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Review

New Foods as a Factor in Enhancing Energy Security

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Abstract: Increasing energy security is a crucial component of achieving the Sustainable Development Goals (SDGs). Three main factors influence energy security: (1) the efficiency of resource use in energy production, (2) the extent of energy losses, and (3) the use of new energy sources. Novel food products can impact these factors, and this paper explores whether they are being studied in the context of reducing energy consumption. Specifically, we investigate the role of technical progress and know-how in the creation and development of novel food products and whether novel methods of food production using artificial intelligence aim to reduce energy expenditures while improving product quality, variety, and the use of new energy sources. This paper seeks to examine the impact determinants of novel foods on energy security, considering economic, technological, social, and environmental aspects of knowledge about new food. To implement the study, the relevant international literature published in the past ten years have been reviewed and methods of modeling, visualization, and descriptive statistics applied. The review is structured into three sections: the first section presents ways to save energy and other resources in the food production chain through the intensive use of artificial intelligence tools; the second section presents the development of novel food products; and the last section presents marketing challenges for novel foods. The findings show that the topic addressed by this paper is currently critical, with many authorities, research centers, food producers, and energy producers interested. However, the research problem remains open, as a systematic review of secondary sources revealed little knowledge of the topic under study, and each author's study presents a new solution. The conclusion is that utilizing new foods and innovative production techniques that require less energy not only enhances production diversity but also improves its quality.

Keywords: new foods; energy saving; artificial intelligence (AI)

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1. Introduction

As humanity makes social and economic progress and grows in number, the demand for and the price of energy are increasing. Energy is obtained from two types of sources—non-renewable (such as coal, oil, natural gas, and radioactive elements) and renewable (such as solar, wind, hydroelectric, geothermal, and biomass). Currently, the world consumes approximately 170,000 TWh of primary energy, out of which 40,000 TWh is derived from coal and 45,000 TWh from oil [1]. The total energy consumption in Poland, e.g., has increased from 169.4 GWh in 2019 to 173.46 GWh in 2021. Due to the deficit of approximately 1 GHw and rising side costs such as the cost of coal, oil, transport, and external costs (e.g., carbon pollution), there is a growing interest in renewable sources of energy. It is expected that wind and solar electricity will account for more than a quarter of total electricity generation by 2026, while the use of fossil fuels is expected to decrease. The total global energy demand is expected to ease in 2023 and to grow by slightly less than 2% in 2023, down from a rate of 2.3% in 2022 and the average annual growth rate of 2.4% observed over the 2015–2019 period. This trend is mainly driven by declining electricity demand in advanced economies, which face the ongoing effects of the global energy crisis and slower economic growth due to COVID-19 [2,3]. However, it is projected that this trend will end in 2024, and the demand growth will accelerate again.

It is important to note that around 30% of the world's energy is used in the agricultural and food industry. Energy is required at every stage of the food value chain, from the production of agricultural inputs to agricultural production in the field, harvesting, processing, food production, transportation, marketing, and consumption. While primary agriculture consumes only about 20% of the sector's energy, food processing, including transportation, accounts for around 40% of energy usage, significantly contributing to global energy consumption along agricultural value chains [4,5]. In developed countries, the agriculture, livestock, and fishing industries consume approximately 25% of total energy, while 45% of this energy is consumed in food processing and distribution, and 30% is used in retail, preparation, and cooking. Developing countries, on the other hand, consume less energy for production but require more energy for distribution and cooking.

The issue of energy is related to two factors that often compete—energy security through energy access and environmental sustainability. In the current scenario of rapidly transitioning to a decentralized, decarbonized, and digital system, it is essential to maintain a balance between these two factors while achieving equivalent goals. In this context, a compromise should be made to address the necessary challenge. The global energy sector faces an energy trilemma that involves sustainable development, energy decarbonization, and the reliable provision of energy [6]. To better understand the opportunities and disruptions of a decentralized energy system, energy security, affordability, and quality priorities need to be assessed. A sustainable energy transition and reduction in energy consumption through fixed asset investments contribute to economic growth. This growth is directly correlated with the quality of the environment in the short term. Investments in fixed assets and reduction in energy consumption are positively associated with environmental quality. Additionally, energy and biological security are strengthened. The decarbonization process can be accelerated, e.g., through the implementation of general carbon taxes.

Energy security and its economic and political stability must be given long-term priority, as supported by numerous opinions [7]. As energy security is crucial for economic growth and development, the energy development rate will need to grow by 3.2% per year, which is nearly three times more than in 2019 and twice as much as in the past [8]. However, according to the International Energy Agency, if humanity continues at the current pace, by 2050, emissions and pollution will increase by 130% [8]. Thus, a comprehensive energy transition development program is necessary to reevaluate the relationship between economics, nature, and the environment. Critical components include transitioning towards more sustainable models and economic structures that promote social equity, investment flows, and energy patterns [9].

