



Entrepreneurship Scope in Food Processing Engineering and Technology: Future Trends and Opportunities

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ABSTRACT

The food processing sector plays a pivotal role in strengthening food security, enhancing value addition, and promoting economic growth, particularly in developing economies. In recent years, Food Processing Engineering and Technology has emerged as a dynamic domain offering vast entrepreneurial opportunities driven by rapid technological advancements, changing consumer preferences, and supportive policy frameworks. This abstract explores the future scope of entrepreneurship in the food processing engineering and technology sector, highlighting emerging trends and innovation-led opportunities. Advances in processing technologies such as automation, artificial intelligence, Internet of Things (IoT), and novel non-thermal processing methods have enabled startups to improve product quality, safety, efficiency, and sustainability. Growing demand for ready-to-eat foods, functional and fortified products, plant-based alternatives, and clean-label foods has further expanded the entrepreneurial landscape. Additionally, sustainability-focused ventures involving food waste valorization, energy-efficient processing, and eco-friendly packaging are gaining prominence under circular economy principles. Government initiatives, food technology parks, incubation centers, and funding mechanisms have strengthened the startup ecosystem, encouraging food engineers to transition from traditional roles to entrepreneurial leadership. Despite challenges related to regulatory compliance, scalability, and market competition, the sector holds significant potential for innovation-driven enterprises. Overall, food processing engineering and technology offers a promising platform for future entrepreneurs to develop sustainable, technology-enabled solutions that address global food system challenges.

KEYWORDS

Food Processing Engineering, Entrepreneurship, Emerging Technologies, Sustainable Food Systems, Value Addition and Startup Ecosystem.

1. Introduction

1.1 Overview of food processing engineering and technology:

Food processing engineering and technology is a multidisciplinary field that applies principles of engineering, food science, microbiology, and chemistry to convert raw agricultural commodities into safe, nutritious, stable, and value-added food products. The discipline covers conventional unit operations such as thermal processing, drying, freezing, extrusion, fermentation, separation, and



packaging, while also integrating modern advances in automation, process control, and quality assurance (Fellows, 2017; Toledo, 2020). The primary objectives of food processing engineering include extending shelf life, ensuring food safety, enhancing nutritional quality, and improving sensory attributes while maintaining economic feasibility. In recent years, the sector has undergone rapid technological transformation due to the adoption of emerging processing technologies such as high-pressure processing (HPP), pulsed electric fields (PEF), cold plasma, ultrasound, and ohmic heating. These novel and non-thermal technologies are increasingly favored because they minimize nutrient loss, reduce energy consumption, and meet growing consumer demand for minimally processed and clean-label foods (Barba et al., 2018; Wei et al., 2025). Furthermore, the integration of digital tools such as sensors, Internet of Things (IoT), artificial intelligence (AI), and predictive modeling has improved real-time monitoring, traceability, and process optimization across food manufacturing systems (Zhou et al., 2022). Food processing engineering thus serves as a critical enabler for innovation, linking agricultural production systems with modern food markets. By facilitating scale-up, standardization, and regulatory compliance, it provides the technical foundation necessary for commercial food enterprises to compete in both domestic and global markets.

1.2 Importance of entrepreneurship in the agri-food sector:

Entrepreneurship plays a vital role in translating scientific and technological innovations in food processing into marketable products and sustainable businesses. In the agri-food sector, entrepreneurial activity contributes to value addition, employment generation, rural development, and reduction of post-harvest losses, which remain a major concern in many developing countries (Ajide et al., 2023). Food processing entrepreneurs act as intermediaries between farmers and consumers by developing diversified products, improving supply-chain efficiency, and introducing innovative business models such as decentralized processing and contract manufacturing. The importance of entrepreneurship has increased significantly due to changing consumer preferences toward convenience foods, functional and fortified products, plant-based alternatives, and ethically produced foods. Entrepreneurs leverage food processing technologies to cater to these niche markets, thereby enhancing competitiveness and profitability (Pan et al., 2024). Additionally, agri-food entrepreneurship supports inclusive growth by encouraging small-scale and women-led enterprises, particularly in rural and semi-urban regions. From a policy and economic perspective, entrepreneurship is recognized as a driver of resilience in food systems. Innovative startups focusing on cold-chain logistics, food waste valorization, by-product utilization, and sustainable packaging contribute to circular economy goals while addressing environmental challenges (Barba et al., 2018; Zhou et al., 2022). As a result, food processing engineers equipped with entrepreneurial skills are increasingly viewed as key agents of transformation in the agri-food sector.

1.3 Global and Indian food processing industry outlook:

At the global level, the food processing industry is experiencing sustained growth driven by urbanization, rising disposable incomes, globalization of food trade, and increased awareness of food safety and nutrition. Market analyses indicate strong expansion in processed foods and food processing equipment markets, supported by advances in automation, smart manufacturing, and sustainable processing solutions (Fortune Business Insights, 2025). The adoption of Industry 4.0 concepts, including AI-based quality control and predictive maintenance, has further created opportunities for technology-oriented food startups.

