption-Related Factors

Consumer's behavior is heavily influenced by their own, societal and neighboring consumers' experiences, and their upbringing. Consumer's intakes of food were heavily influenced by the involvement of his family members. Above all, the product's quality and accessibility were the keys and critical factors of his purchasing decisions. Touch and feel (kinaesthetic) aspects of any promotional action affected consumers [53]. A study was conducted for the selection of soft drinks in rural Tamil Nadu using Garrets ranking technique in order to explore the factors affecting the soft drink preference of rural consumers. They discovered that product quality came first, followed by retail price. The key elements that impacted rural buyers of a certain brand of goods were its quality and availability [54].

Livestock Preferences

Muzayyanah et al. [55] reported that the consumer's preference and perception for processed livestock products over fresh livestock products has altered. In terms of both variety and quantity, demand for processed food generated from livestock products is steadily expanding. Meatballs, nuggets, and sausages are the popular beef products for home cooking,

accounting for the bulk of processed meat products consumed. Meat products are consumed 1–3 times each week, whereas fish products are consumed only once or twice a month [56].

Sequence Transformation in Food Consumption

As a result of increased per capita income, women's work, changing lifestyles, and other environmental factors, food shopping and consumption habits have evolved. Per capita consumption of minimally processed meals and non-cereal-based foods is rapidly increasing in emerging nations such as India [57]. Total energy consumption has risen in developed countries like USA during the previous two decades, with a shift away from meals and toward snacking, as well as consumption at home and away from home [58]. This type of transition may be found all around the world. According to a study conducted in Spain between 1992 and 2003, there was a significant decrease in fruit and vegetable consumption and an increase in food consumption outside of the home and in between meals [59]. Money, food availability, and the modernity of the food business have all increased as a result of urbanization, resulting in dietary changes [60]. The use of supermarkets has risen across the board, from cities to villages, and from upper- and middle-class to working-class households. Residents of cities spend higher proportion of their income on processed meals.

Preference for Ready-to-Eat Food by Consumers

Consumers all over the world are short on time and unable to prepare meals from scratch. Customers are most likely to consume RTE meals at dinnertime, with breakfast being the least probable. Customers prefer to buy RTE meals from the same store where they regularly shop, increasing the frequency of their purchases. Meal quality (taste, look, texture), socioeconomic considerations (availability, pricing, and culture), physiologic factors (nutrient and energy requirements), and psychological aspects (behavior, moods, and attitude toward eating) all impact consumer food choices [61]. The brand of RTE food products, on the other hand, has a role in customer purchasing decisions. Brand awareness provides a sense of familiarity, which is important to remember while selecting products like soaps, as well as a sense of presence, dedication, and substance. Traditional mass media, event marketing, public relations, sampling, and other attention-getting strategies are employed to raise awareness [62]. One of the most commonly utilized branding tactics is brand extensions [63].

Future Applications in Food Processing and Preservation

Table 2 summarizes a few sustainable techniques of food processing and preservation with the purpose and motive of development. Some of the newer approaches being researched include high-pressure processing, pulsed illumination, cold atmospheric plasma, pulsed electric field (PEF), microwave, ultrasound, and ohmic heating. Alternatives are being studied because they are thought to be more sustainable. The fundamental goal of developing non-thermal and mostly non-thermal technologies was to find alternatives to existing thermal and renewable energy source chemical preservation methods, as well as synergies between them [64]. There is also a lot of pressure. PEF supported sterilization [65], as well as assisted sterilization methods [65]. Reineke et al. [66] used high hydrostatic pressure for ecologically friendly and energy-efficient food processing, including improved cell membrane breakdown and mass transfer by PEF, wastewater treatment, and the creation of alternative PEF support procedures.

Table 2 Various methods of food preservation with their purpose of sustainable development

S No	Food processing stages	Types of emerging methods	Purpose of sustainable development	References
1	Raw material quality	1. Non- destructive techniques 2. Hyperscale imaging 3. Spectroscopic techniques	Imaging, spectroscopy-based, and other relevant applications such as dielectric, electronic nose, electronic tongue, and acoustic approaches are among the rapidly developing non-destructive technologies for the evaluation of food quality	[91]
2	Gentle processing	1. Cold plasma technology 2. Pulse electric field 3. Cavitation technologies 4. High-pressure processing 5. Ozone processing	The moment to secure an abundant food supply to feed Nigeria's citizens cannot be better than now when the country's population is growing at an alarming rate. It is impossible to overstate the importance of developing food processing and preservation technologies that can reduce food losses and wastage during surplus seasons	[92]
3	Food packaging	1. Smart packaging 2. Modified packaging 3. Edible coating and films	Sustainable packaging is defined as a sort of packaging that can offer food essential protection while also being biodegradable and able to be disposed of as organic waste in landfills to biodegrade naturally. Sustainable packaging thus becomes a component of the circular economy	[93]
4	Freezing/cooling	1. Individual quick freezing 2. Cells alive system	Freezing is a well-known food preservation technique that yields high-quality, nutritious meals with an extended shelf life. Some new freezing technologies are merely refinements of current methods that yield considerably faster surface heat transfer rates than earlier systems, hence improving product quality by allowing for quick freezing	[94]
5	Storage/distribution	1. Cold chain distribution 2. Sensor enabled storage (E.g., RFID)	Three goals are served by the creation of a long-term, multi-channel fresh food distribution network. For starters, it addresses consumers' shifting preferences for online shopping. Second, the model looks into the Buy Online Pickup in Store (BOPS) distribution network in the context of the food supply chain. Finally, the model proposes new farming rules approved by the Indian government, which allow farmers to sell their product wherever they want instead of having to sell in government-controlled Mandis	[95]
6	Preparation/consumption	1. Microwave 2. Infrared 3. Inductive heating 4. Ready to eat	The task of persuading people to switch their eating habits to a more environmentally sustainable food consumption (ESFC) pattern is growing more difficult. Food preferences, choices, and eating habits are famously difficult to change since they are such an essential part of people's lives and social environments. Many individuals have positive attitudes toward sustainable food, but there is still a significant gap between positive sentiments and actual purchases and consumption of more sustainable foods	[96]