Assuring sustainable growth and development in the long run calls for technical, social, political, economic, ethical, and research integrity solutions to ensure a reliable supply of clean and affordable energy and nutritious food for everyone, which highly impact well-being and health. With the developed countries committed to the achievement of the seventeen Sustainable Development Goals (SDGs), this applies particularly to the following SDGs: good health and well-being (3), affordable and clean energy (7), and responsible consumption and production (12) [10]. Increasing resource use efficiency to create energy and reducing energy losses is the main solution to enhance energy security. New, more sustainable foods offer a potential to help in achieving this goal.

The aim of this paper is to investigate the impact of new foods on energy security, covering economic, technological, and social aspects. For this, several research questions have been explored: (1) whether new foods have been studied in the context of reducing energy consumption; (2) the role that technical progress and knowledge play in the development of new foods; (3) whether new methods of food production using artificial intelligence (AI) aim to reduce energy expenditure and improve product quality and variety; and finally, (4) whether the process of generating new foods is market-sustainable. The research was conducted using the method of standard literature review applied to global literature from the last ten years, including theoretical, empirical, and statistical works found on four academic literature databases: Scopus, Web of Science, Science Direct, and Google Scholar. To ensure systematic results, three criteria have been applied: keywords, scientific nature of publications, and research area. Works selected have been published from 2012 to 2023 and focused on economic, social, technological, and environmental aspects. Both authors independently evaluated the chosen literature. Only highly rated publications were selected based on how helpful the literature was in solving the research questions. The resulting database of 200 works required further analysis, and the findings are presented in individual chapters of the review. In our examination, we applied various methods including deduction, analysis, and literature review. The paper is divided into three logically organized sections. The first section explores new methods to save energy in the food chain that heavily rely on the use of artificial intelligence. The other two sections cover the definition and design of novel food products, as well as the challenges novel food products face in relation to consumer acceptance.

The topic discussed in this paper is highly significant and up-to-date, which is supported by the attention of many authorities, research centers, scientists, as well as food and energy producers, as the bulk of the scientific, white, grey, and other non-scientific literature indicates, e.g., [11]. However, despite the considerable attention it has received, the research problem remains still open and relevant.

2. AI-Aided Ways to Save Energy in Food Production

Energy intensity across all EU countries, measured in kG of oil equivalent per thousand pounds, showed a decline during the period 2011–2021 in all countries. The countries that made the most progress in this regard were Bulgaria, Estonia, and Malta [12]. These achievements were possible in part due to the use of new, more efficient food drying technologies [13], overcoming barriers, applying new ideas [14], waste management, and modernization of production processes, e.g., [15]. Energy savings in the food industry's cold supply chains also contributed to reducing energy consumption [16].

In the European Union, all member states have been required to reduce their industrial energy consumption steadily from 2011 to 2021. As per the regulations, these countries must save an average of 1.5% of their total energy consumption yearly by 2030. The annual energy savings will begin at 1.3% until the end of 2025, and then gradually increase to 1.9% during the final period until the end of 2030 [17]. Meeting these recommendations requires broader energy conservation in the food sector and the economy in general. The food industry encompasses all steps from the farm to the consumer, including agriculture, purchasing, wholesaler processing, commercial units, and the final customer. This process takes a considerable amount of time and involves multiple stages: raw materials are produced, stored, processed, and transported between different units as the product becomes more mature or finished. These activities are influenced by environmental conditions such as temperature, humidity, and light, which can affect the quality of the material or product. Depending on the type of food product, the appropriate physical conditions, especially temperature and humidity, need to be maintained and monitored during transportation of raw materials, semi-finished, or finished food products [18]. Published research shows that 33% of the world's food is wasted along the food chain [19–21], and with it the energy and other resources used for its production and marketing, making food waste and loss a serious challenge. It is estimated that around 14% of the food produced is lost between the time of harvest and delivery to the market. Furthermore, approximately 18% of global food production is wasted, with 11% of this waste happening in households, 5% in restaurants and bars, and 2% in trade [22].

The social and economic significance of the aforementioned issues prompts their management through information technology (IT) such as artificial intelligence (AI) and machine learning (ML). Since the late 1950s, there has been an ongoing a shift from mechanical electronic technology to digital electronics. This transformation has accelerated in the past 50 years, driven by the invention of the Internet and advancements in computer hardware and mobile technology, leading to what is known as the digital revolution [23]. The rapid development of information and communication technology has transformed various aspects of social life, economies, businesses, and management, leading to the emergence of digital economy [24]. In Europe, this process has been particularly intensive in the past decade. Since 2015, digital adoption has increased notably throughout the EU, with the digital economy and society index (DESI), an index tracking indicators on Europe's digital performance, rising from below 40 in 2015 to above 60 in 2020 [25].