India represents one of the fastest-growing food processing markets worldwide due to its large agricultural base, diverse raw materials, and expanding consumer market. According to India Brand Equity Foundation (IBEF, 2024), the Indian food processing industry reached approximately INR 30.49 lakh crore (US\$ 354.5 billion) in 2024 and is expected to witness strong growth in the coming years. Government initiatives such as the Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PM-FME) Scheme, Production Linked Incentive (PLI) Scheme for food processing, and the development of Mega Food Parks have significantly strengthened the entrepreneurial ecosystem

(MoFPI, 2024). The Indian government has also increased budgetary allocations and investment incentives to promote innovation, exports, and value-chain integration in the sector (Press Information Bureau, 2024). These developments have created favorable conditions for startups and small enterprises in areas such as ready-to-eat foods, traditional and ethnic products, functional foods, and sustainable packaging. Consequently, the convergence of market growth, technological advancement, and policy support positions food processing engineering and technology as a highly promising domain for future entrepreneurship.

2. Role of Food Processing Engineering in Entrepreneurship

Food processing engineering plays a central role in enabling entrepreneurship by converting scientific knowledge and agricultural resources into commercially viable food products. By integrating engineering design, process innovation, quality assurance, and regulatory compliance, food processing engineers act as key facilitators in transforming traditional food practices into scalable, market-oriented enterprises. The application of food engineering principles supports product diversification, cost reduction, enhanced safety, and sustainability, all of which are essential for entrepreneurial success in the competitive agri-food sector (Fellows, 2017; Toledo, 2020).

2.1 Value addition and post-harvest loss reduction

Value addition is a primary driver of entrepreneurship in food processing, allowing startups to increase the economic worth of raw agricultural commodities through processing, packaging, branding, and preservation. In developing economies, post-harvest losses of fruits, vegetables, cereals, and perishables remain a critical challenge, often ranging between 20–40% due to inadequate storage, processing, and transportation infrastructure (FAO, 2022). Food processing engineering provides technological solutions that convert surplus or perishable produce into shelf-stable products such as dehydrated fruits, frozen vegetables, fermented foods, ready-to-eat meals, and convenience snacks, thereby minimizing losses and improving farmer incomes (Kader, 2013). Entrepreneurial ventures benefit significantly from engineering-led value addition strategies, including minimal processing, fortification, and functionalization of foods. Technologies such as controlled atmosphere storage, modified atmosphere packaging (MAP), and refrigeration systems have enabled startups to extend the shelf life of fresh produce while retaining nutritional quality (Caleb et al., 2016). Furthermore, food engineers design processing systems that allow utilization of by-products such as fruit peels, bran, oilseed cakes, and whey for the production of nutraceuticals, dietary fiber, bioactive compounds, and animal feed, aligning with circular economy principles (Barba et al., 2018). Small and medium food enterprises increasingly adopt decentralized and modular processing units developed by food engineers to operate near production sites. These systems reduce transportation costs and losses while promoting rural entrepreneurship and employment generation (Ajide et al., 2023). Thus, value addition supported by food processing engineering is a cornerstone of sustainable and inclusive agri-food entrepreneurship.

2.2 Engineering interventions in food preservation and processing

Engineering interventions in food preservation and processing form the technological backbone of food-based entrepreneurial ventures. Traditional preservation methods such as thermal processing, drying, smoking, salting, and fermentation continue to be widely applied; however, modern entrepreneurs increasingly rely on advanced engineering solutions to meet regulatory standards and consumer expectations for safety, quality, and convenience (Toledo, 2020). Thermal processing technologies, including pasteurization, sterilization, and retort processing, remain essential for ensuring microbial safety and shelf stability of processed foods. Food processing engineers optimize time–temperature combinations using heat transfer models to minimize nutrient degradation while ensuring safety compliance (Fellows, 2017). Non-thermal and emerging technologies such as high-pressure processing (HPP), pulsed electric fields (PEF), ultrasound, and cold plasma have gained prominence among startups producing premium and minimally processed foods, as these technologies

preserve sensory and nutritional quality while extending shelf life (Barba et al., 2018; Wei et al., 2025). Packaging engineering also plays a critical role in entrepreneurship by protecting food products and enabling market differentiation. Innovations in active packaging, intelligent packaging, and biodegradable materials have created new entrepreneurial opportunities, particularly in response to sustainability concerns and regulatory pressures on plastic usage (Caleb et al., 2016). Food processing engineers contribute by selecting suitable packaging materials, designing sealing and filling systems, and ensuring compatibility with processing and distribution requirements. Overall, engineering interventions enhance process efficiency, ensure regulatory compliance, and allow entrepreneurs to deliver safe, high-quality products to diverse markets, thereby strengthening the viability and competitiveness of food startups.

2.3 Process optimization and scale-up for startups

Process optimization and scale-up are critical challenges for food startups transitioning from laboratory or pilot-scale production to commercial manufacturing. Food processing engineers play a vital role in this phase by applying principles of mass and energy balance, process modeling, and equipment design to ensure consistent product quality, operational efficiency, and economic feasibility (Toledo, 2020). Inadequate scale-up strategies often result in product variability, increased costs, and regulatory non-compliance, highlighting the importance of engineering expertise in entrepreneurial success. Optimization techniques such as response surface methodology (RSM), computational fluid dynamics (CFD), and statistical process control (SPC) are increasingly used by food engineers to fine-tune processing parameters, reduce waste, and improve yield (Zhou et al., 2022). Automation and digitalization further support startups by enabling real-time monitoring, traceability, and predictive maintenance, which reduce downtime and operational risks. Scale-up also involves compliance with food safety management systems such as HACCP, ISO 22000, and regulatory standards mandated by national and international agencies. Food processing engineers ensure that equipment layout, sanitation design, and process flow meet hygiene and safety requirements, facilitating market entry and export potential (Fellows, 2017). Additionally, engineers support cost optimization by selecting appropriate equipment capacity, energy-efficient technologies, and flexible production systems that can adapt to market demand. Through systematic process optimization and successful scale-up, food processing engineering empowers entrepreneurs to transform innovative ideas into scalable, profitable, and sustainable food enterprises.