Table 2 (continued)

S No	Food processing stages	Types of emerging methods	Purpose of sustainable development	References
7	Waste processing	1. Separation 2. Recovery and reuse 3. Bioconversion with fertilizer	Food waste is a resource because the functionalized molecules trapped in it have great energy, chemical, and material potential. Food waste can be transformed into a variety of high-value products, including platform chemicals, biomaterials, biofuels, biochar, and bio oil, using a variety of biological, thermal, and chemical processes	[97]

PEF's potential was demonstrated. For high-energy beet sugar processing, Chemat et al. [68] introduced green food processing systems, with an emphasis on extraction techniques.

Upcoming Challenges in Food Industries

Food security should include the integration of sustainability as a new and extra component [69]. Understanding purchasing trends, societal conventions, behavior, and lifestyles require a multidisciplinary approach. This strategy will assist in the modification of appropriate transformations to reduce waste, ecological footprints, and carbon emissions to construct food ecosystems for long-term urbanization [70]. More emphasis is needed on the preparation of business models that use an interdisciplinary approach to construct plausible business arguments for a wide range of stakeholders, while there is widespread agreement on the significance of employing approaches to improve closed-loop system to build circular biological economy, adoption, and realization of opportunities at reduced speed. Microorganism–host (human, plant, animal) interactions, along with food–microbiome–human interrelations, will be crucial to future resource-efficient food processing. Edible microbial biomass [71], culture and enzymes techniques [72], and the utilization of fermentation methods to minimize toxins [73] are all its examples. Processed foods must contribute to nutrition and health in a scientifically supported way [72]. Such multidisciplinary talks and activities have been attempted [74, 75]. Food scientists and nutrition scientists must collaborate and communicate more effectively. Integration of food value chain, which will need concerted interdisciplinary operations [76], is a huge issue, particularly shifting from "precision" agriculture to "precision" food waste and water management to establish sustainable and responsible food chain [77].

Future Perspectives

The development of efficient processes that use less energy and resources, as well as a decline in the material and energy content of goods and packaging, defines the industrial economy of the twenty-first century. Although nearly all of this is being driven by economics, corporations are naturally publicizing their successes in this field given the growing consumer (and subsequently governmental and media) interest in sustainability. Retailers are forcing their suppliers to submit details of different characteristics that relate to consumer expectations for more sustainable and ecologically friendly products and packaging. The metrics used to evaluate the sustainability of packaging will be improved and, ideally, included into an international standard as this trend continues. To ensure that the policies governments and socially conscious firms implement actually do result in a more sustainable society with the fewest possible unintended consequences, much more research is still needed.

Conclusion

Contrarily, a complex-multiface issue like sustainable food systems is unlikely to be resolved in many other nations due to inadequate budgetary funding or the lack of an integrated plan. According to the data, the plans that addressed sustainability received the least funding, and several significant restrictions on food consumption made no mention of environmental sustainability. The results point to a technique that can aid in the integration of sustainability throughout the whole food supply chain by policymakers. This does not imply a preference for a single sustainable diet, one sustainable farming method, or one

model of sustainable food systems in a nation as diverse as India in terms of geographical and sociocultural variety. With only 10 years to complete the sustainable development goals, policymakers, researchers, and practitioners are examining how food management systems might be strengthened and beneficial for the long-term wellbeing of people and planets. Behavioral food policy, an approach to policy that emphasizes behavior, is said to be able to support and maintain systemic improvements. Many nations, towns, and regions are turning more and more to behavioral insights to alter their food systems. According to the findings, context-sensitive approaches that take into account a population's choices and behavior produce strategies, policies, and measures that are more effective, acceptable, adequate, and suited to their intended purposes than conventional model-based approaches. A fundamental change in societal values (such as the rejection of food waste), a disruptive crisis (such as the COVID pandemic), disruptive innovations using newer technologies (such as digitization and biotechnology), and, on rare occasions, visions and better ideas promoted by charismatic and reliable leaders. The current double crisis contains all four variables. It might also be advantageous by enabling people to work together to develop and test new policy tools that can feed the world while protecting the environment's resources and biodiversity and ensuring equal access for everyone. The first noticeable effects of such revolutionary changes to the food system may be seen at the UN Food Systems Summit, which will bring together researchers, social workers, practitioners, and policymakers from all over the world to discuss and sponsor game-changing solutions for a more sustainable, just, and health-promoting food system.

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Declarations

Competing Interests The authors declare no competing interests.

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