AI and computer science can improve agricultural production for consumer needs, according to various authors, e.g., [26], including food processing in terms of its sensory advantages and distribution channels. The literature on the subject covers various scenarios and use cases of machine learning, machine vision, and sustainable global learning for future food production [27]. As the food production chain encompasses various stages, it is essential to involve energy-efficient technologies throughout the whole chain including farming, appropriate packaging, and maintaining proper temperature during transport and storage. The following section explores the potential and the application of these new technologies to save energy along the food chain in more detail.

2.1. Artificial Intelligence and Machine Learning

The definition of artificial intelligence is complex, but for the purpose of clarity, it is limited to artificially intelligent systems, simulating human intelligence processes, especially computer systems. Specific applications of AI include expert systems, natural language processing, speech recognition, and machine vision [28]. There are various definitions available, but most of them fall into one of the following four categories: systems that can think like humans, act like humans, think rationally, and act rationally. Additionally, an AI computer should have the ability to gather knowledge, apply it, and learn. Machine learning is a branch of artificial intelligence (AI) and computer science focusing on the use of data and algorithms to imitate the way humans learn, gradually improving its accuracy [29]. Artificial intelligence models require large amounts of labeled data, which can be expensive and biased. Self-supervised learning provides a solution by allowing models to learn from unlabeled data without overt labeling. This approach enables the model to learn from large datasets without the need for human labeling [30]. With the help of computer technologies and artificial intelligence, it is now possible to use large sets of experimental data from actual production processes to create new equipment and algorithms for real-time intelligent machines. These machines can build models that characterize individual manufacturing processes, which can facilitate production operations and product quality controls. These models are commonly known as artificial intelligence-based computer vision [31]. Investment activity in this area is dominated by start-ups and rising [32], with the global market growth from EUR 0.5 trillion to EUR 4.1 trillion between 2012 and 2015.

During the latter half of 2010, advancements in the fields of nutritional science, food chemistry, food analytical methods, and artificial intelligence started to intersect. For instance, AI has been integrated into nutritional epidemiology by facilitating dietary pattern analysis and identifying foodborne illnesses using large-scale data analysis. Additionally, AI has been useful in food toxicity assessment, image diagnosis, and personalized nutrition [33]. Other technologies based on the so called fourth-generation (4.0 IR) technologies such as the Internet of Things, cyber-physical systems, smart manufacturing, smart factories, cloud computing, and cognitive computing, which make up the Industry 4.0, can also improve food production processes [34]. One such example is 'Food Traceability 4.0' (FT 4.0), i.e., tracking food products using digital technologies in the food chain. Application of FT 4.0 has enormous potential to improve food tracking, reduce food waste, and prevent food fraud, leading to smarter food traceability. This, in turn, creates new opportunities in the food industry and improves customer trust [35].

2.2. Artificial Intelligence in Agriculture

World agriculture is on the cusp of significant improvements as AI technologies rapidly advance and become more widely used in this area. AI has the potential to revolutionize crop management and agricultural productivity by enabling rapid diagnosis of plant diseases, efficient application of agrochemicals, and providing expert agronomic advice to growers. However, the systemic risks of using ML and AI models as expert systems in agriculture are often under-appreciated and poorly understood. Some of the key risk factors include the interoperability, reliability, and relevance of data [36]. The suggested risk-mitigation measures are applying frameworks for responsible and human-centered innovation, setting data cooperatives for improved data transparency and ownership rights, and initial deployment of agricultural AI in digital sandboxes [36].

By analyzing large data sets, AI algorithms can extract valuable information that supports decision-making and management in areas such as crop farming, animal production, automatic control processes, and robotics. These models and the information they provide are essential tools for improving the efficiency and productivity of agri-food systems. The collection of data in various agri-food sectors such as cultivation, field crop production, horticulture, animal production, water management, irrigation, machinery, barriers, and challenges can lead to better management decisions but also create new challenges. The use of AI technology in this domain brings up various risks, ethical issues, and societal implications. Questions must be raised about how to govern the usage of these technologies, and how to incorporate socio-ethical value considerations into the policy and legal frameworks under development [37] as current agricultural practices transition to smart farming, robotic farming, and the use of automated drones [38].