3. Emerging Entrepreneurial Opportunities

Rapid changes in consumer lifestyles, dietary preferences, and technological capabilities have created diverse entrepreneurial opportunities within the food processing engineering and technology sector. Food processing engineers are uniquely positioned to capitalize on these opportunities by applying scientific and engineering principles to develop innovative, safe, and market-oriented food products. Among the most promising domains are ready-to-eat and ready-to-cook foods, functional and fortified products, plant-based and alternative proteins, and traditional foods upgraded through modern processing technologies (Fellows, 2017; Toledo, 2020).

3.1 Ready-to-eat and ready-to-cook food products

Ready-to-eat (RTE) and ready-to-cook (RTC) food products represent one of the fastest-growing segments in the global food processing industry. Urbanization, increasing participation of women in the workforce, nuclear family structures, and time-constrained lifestyles have significantly increased demand for convenient foods requiring minimal preparation (OECD, 2023). RTE and RTC products such as instant meals, frozen foods, retort-packed curries, snacks, and semi-processed ingredients offer substantial entrepreneurial potential due to their scalability and wide consumer acceptance. Food processing engineering plays a crucial role in ensuring the safety, quality, and shelf stability of RTE and RTC products. Entrepreneurs rely on technologies such as retort processing, freezing, dehydration,



extrusion, and aseptic packaging to extend shelf life while maintaining sensory attributes (Fellows, 2017). Process optimization and hygienic equipment design are essential to meet stringent food safety regulations, particularly for products with extended ambient storage (Toledo, 2020). Startups adopting energy-efficient and modular processing systems can reduce production costs and improve flexibility in responding to market demand. In emerging economies like India, RTE and RTC foods also present opportunities to commercialize traditional dishes in standardized and packaged forms, catering to both domestic and export markets. Government support through food parks and cold-chain infrastructure has further strengthened the ecosystem for entrepreneurs in this segment (MoFPI, 2024).

3.2 Functional foods, nutraceuticals, and fortified foods

Functional foods, nutraceuticals, and fortified products constitute a rapidly expanding market segment driven by increasing consumer awareness of health, nutrition, and disease prevention. Functional foods provide health benefits beyond basic nutrition, often through the inclusion of bioactive compounds such as antioxidants, probiotics, dietary fiber, omega-3 fatty acids, and phytochemicals (Granato et al., 2020). This trend presents strong entrepreneurial opportunities for food processing engineers with expertise in ingredient functionality, formulation, and process stability. Engineering interventions are critical in preserving the bioavailability and efficacy of functional ingredients during processing and storage. Technologies such as microencapsulation, controlled release systems, spray drying, and freeze drying are widely used to protect sensitive bioactives and enhance their stability in food matrices (Barba et al., 2018). Fortification strategies targeting micronutrient deficiencies—such as iron, iodine, vitamin D, and vitamin B12—have gained prominence, particularly in public health-oriented food enterprises (WHO, 2022). Entrepreneurs in this domain must navigate complex regulatory frameworks governing health claims, ingredient safety, and labeling. Food processing engineers contribute by ensuring compliance through validated processing conditions, quality control protocols, and shelf-life studies (Granato et al., 2020). With rising demand for preventive healthcare and personalized nutrition, functional and fortified foods offer long-term growth potential for innovation-driven startups.

3.3 Plant-based, alternative protein, and clean-label foods

Plant-based foods, alternative proteins, and clean-label products have emerged as transformative trends in the global food industry, driven by concerns related to sustainability, environmental impact, animal welfare, and health (Tziva et al., 2020). Entrepreneurs are increasingly exploring plant-derived proteins from legumes, cereals, oilseeds, algae, and fungi as alternatives to conventional animal-based products. This segment offers vast opportunities for food processing engineers to innovate in product development and process design. Food processing engineering enables the extraction, modification, and texturization of plant proteins to mimic the sensory properties of meat and dairy products. Technologies such as extrusion cooking, shear cell processing, fermentation, and enzymatic modification are central to producing meat analogues, dairy alternatives, and high-protein snacks (Dekkers et al., 2018). Clean-label foods, characterized by minimal processing and the absence of artificial additives, further require careful selection of processing methods that maintain functionality while meeting consumer expectations (Tziva et al., 2020). Startups operating in this space benefit from interdisciplinary knowledge combining food engineering, material science, and sensory analysis. However, challenges related to cost, scalability, and consumer acceptance persist. Engineering-led process optimization and ingredient innovation remain key to overcoming these barriers and enabling commercial success.

3.4 Traditional and ethnic foods with modern processing

Traditional and ethnic foods represent a culturally rich and economically significant opportunity for entrepreneurship, particularly in countries with diverse culinary heritage. Globalization and migration have increased international demand for ethnic foods, creating export opportunities for standardized and packaged traditional products (Rai et al., 2021). Food processing engineers play a vital role in modernizing traditional foods while preserving their authenticity. Modern processing technologies allow entrepreneurs to extend the shelf life of traditional foods without compromising sensory quality.

Fermentation control, thermal processing, dehydration, freezing, and retort packaging are commonly applied to products such as traditional snacks, fermented foods, sweets, and regional delicacies (Fellows, 2017). Standardization of recipes, process parameters, and quality attributes is essential for large-scale commercialization and regulatory approval. Entrepreneurial ventures focusing on traditional foods also benefit from value addition through branding, geographical indication (GI) tagging, and sustainable packaging. By integrating indigenous knowledge with scientific processing methods, food processing engineers can create differentiated products that appeal to both local and global consumers (Rai et al., 2021). This convergence of tradition and technology not only preserves culinary heritage but also generates employment and supports rural economies.

4. Technological Innovations Driving Future Entrepreneurship

Technological innovation is a major catalyst shaping the future of entrepreneurship in food processing engineering and technology. Rapid advancements in automation, digitalization, novel processing techniques, and sustainable packaging have transformed traditional food manufacturing into a knowledge-intensive, innovation-driven sector. These technologies lower entry barriers, improve efficiency, enhance food safety, and enable startups to respond quickly to evolving consumer demands. Food processing engineers, with their strong technical foundation, are therefore well positioned to lead technology-enabled entrepreneurial ventures (Fellows, 2017; Toledo, 2020).

4.1 Automation, robotics, and smart food factories

Automation and robotics are increasingly being adopted in food processing industries to improve productivity, consistency, and hygiene. Automated systems for sorting, grading, mixing, filling, and packaging reduce labor dependency, minimize human error, and enhance operational efficiency, making them particularly attractive for entrepreneurial ventures seeking scalability (Kumar et al., 2021). Robotics applications, including robotic arms, vision-guided pick-and-place systems, and automated palletizers, are now widely used in food handling and packaging operations. The concept of smart food factories integrates automation with digital monitoring and control systems to create flexible and responsive manufacturing environments. Smart factories use sensors, programmable logic controllers (PLCs), and real-time data analytics to optimize energy use, reduce waste, and ensure consistent product quality (Zhou et al., 2022). For startups, modular automation solutions offer cost-effective pathways to gradually scale operations without large upfront investments. Food processing engineers play a crucial role in designing automated layouts, selecting appropriate equipment, and ensuring compliance with hygiene and safety standards (Fellows, 2017).

4.2 Artificial intelligence and IoT in food processing

Artificial intelligence (AI) and the Internet of Things (IoT) have emerged as transformative technologies in food processing, enabling data-driven decision-making and predictive control. IoT devices, such as smart sensors and connected equipment, allow continuous monitoring of critical parameters including temperature, humidity, pressure, and microbial load across the processing and storage stages (Zhou et al., 2022). These systems enhance traceability, reduce spoilage, and support regulatory compliance, which are vital for entrepreneurial food enterprises. AI-based tools are increasingly applied in quality inspection, process optimization, and demand forecasting. Machine learning algorithms can analyze large datasets to detect defects, predict shelf life, and optimize processing conditions, thereby reducing costs and improving product consistency (Qian et al., 2023). For startups, cloud-based AI solutions provide affordable access to advanced analytics without extensive infrastructure. Food processing engineers with skills in data interpretation and systems integration are essential for deploying these technologies effectively in entrepreneurial settings.

4.3 Novel processing technologies (HPP, PEF, cold plasma, 3D food printing)

Novel and emerging food processing technologies have opened new avenues for entrepreneurship by enabling the production of high-quality, minimally processed, and value-added foods. High-pressure processing (HPP) is widely recognized for its ability to inactivate microorganisms while preserving nutritional and sensory attributes, making it suitable for premium juices, ready-to-eat meals, and seafood products (Barba et al., 2018). Although capital-intensive, shared processing facilities and contract processing models have made HPP accessible to startups. Pulsed electric fields (PEF) and cold plasma technologies are gaining attention for their effectiveness in microbial inactivation and enzyme control at low temperatures. These technologies support the development of clean-label foods with extended shelf life and minimal chemical preservatives (Wei et al., 2025). Food processing engineers are instrumental in adapting these technologies for industrial use by optimizing process parameters and ensuring safety validation. Three-dimensional (3D) food printing represents an emerging frontier in personalized nutrition and customized food design. By enabling precise control over shape, texture, and nutrient composition, 3D food printing offers entrepreneurial opportunities in healthcare nutrition, elderly foods, and specialty products (Sun et al., 2023). While still in the early stages of commercialization, advancements in printable food materials and equipment design are expected to expand its adoption in the coming years.

4.4 Sustainable packaging and biodegradable materials

Sustainable packaging innovations have become a critical driver of entrepreneurship due to growing environmental concerns and regulatory restrictions on single-use plastics. Entrepreneurs are increasingly adopting biodegradable, compostable, and bio-based packaging materials derived from starch, cellulose, chitosan, and polylactic acid (PLA) to reduce environmental impact (Siracusa et al., 2020). Food processing engineers contribute by evaluating material properties, barrier performance, and compatibility with food products and processing conditions. Active and intelligent packaging technologies further enhance sustainability and food safety by incorporating antimicrobial agents, oxygen scavengers, and freshness indicators. These innovations help reduce food waste and extend shelf life, creating additional value for both producers and consumers (Caleb et al., 2016). Startups focusing on eco-friendly packaging solutions benefit from strong consumer acceptance and policy support, particularly in export-oriented markets. The integration of sustainable packaging with circular economy principles, such as recyclability and waste valorization, presents long-term entrepreneurial opportunities. Food processing engineers, by combining material science knowledge with processing expertise, are key to developing packaging solutions that balance performance, cost, and environmental sustainability.