2.3. Artificial Intelligence in Food Processing and Distribution

Numerous papers and books have presented and evaluated AI- and ML-based approaches for various food processing operations, including drying, frying, baking, canning, extrusion, encapsulation, and fermentation, to predict the kinetics of these processes [39]. The development of ML-based models and their practical implementation can be achieved through a step-by-step procedure, as outlined in [40]. Another area of the food production chain in which the integration of artificial intelligence (AI) applications is becoming increasingly popular is transportation. Here, ICT technologies can help optimize transportation routes and reduce losses [41] and costs [42,43]. By applying machine learning (ML) and robotics, it is possible to control transportation routes and ensure the safe transportation of fresh or sensitive food [44]. The goal of these methods is to integrate various elements of the food transport chain to maintain better quality, sustainability, and efficiency.

According to STATISTA, the demand for food robotics equipment is expected to increase by about 5 million units in the next 5 to 7 years, among others due to the implementation of AI and ML in the food industry [45]. The use of these technologies can bring numerous benefits, such as reducing packaging costs, speeding up service, increasing consumer satisfaction, and minimizing human errors [38]. This, in turn, leads to lower losses, increased positive feedback, and increased consumer trust [46]. AI applications also reduce the time taken for placing orders by voice, making the process more personal and advantageous, especially in large processing plants. This brings profits, particularly in the long term. The elimination of irregularities contributes to reducing losses and costs within the company. For instance, errors in quality levels, numerous complaints due to incorrect grammage, poor labeling or marking, and exceeding permitted temperatures or humidity during storage and transportation can be avoided [18].

Artificial intelligence enabled agents, Internet of Things (IoT), sensors, and blockchain technology can be combined to maximize the supply network and increase the revenue of all parties involved along the agri-food value chain [47]. Blockchain is a technology that can record multiple transactions from multiple parties across a complex network. Changing the records inside the blockchain requires the consensus of all parties involved, thus giving a high level of confidence in the data [48]. This way, blockchain technology can support the traceability and transparency of the food supply chain, possibly increasing the trust of consumers, and in combination with AI, intelligent precision farming can be achieved.

The list of scientific papers exploring different applications of new technologies in a variety of food processing operations is long, while more systematic and comprehensive works are few. Among the latter, the following books are especially helpful [49–52].

2.4. Artificial Intelligence in Preservation and Storage of Food

A significant issue in the food chain is the storage and preservation of food. Every year, a large amount of food becomes spoiled during transportation and storage due to the inability to maintain freshness for an extended period of time. However, the new phase change technology for cold energy storage has revolutionized cold chain logistics. This technology offers several advantages, including stable temperatures and high energy storage density [53]. Effective temperature control is crucial for maintaining freshness and preventing spoilage throughout the food supply chain [18,54]. Having materials that can reduce temperature fluctuations and keep perishable produce fresh for a longer time is crucial. According to Chen et al., phase change materials (PCMs) can absorb or release large amounts of latent heat during phase transition, with minimal temperature fluctuations [55,56].

The literature review shows that only a few studies address the use of PCMs to preserve food freshness. Refrigeration systems using cold storage PCMs have been found to maintain the ideal temperature state in refrigerated trucks. Additionally, the cost of this method is half that of traditional refrigeration transportation [57]. Adding a phase change cold storage layer to the reefer enclosure reduced total energy consumption by 4.7% compared to conventional cold storage [58]. There have been several recent reports on insulation PCM boxes that are suitable for refrigerated transportation of fruits and vegetables. These boxes come in various forms, such as trays, multilayer films, foams, and others. Additionally, a new study has provided a novel idea for the design of temperature control materials that can be used in cold chain transportation of food, vegetables, and fruits [53].

2.5. Artificial Intelligence and Energy Issues

Application of AI also offers a vast potential for energy saving. The management of electrical grids is becoming increasingly complex as the world shifts towards renewable energy sources such as solar and wind power. This is where AI can play a crucial role. By predicting fluctuations in demand and adjusting the supply accordingly, AI can help balance the grid, prevent blackouts, and increase energetic efficiency. Additionally, AI can optimize the placement and operation of renewable energy infrastructure, such as wind turbines and solar panels, to maximize their energy output. It can also help reduce energy consumption in frozen food transportation by optimizing routes and traffic, reducing fuel consumption, and CO_2 emissions [59]. In manufacturing, AI can optimize processes, identify inefficiencies, and improve energy efficiency to reduce costs. Harnessing the power of AI can work towards a world where energy is used efficiently, waste is minimized, and the reliance on fossil fuels is reduced [60].

There are three technological gaps that hinder the application of AI in energy saving: (a) difficulty in selecting or combining technologies, (b) various energy-saving effects, and (c) AI effects on control characteristics. AI can optimize manufacturing processes and reduce energy consumption by identifying inefficiencies in production lines and suggesting adjustments. It can help you optimize energy sources and automate energy-saving actions. AI algorithms can also predict energy demand and supply, allowing us to reduce greenhouse gas emissions and mitigate the effects of climate change. A universal workflow combining various AI technologies can achieve consistent energy-saving effects by providing qualitative and quantitative recommendations tailored to different application fields by Squeo [61].

As demonstrated above, AI and robotics are poised to revolutionize every aspect of the food industry, from agriculture and manufacturing to distribution, cooking, and the creation of new products and food sorting options, while the application of ML can help optimize various processes and production kinetics, reduce energy consumption, optimize time, and achieve better-quality products [44]. Moreover, AI can assist businesses in developing sustainable processes, products, and services, thus minimizing their environmental impact. Prioritizing the application of AI technologies in the pursuit of a greener, more sustainable future, offers potential to make a significant impact on reducing carbon emissions and slowing down climate change.

However, developing such technologies requires significant scientific and experimental effort. Also, some experts believe that the ability of AI to create new food products is somewhat exaggerated, as the quality and acceptance of food go beyond the quality and quantity of individual basic ingredients [62]. The type, quality, and quantity of additional ingredients, as well as their characteristics that affect the look, smell, taste, and texture, are equally important. As the demand for better-quality, sustainable food grows, there will be an increasing need for suppliers to meet these expectations. Research laboratories and their employees will play an important role in this transformation, where non-rational factors such as taste, colors, aroma, composition, and other sensory and emotionally connotated properties play a vital role.

3. Design of Novel Food

Various organizations and individuals, directly or indirectly involved in food production, distribution, quality control, sales, and market operations, are constantly seeking new ideas to overcome technical challenges and introduce innovative food products. The interpretation of the concept of a new food product varies across the literature. However, in most countries, the legal definition of a new food product is well-defined. For example, in the United States, the Federal Trade Commission recommends that the term "new" should only be attributed to products that have been available on the market through the usual distribution network for a maximum of six months. Despite the passage of time, Ph. Kotler, in his well-known book [63], suggests that new products can be categorized based on their degree of novelty and innovation. These categories include products that create a completely new market and those that enable companies to enter an existing market for the first time, which can be achieved either through horizontal development (by substitution) or vertical development (by quality). Additional products complementing the existing offer, improved and repositioned products for new markets or market segments, are also considered new product lines [64,65].

In the European Union, novel food is defined as food that has not been consumed to a significant degree by humans in the EU before 15 May 1997, when the first regulation on novel food came into force. Novel food includes newly developed and innovative products, as well as those produced using new technologies, traditional foods from outside the EU, and products not consumed before May 1997 [66]. Novel foods must be safe for consumers and properly labeled to avoid misleading consumers. If a novel food is intended to replace another food, it must not be nutritionally advantageous for the consumer. Pre-market authorization of novel foods is necessary based on an evaluation that adheres to the principles mentioned above. In the European Union, the complexities and risk assessments of novel foods are overseen by the European Food Safety Authority (EFSA). When preparing a novel food application, all available knowledge on the novel food should be considered [67].

New foods can be categorized based on their nature or source. Botanical, animal-based, and microorganism-based foods are significant areas of interest, with consumers, policymakers, and the industry increasingly exploring alternative and sustainable dietary choices [68].

3.1. Development of New Food Products

Developing ideas for new food products or secondary versions of existing ones requires a thorough development process to create a mature design. The journey from the initial idea to the final product can be lengthy due to the need to fulfill several requirements at once. The process of introducing an innovation follows a series of steps outlined below (Table 1).

Table 1. Stages in the development of novel foods. Based on Zarba C. et al. [69].

Action	Scope of Activity
Concept	Exploring market needs and technological opportunities.
Analysis	Literature studies. Consultation and observation of similar activities in the past. Pilot, quarter, or semi-technical studies. Analyzing environmental impact (water, energy consumption). Experiencing how to use, describe, and characterize it.
Preliminary tests	Assessing costs, opportunities for innovation and optimization under conditions of incomplete information and uncertainty.
Economic analysis	Analysis and decision to continue or abandon the project.
Implementation	Two-thirds of products reach the industrial production phase.

New products can be created through original designs, modifications, and improvements to existing products. These changes can be in functional, social, or symbolic dimensions and can be accompanied by new services. In the food market, the number of truly innovative products is limited. There are twelve categories of novel food products, including convenient, light, organic, ethnic, healthy, premium, deluxe, delicatessen, nostalgic, purposeful, variant, and truly new [70–72].

According to recent classifications, there are seven conditions that food producers must consider when creating novel products [68]. These include meeting consumer demands and sensory attributes, considering the seasonality of ingredients, sourcing and distributing local ingredients, ensuring the safety and traceability of ingredients and final products, manufacturing the food products on a large scale, and minimizing the environmental impact.