5. Sustainability and Circular Economy-Based Ventures

Sustainability and circular economy principles have become central to future entrepreneurship in food processing engineering and technology. Growing environmental concerns, resource scarcity, climate change impacts, and stricter regulatory frameworks have compelled the food industry to transition from linear “take–make–dispose” models toward circular systems that emphasize resource efficiency, waste reduction, and value recovery (Geissdoerfer et al., 2017). Food processing engineers play a pivotal role in designing sustainable ventures by integrating engineering solutions that enable waste valorization, energy-efficient processing, and responsible resource management.

5.1 Food waste valorization and by-product utilization

Food waste and by-products generated across the food supply chain represent both a major sustainability challenge and a significant entrepreneurial opportunity. Globally, approximately one-third of all food produced is lost or wasted, leading to economic losses and environmental degradation (FAO, 2021). In food processing industries, by-products such as fruit peels, seeds, pomace, bran, whey,

oilseed cakes, and shells are often underutilized despite their rich nutritional and functional properties. Food processing engineering enables the transformation of these by-products into value-added products through physical, chemical, and biotechnological interventions. Technologies such as drying, extrusion, fermentation, enzymatic hydrolysis, and membrane separation are commonly employed to recover bioactive compounds, dietary fibers, proteins, and natural pigments from food waste streams (Mirabella et al., 2014; Barba et al., 2018). These recovered components can be utilized in the development of functional foods, nutraceuticals, animal feed, biodegradable packaging materials, and bio-based chemicals. Entrepreneurial ventures focused on food waste valorization align strongly with circular economy goals by closing material loops and reducing environmental impact. Startups engaged in upcycling surplus produce into snacks, powders, and fermented products have gained consumer acceptance, particularly in sustainability-conscious markets (Galanakis, 2020). Food processing engineers contribute by optimizing extraction efficiency, ensuring food safety, and scaling up valorization processes for commercial viability. Such ventures not only generate new revenue streams but also support waste reduction targets and sustainable development goals.

5.2 Energy-efficient and eco-friendly processing systems

Energy consumption is one of the most significant operational costs and environmental burdens in food processing industries. Conventional processing methods often rely on energy-intensive thermal operations, contributing to high greenhouse gas emissions. As a result, energy-efficient and eco-friendly processing systems have emerged as key drivers of sustainable entrepreneurship (Kumar et al., 2021). Food processing engineers are at the forefront of developing and implementing technologies that reduce energy use while maintaining product quality and safety. Innovations such as heat recovery systems, optimized thermal processing, microwave and radio-frequency heating, and non-thermal technologies like high-pressure processing and pulsed electric fields have demonstrated significant potential for energy savings (Barba et al., 2018). Process integration and optimization techniques, including pinch analysis and energy audits, further support startups in minimizing energy losses and operational costs (Toledo, 2020). The adoption of renewable energy sources such as solar, biomass, and biogas in food processing units has also gained momentum. Biogas production from organic waste streams offers dual benefits by generating renewable energy and reducing waste disposal issues (Galanakis, 2020). Entrepreneurial ventures that integrate energy-efficient technologies and renewable energy systems benefit from reduced operating costs, improved environmental performance, and enhanced brand value. Food processing engineers play a critical role in designing these systems, evaluating techno-economic feasibility, and ensuring regulatory compliance.

5.3 Water and resource management innovations

Water is a critical resource in food processing operations, used extensively for washing, processing, heating, cooling, and sanitation. However, increasing water scarcity and stricter environmental regulations have highlighted the need for efficient water and resource management strategies (OECD, 2021). Sustainable entrepreneurship in food processing increasingly depends on innovative solutions that minimize water consumption and wastewater generation. Food processing engineers develop and implement water-efficient technologies such as closed-loop water systems, clean-in-place (CIP) optimization, membrane filtration, and advanced wastewater treatment processes. Membrane technologies, including reverse osmosis and ultrafiltration, enable water reuse and recovery of valuable components from effluents, supporting both sustainability and profitability (Mekonnen and Hoekstra, 2016). Additionally, real-time monitoring and automation systems allow startups to track water usage, detect leaks, and optimize resource allocation. Resource management innovations extend beyond water to include raw material efficiency, packaging reduction, and emission control. Life cycle assessment (LCA) tools are increasingly used by food entrepreneurs to evaluate environmental impacts and guide sustainable decision-making (Geissdoerfer et al., 2017). By adopting resource-efficient practices, startups can achieve compliance with environmental standards while gaining competitive advantage in eco-conscious markets. Overall, sustainable and circular economy-based ventures offer long-term

entrepreneurial potential by addressing environmental challenges while creating economic value. Food processing engineers, through their expertise in process design, optimization, and systems integration, are essential enablers of this transition toward sustainable food systems.

6. Startup Ecosystem and Government Support

A robust startup ecosystem and strong government support mechanisms are critical enablers for entrepreneurship in food processing engineering and technology. Given the capital-intensive nature of food processing, stringent regulatory requirements, and the need for technical validation, entrepreneurs require institutional support to reduce risk and accelerate commercialization. In recent years, the convergence of incubation infrastructure, targeted government schemes, and strengthened academia–industry collaboration has significantly improved the entrepreneurial landscape in the agri-food sector (Audretsch et al., 2020; MoFPI, 2024).