Another six-point model of product innovation was presented by Hittmar et al. [73]. Its components include the following steps: (1) ensuring the information base; (2) realization of organizational changes; (3) the move to lateral changes; (4) the identification of the innovation process and its management; (5) creating a map of the process; and (6) process optimization. Meanwhile, Bigliardi et al. [74] classify three models of innovation implemented in the food industry: technology push, demand-pull, and stage gate. Another interesting model supported by open innovation has been proposed in the early 2000s by Aiking and de Boer [75]. In this model, food design involves applying design thinking to every step of the food value chain. The aim is to promote innovation centered on humans throughout the whole food value chain, from production to disposal.

The development of new food products requires the use of innovative methods and engineering processes that ensure the product properties are unique and environmentally safe. Proper control of nutrient availability, satiety, and overall well-being can influence consumer health. Sensory profiles can also be adjusted, which is important when introducing new raw materials and technologies that can shape food choices and habits. Poor sensory experiences or consumer biases can affect these decisions [76].

As part of the product development process, the screening and evaluation of numerous product ideas is an essential activity. The objective is to identify and shortlist the most promising product ideas with the greatest potential for success. This process is iterative and involves multiple rounds of evaluation, during which the number of product ideas is reduced (Figure 1). As the product design process continues, the expenditure associated with product development increases.

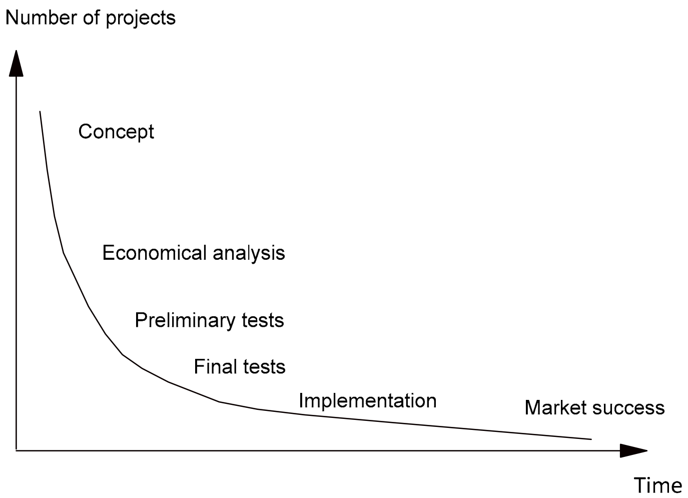

Figure 1. Number of innovative ideas at different stages of the product development process. Source: [77], p. 398.

Establishing connections between the level of achievement in launching new food products and the various factors impacting this level is crucial. To evaluate the success of these launches, one must consider aspects such as market share, sales targets, future profits, technical aspects, company impact and reputation, competitiveness, research and development activities, quality management, implementation speed, and how well the products meet consumer expectations. Steward-Knox and Mitchell argue that "consumer knowledge and retailer involvement are key success factors in food product development" [78]. Costa et al. suggest that both technical knowledge and market information are essential for effective product development [79]. Novel food technologies are important for food security, safety, and sustainability. However, consumers are often hesitant to accept them, as discussed by Siegrist and colleagues [46,80]. It is crucial for food-producing companies to anticipate the inevitable expenses of developing new products, regardless of whether they succeed or fail. The company's top management should play an active role in the product development process by establishing the vision, aligning resources, and rallying support from team members. The most significant methods for finding an idea for a new food product include:

- developing a list of the product's current attributes and looking for possible improvements;
- analyzing relationships between attributes in similar products;
- identifying structural elements of the product (morphological method);
- brainstorming in combination with the Ishikawa method.

New ideas can originate from various sources within and without the organization, such as R&D, distributors, consulting firms, universities, and industry institutes. These ideas help shape the new product and ensure that it is competitive and meets the approval of potential buyers. A combination of intellectual and practical efforts is required to define the characteristics of the new product and ensure it is successful in the market. Thus, the role of R&D representatives has been growing in recent years due to two reasons. Firstly, they are experts in product and technological requirements for its creation, and secondly, they are needed to create a prototype or a model of a new product, select appropriate technologies, raw materials, and compositions to ensure its economic implementation, and make sure the product is attractive and stable for the consumer during distribution and use, and resistant to the variability of conditions [81].

Many companies rely on analyzing their competitors' products to generate new ideas. This can involve purchasing their products and studying their quality features or gathering information from published sources [82]. Such activities are often part of the company's imitation strategy, especially when targeting sales to segments with low. In large companies, the process of developing new food product concepts is typically formalized and includes the following: idea generation, evaluation and screening, market research, product specification, feasibility study, production process development, and prototype development and testing [83]. This is performed to better organize activities, improve management efficiency, and comply with quality management systems such as ISO 9001 and ISO 26000 [84]. Despite the diversity of approaches and positions, the following elements can be distinguished: (1) identifying opportunities and needs, (2) creating an idea to meet these needs, (3) creating a product that materializes the idea, (4) involvement in a variety of activities prior to the start of production, making up the whole.