6.1 Incubation centers and food technology parks

Incubation centers and food technology parks play a pivotal role in nurturing early-stage food processing startups by providing access to shared infrastructure, technical expertise, and business mentoring. Food business incubators typically offer pilot-scale processing facilities, testing laboratories, packaging units, cold storage, and quality assurance support, which are otherwise unaffordable for startups in their initial stages (Aernoudt, 2004). These facilities enable entrepreneurs to validate product concepts, optimize processes, and comply with food safety regulations before scaling up. Food technology parks and mega food parks further strengthen the ecosystem by integrating processing units, logistics, warehousing, and support services within a single cluster. Cluster-based development reduces operational costs, improves supply-chain efficiency, and promotes collaboration among enterprises (Rao et al., 2021). In India, the establishment of Mega Food Parks and Agro Processing Clusters has created region-specific hubs for food entrepreneurship, particularly benefiting small and medium enterprises (MoFPI, 2024). Food processing engineers play a central role within incubators and technology parks by assisting startups in equipment selection, process design, scale-up trials, and compliance with hygiene and safety standards. Studies have shown that startups emerging from incubation programs exhibit higher survival rates, faster commercialization, and improved innovation performance compared to non-incubated firms (Hausberg and Korreck, 2020). Thus, incubation infrastructure acts as a foundation for technology-driven food entrepreneurship.

6.2 Government schemes and funding opportunities

Government policies and funding mechanisms are essential for promoting entrepreneurship in food processing engineering and technology, particularly in developing economies. Recognizing the sector's potential for employment generation, value addition, and export growth, governments have introduced a range of schemes to support food processing startups (World Bank, 2020). These initiatives address key challenges related to access to finance, infrastructure, technology, and market linkages. In India, the Ministry of Food Processing Industries (MoFPI) has launched several flagship schemes, including the Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PM-FME) Scheme, Production Linked Incentive (PLI) Scheme for food processing, and the Mega Food Park Scheme (MoFPI, 2024). These programs provide financial assistance for capital investment, technology upgradation, branding, and capacity building. Startups also benefit from credit-linked subsidies, venture capital funds, and startup grants offered through national innovation missions and development banks (IBEF, 2024). Internationally, food startups receive support through innovation grants, public–private partnerships, and sustainability-focused funding aligned with climate and circular economy goals (OECD, 2022). Government-backed funding reduces early-stage financial risk and encourages entrepreneurs to invest in advanced processing technologies and sustainable practices. Food processing engineers contribute by preparing techno-economic feasibility reports, ensuring compliance with scheme guidelines, and optimizing project design to maximize funding benefits.



6.3 Role of academia–industry collaboration

Academia–industry collaboration is a critical driver of innovation and entrepreneurship in food processing engineering and technology. Universities and research institutions serve as sources of scientific knowledge, skilled human resources, and technological innovations that can be commercialized through startups and spin-off companies (Etzkowitz and Leydesdorff, 2000). Collaborative models such as technology transfer offices, industry-sponsored research, and joint incubation programs facilitate the translation of research outcomes into market-ready products. Food processing engineers trained in academic institutions often act as innovation intermediaries by bridging theoretical research and industrial application. Collaborative research projects enable startups to access advanced laboratories, pilot plants, and expert guidance, reducing development time and costs (Perkmann et al., 2013). Furthermore, industry participation in curriculum design, internships, and live projects ensures that graduates acquire entrepreneurial and industry-relevant skills. Successful academia–industry partnerships have been shown to enhance innovation performance, improve technology adoption, and increase the commercialization rate of research outputs (Audretsch et al., 2020). In the food processing sector, such collaborations support the development of novel products, validation of emerging technologies, and adherence to regulatory standards. Government-supported programs that incentivize collaborative research and startup incubation within universities further strengthen this ecosystem (OECD, 2022).

7. Challenges and Risk Management

Despite the significant growth potential of entrepreneurship in food processing engineering and technology, startups in this sector face multiple challenges that can affect their sustainability and long-term success. These challenges arise from strict regulatory frameworks, intense market competition, evolving consumer preferences, and complex supply-chain dynamics. Effective risk management strategies, supported by sound engineering and managerial practices, are therefore essential for food entrepreneurs to navigate uncertainties and achieve scalable growth (Fellows, 2017; Audretsch et al., 2020).

7.1 Regulatory and food safety compliance

Regulatory and food safety compliance is one of the most critical challenges for food processing startups. Food products directly impact public health, and therefore food businesses are subject to stringent regulations related to hygiene, processing standards, labeling, and traceability. Regulatory frameworks such as Hazard Analysis and Critical Control Point (HACCP), ISO 22000, Codex Alimentarius standards, and national food safety laws require systematic control of hazards across the entire food production chain (Codex Alimentarius Commission, 2020). For startups, compliance with these regulations can be resource-intensive due to the need for specialized infrastructure, documentation, validation studies, and trained personnel. Inadequate understanding of regulatory requirements often leads to delays in product launch, financial losses, or legal penalties (Unnevehr and Jensen, 2019). Food processing engineers play a key role in mitigating regulatory risks by designing hygienic equipment layouts, validating processing conditions, and implementing food safety management systems from the early stages of enterprise development (Toledo, 2020).

Risk management in this context involves proactive compliance planning, regular audits, employee training, and adoption of digital traceability systems. The integration of automation and sensor-based monitoring further enhances food safety assurance by enabling real-time detection of deviations and rapid corrective actions (Zhou et al., 2022). Thus, regulatory compliance, although challenging, can become a competitive advantage when effectively managed.