Several strategies informing the creation process of new food can be adopted by the team responsible. The type of new product strategy chosen is determined by three continuous variables: (1) the degree of innovation in the product (continuous or radical innovation); (2) the type of marketing orientation (demand, customer); and (3) the type of technological orientation (current, completely new, etc.) [77]. The following figure places the variables and the strategies graphically in a 3D space of innovation, marketing, and technology, with final states as corners of a cube (Figure 2).

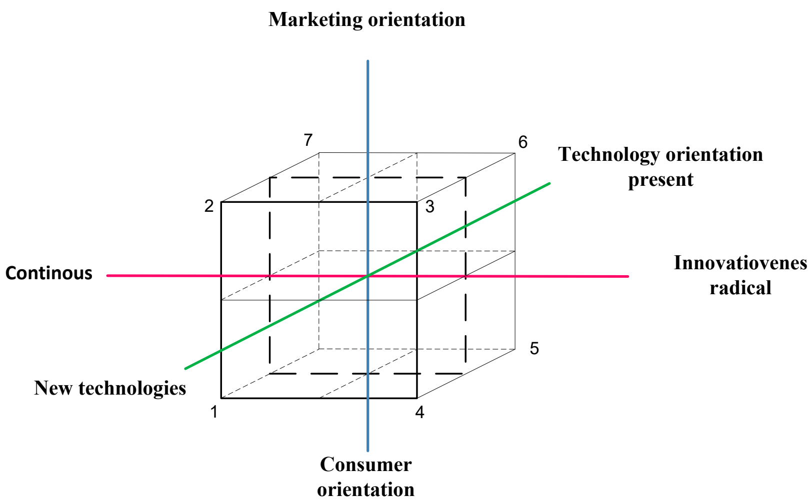

Figure 2. Product strategy space. Source: [77], p. 404.

Strategies 1 to 4 focus on the use of new technology and research for development, while strategies 5 to 8 are more conservative in terms of technology. However, for specific products, these strategies may not be used in their pure form. For example, strategy 4 is consumer-focused and open to radical innovation and new technology. Strategy 6 involves concentric product diversification, which aims to meet the needs of a new group of consumers through radical innovations while utilizing current technology. On the other hand, strategy 8 is about segmental product differentiation. It aims to expand the scope of satisfying the needs of current and new consumers through continuous and dynamic innovations to master new market segments, without the need to change technology.

A selection process for new food product ideas is often conducted using the 'weighted index' method [85–87]. The process of evaluating new product proposals involves assigning scores to each main factor based on their importance: idea generation, concept testing, feasibility (regulations, technology, formulation, ingredients, processing, facilities, packaging, distribution, shelf life, safety, and finance), test marketing, commercialization, or product life cycle. The sum of these scores should be close to 100, and the scores of the sub-factors within each main factor cannot exceed the assigned value. The proposals with the highest scores have the best chance of being implemented. It is possible to modify the list of main and sub-factors based on specific needs.

When selecting a new food product from several options, there are various general factors that need to be considered. These include assessing the legal conditions, determining whether the innovation idea aligns with the product objectives, gauging compatibility with the company's marketing mix strategy (including product, pricing, distribution, and promotion policies), evaluating the idea in relation to the resources available to the company (such as research and development, production, human resources, and financial and managerial capabilities), and ensuring that it aligns with the company's goals, such as fitting in with the current product portfolio and maintaining competitiveness in the market. Factors are scored with weights as percentages, summing to 100%. Proposals scoring below 55% are disqualified, while scores between 70 and 85% are excellent [86].

3.2. Artificial Intelligence in Development of Novel Food

The role of information technology is becoming increasingly crucial in the design processes of new foods. Initially, ICT was used primarily for information and education purposes such as weather reports, crop prices, and monitoring. It also played an important role in improving the food supply chain [88,89]. Over the past decade, AI has brought about significant changes in the food industry. It has helped in devising effective marketing strategies, boosting food sales, and analyzing eating habits and preferences. AI has also played a crucial role in food design, new product development, and predicting health problems associated with food consumption [90]. Furthermore, AI has emerged as a major solution to food waste problems by estimating food demand quantity, predicting waste volumes, and supporting effective cleaning methods through smart waste management [91,92].