7.2 Market competition and consumer acceptance

Market competition represents another major challenge for food processing entrepreneurs, particularly in saturated markets dominated by established brands. New entrants must compete on multiple fronts, including price, quality, innovation, branding, and distribution reach. Limited marketing budgets and lack of brand recognition often constrain the ability of startups to penetrate mainstream markets (Porter, 2008). Consumer acceptance is closely linked to product attributes such as taste, texture, appearance, price, and perceived health or sustainability benefits. Innovative products—such as functional foods, plant-based alternatives, or novel processed foods—may face resistance due to unfamiliarity or skepticism regarding safety and efficacy (Tziva et al., 2020). Food processing engineers contribute to overcoming these challenges by optimizing product formulation, ensuring consistent quality, and conducting sensory evaluation studies to align products with consumer expectations (Granato et al., 2020).

Risk mitigation strategies include market research, pilot launches, consumer education, and transparent labeling practices. Collaborations with retailers, food service providers, and digital platforms can enhance market access and visibility for startups. Additionally, certification schemes and quality labels can build consumer trust and differentiate products in competitive markets (Unnevehr and Jensen, 2019).

7.3 Supply chain and scalability challenges

Supply-chain management and scalability present significant operational risks for food processing startups. Reliable access to raw materials, especially agricultural commodities, is often affected by seasonality, climate variability, price fluctuations, and quality inconsistencies (FAO, 2021). Disruptions in logistics, storage, and distribution further compound these challenges, particularly for perishable products requiring cold-chain infrastructure. Scaling up from pilot-scale production to commercial manufacturing introduces additional complexities related to equipment capacity, process consistency, cost control, and workforce management. Inadequate scale-up planning can result in quality variability, increased waste, and reduced profitability (Toledo, 2020). Food processing engineers play a critical role in addressing scalability challenges by applying principles of process modeling, equipment design, and systems integration to ensure smooth transition across production scales. Risk management strategies include diversification of raw material sources, long-term supplier contracts, and adoption of decentralized or modular processing systems. Digital supply-chain tools and predictive analytics can improve demand forecasting, inventory management, and logistics coordination, thereby enhancing resilience (Kumar et al., 2021). Furthermore, strategic partnerships with logistics providers and participation in food processing clusters or technology parks can help startups achieve economies of scale and reduce operational risks.

8. Future Outlook

The future of entrepreneurship in food processing engineering and technology is strongly shaped by rapid digital transformation, expanding global market opportunities, and evolving skill requirements for food engineers. Advances in digital technologies, globalization of food trade, and the increasing complexity of food systems are redefining how food enterprises are conceptualized, developed, and scaled. These trends present both opportunities and challenges, requiring food processing engineers to adopt interdisciplinary roles and entrepreneurial mindsets to remain competitive in the evolving agri-food landscape (Fellows, 2017; Audretsch et al., 2020).

8.1 Digital transformation in food entrepreneurship

Digital transformation has emerged as a cornerstone of future food entrepreneurship, enabling data-driven decision-making, operational efficiency, and enhanced consumer engagement. Technologies such as artificial intelligence (AI), Internet of Things (IoT), blockchain, and cloud computing are

increasingly integrated into food processing and supply-chain management systems (Zhou et al., 2022). For entrepreneurs, digital tools reduce information asymmetry, optimize resource utilization, and improve transparency across the food value chain. In food processing operations, digitalization enables real-time monitoring of processing parameters, predictive maintenance of equipment, and automated quality control. AI-driven analytics allow startups to optimize formulations, predict shelf life, and respond proactively to quality deviations, thereby reducing waste and improving profitability (Qian et al., 2023). Blockchain-based traceability systems further enhance food safety assurance and consumer trust, particularly in premium and export-oriented markets (Kumar et al., 2021).

Digital platforms also reshape market access and consumer interaction. E-commerce, direct-to-consumer (D2C) models, and digital marketing enable food startups to reach wider audiences with relatively low investment. Personalized nutrition services, subscription-based food models, and data-enabled product customization represent emerging entrepreneurial opportunities facilitated by digital transformation (Granato et al., 2020). Food processing engineers with digital literacy and data analytics skills will therefore be central to future food enterprises.

8.2 Export-oriented and global market opportunities

Globalization of food trade and rising international demand for diverse, safe, and high-quality food products present significant export-oriented opportunities for food entrepreneurs. Processed foods, functional products, traditional and ethnic foods, and plant-based alternatives are experiencing increased demand in global markets due to changing dietary preferences and demographic shifts (OECD, 2022). Food processing engineering and technology provide the technical foundation necessary to meet international quality, safety, and labeling standards. Export-oriented entrepreneurship requires adherence to stringent regulatory requirements, including Codex Alimentarius standards, Hazard Analysis and Critical Control Point (HACCP) systems, and country-specific import regulations (Codex Alimentarius Commission, 2020). Food processing engineers play a vital role in ensuring compliance through validated processing methods, quality assurance systems, and shelf-life studies (Toledo, 2020). Advances in packaging technology, cold-chain logistics, and digital traceability further support the expansion of food startups into global markets. Emerging economies such as India are well positioned to leverage their agricultural diversity, traditional food heritage, and cost advantages to expand exports of value-added food products. Government initiatives supporting export promotion, quality certification, and market access have strengthened the global competitiveness of food processing enterprises (IBEF, 2024). Entrepreneurs who combine technological innovation with strategic branding and market intelligence can successfully penetrate international markets and build globally recognized food brands.

8.3 Skill development and interdisciplinary roles for food engineers

The evolving landscape of food entrepreneurship demands a new set of skills and interdisciplinary competencies from food processing engineers. Beyond technical expertise in processing and preservation, future food engineers must possess knowledge of business management, regulatory affairs, digital technologies, sustainability, and consumer behavior (Fellows, 2017). This shift reflects the increasing complexity of food systems and the need for integrated solutions that balance technical, economic, and environmental considerations. Skill development initiatives focusing on entrepreneurship, innovation management, and digital literacy are essential to prepare food engineers for leadership roles in startups and technology-driven enterprises. Academic institutions and training programs increasingly emphasize experiential learning, industry collaboration, and startup incubation to bridge the gap between education and entrepreneurial practice (Etzkowitz and Leydesdorff, 2000; Audretsch et al., 2020). Interdisciplinary collaboration with experts in data science, biotechnology, materials science, and marketing further enhances innovation capacity. Food engineers are also expected to play strategic roles in addressing global challenges such as food security, climate change, and sustainability. By applying systems thinking and life cycle assessment tools, they can contribute to the design of resilient and sustainable food enterprises (Geissdoerfer et al., 2017). Consequently, the



future outlook for food processing engineering and technology highlights the importance of continuous learning, adaptability, and entrepreneurial orientation in shaping successful careers and enterprises.

9. Conclusion

The entrepreneurship landscape in food processing engineering and technology is undergoing a significant transformation driven by technological innovation, sustainability imperatives, and evolving consumer demands. This review has highlighted the strategic importance of food processing engineers as entrepreneurs who not only contribute to economic growth but also play a critical role in strengthening food systems, reducing post-harvest losses, and ensuring food security. By integrating engineering expertise with entrepreneurial vision, food processing engineers are uniquely positioned to address complex challenges across the agri-food value chain and to create resilient, scalable, and socially responsible food enterprises (Fellows, 2017; Audretsch et al., 2020).

9.1 Strategic importance of food processing engineers as entrepreneurs

Food processing engineers possess a multidisciplinary skill set encompassing process design, product development, quality assurance, and systems optimization, which forms a strong foundation for entrepreneurial success. Their technical competence enables the translation of agricultural raw materials into value-added food products while ensuring compliance with safety, quality, and regulatory standards. In an era where food systems face mounting pressures from population growth, climate change, and resource constraints, the entrepreneurial engagement of food processing engineers has become strategically essential (FAO, 2021). As entrepreneurs, food processing engineers act as innovation catalysts by adopting advanced processing technologies such as high-pressure processing, pulsed electric fields, cold plasma, and extrusion-based systems to enhance product quality and shelf life (Toledo, 2020). Their ability to integrate emerging digital tools, including artificial intelligence, automation, and smart sensors, further strengthens operational efficiency and decision-making in food enterprises (Zhou et al., 2022). These capabilities allow engineer-entrepreneurs to differentiate their offerings, reduce production risks, and achieve competitive advantage in increasingly complex markets. Moreover, food processing engineers contribute significantly to inclusive and regional development by supporting decentralized processing models and small-scale food enterprises. Such models facilitate rural entrepreneurship, enhance farmer incomes, and reduce post-harvest losses through localized value addition (Kumar and Kalita, 2017). By bridging the gap between agricultural production and consumer markets, food processing engineers serve as critical enablers of sustainable food system transformation.

9.2 Pathways for sustainable and technology-led growth

Sustainable and technology-led growth in food entrepreneurship requires the strategic alignment of technological innovation, environmental stewardship, and economic viability. Food processing engineers play a central role in designing energy-efficient processes, water-saving technologies, and waste valorization pathways that support circular economy principles (Geissdoerfer et al., 2017). The conversion of food by-products into functional ingredients, bioactive compounds, or biodegradable packaging materials exemplifies how engineering-led entrepreneurship can simultaneously address sustainability challenges and create new revenue streams (Mirabella et al., 2014). Digital transformation represents another critical pathway for future growth. The integration of Industry 4.0 technologies into food processing systems enables predictive quality control, real-time traceability, and data-driven process optimization (Kumar et al., 2021). These digital capabilities enhance transparency, improve supply-chain resilience, and support compliance with global food safety standards, thereby facilitating access to export markets (Codex Alimentarius Commission, 2020). For entrepreneurs, digitalization reduces operational uncertainties and fosters scalable business models adaptable to dynamic market conditions. Capacity building and skill development are equally important for sustaining long-term growth. Entrepreneurial education programs, incubation centers, and industry–



academia partnerships provide critical platforms for translating research innovations into commercial applications (Etzkowitz and Leydesdorff, 2000). Food processing engineers equipped with entrepreneurial, managerial, and digital competencies are better prepared to navigate regulatory complexities, market competition, and technological disruptions. Continuous professional development and interdisciplinary collaboration will therefore remain essential components of successful food entrepreneurship ecosystems.

9.3 Toward resilient and future-ready food enterprises

Looking ahead, the convergence of technology, sustainability, and entrepreneurship is expected to redefine the role of food processing engineers in global food systems. Future-ready food enterprises will prioritize resilience, adaptability, and responsible innovation to respond to emerging challenges such as climate variability, supply-chain disruptions, and shifting consumer preferences (OECD, 2022). Food processing engineers, as entrepreneurial leaders, will be instrumental in driving this transformation by applying systems thinking and evidence-based decision-making. Policy support, access to finance, and market linkages will further shape the entrepreneurial landscape. Government initiatives that promote food processing infrastructure, innovation funding, and export facilitation can significantly enhance the success rate of engineer-led startups (IBEF, 2024). When combined with robust risk management strategies and ethical business practices, these enabling factors contribute to the creation of sustainable food enterprises with long-term societal impact.

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