Information and computer technology applications can be used at different stages of food product development, including process management, R&D, consumer research (needs, preferences, testing, predictions), market analytics, product design, and post-product marketing. A report issued by the European Food Safety Authority indicates that food safety regulations are expected to undergo a transition towards the utilization of artificial intelligence (AI), with a primary focus on machine learning (ML), for the purpose of real-time big data analysis to assess risks. Based on the intensified cooperation with society, and an increase in the amount of information provided by society, AI will facilitate a much more effective risk assessment [93]. The aim of these methods is to reduce the need for costly and time-consuming physical experiments on foods by using laboratory-designed digital equivalents [94]. Extrapolating big data enables also taking into consideration individual customer feedback and thus creating individualized niche products [95].

However, when it comes to food, naturalness is often viewed positively, while technological applications are seen negatively [80]. In fact, according to multiple sources, approximately 80% of new products developed by large food and beverage companies end up failing [96]. Improving consumer satisfaction is crucial for the success of novel food products, and the challenges and ways to achieve this will be discussed in the following section.

4. Acceptance of Novel Food

It is becoming increasingly important to cater to the demand for sustainable and healthy food products, as well as keep up with societal changes. However, many adults tend to stick to familiar foods due to their past experiences. Recent studies reveal that people's individual preferences have a significant impact on how they react to new and unfamiliar foods [97]. The acceptance or rejection of these foods by consumers depends on several factors, such as their mental traits, values, attitudes, expectations, and dietary preferences. Therefore, product developers must consider these factors during the development process.

The success of a new product in the market depends on its quality, which is determined by the degree of healthiness, attractiveness, and availability of food, considering the raw materials, technology, and price. The most significant characteristics of food that consumers consider during purchase are freshness, appearance, taste, smell, and durability. These characteristics are related to sensory attributes and can be evaluated based on personal experience. Health effects, ease of preparation, fat content, and the absence of harmful substances are also important factors to be considered.

The success factors for new products on the market, besides consumer needs and preferences, also include new trends. As a result, food companies should pay close attention to existing and future trends and may even partner with consumers to develop new products. Additionally, the marketing activities used by the company play a significant role in determining the market success of new food products. Companies must keep in mind that the final consumers ultimately decide whether new products will succeed in the market [98]. Many studies show that specific reasons for product failure include food neophobia, rejection of novel technology, suboptimal stimulation levels, sensory/consumer research limitations, and inadequate marketing support [99,100]. Specifically, Tuorila and Hartmann [97] have identified that traits such as disgust, food neophobia, and related factors can significantly impact a person's willingness to try new foods and become a major barrier to accepting novel food alternatives. In their research, they discuss two new food trends: meat alternatives and products for health and well-being. They conclude that launching new foods successfully requires a thorough understanding of how consumers perceive the product and the traits that determine whether they will accept or reject it. It is noteworthy that packaging design and linguistics have been shown to create an emotional attachment to the product surpassing the effect of taste [101]. This information has enabled innovative technologies to be applied along the agri-food chain in optimization of packaging and marketing materials, including graphics and advertisements. Emerging opportunities, such as new raw materials and technologies that enable prolonged shelf-life, also promote the development of new food products (Table 2).

Table 2. Motives for developing novel foods from the perspectives of consumers and the industry.

Perspective of Consumers		Perspective of Industry
Organic	Personalized nutrition	New resources
Sensory properties	Food variety	Extension of shelf-life
Well-being	Ethical concerns	Business profit
Allergies intolerances	Animal welfare	Technological advances
		Energy consumption

Source: own compilation based on [97].

Meat and meat products have a significant impact on the environment, particularly in terms of water, carbon, and energy footprints. Therefore, it is essential for the food industry to educate consumers about meat substitutes and cultured meat. However, studies show that consumers prioritize sensory properties over environmental concerns [102–104]. To encourage sustainable and healthy diets, food designers can enhance product acceptability using molecular gastronomy principles. In doing so, new food concepts aim to meet consumer expectations in terms of taste, appearance, nutritional value, and health benefits. Product positioning and marketing play a significant role in the development of these concepts, with consulting agencies driving the process. One such start-up, Innogusto, established in 2018, aims to create gastronomic dishes using meat alternatives such as insects, algae, fungi, and microorganisms, to increase the acceptance of these protein sources in the future [105]. Similar strategies have been developed and implemented to tackle food production problems. These include methods to improve agricultural productivity, optimize resource use (such as water, energy, and packaging materials), enhance food nutrition through genetic engineering, produce new alternatives to food and food ingredients (such as cellular cultures, insects, algae, and dietary fibers), and preserve biodiversity. These solutions aim to meet current and future food demands sustainably by optimizing natural resources (water and energy) and restructuring the food industry models [106].

Gathering information from potential and existing clients is crucial for any business to develop new products. There are various ways of obtaining such information, e.g., categorized interviews like survey interviews and uncategorized interviews that can be conducted by sales representatives, interviewers, or distributors, such as wholesalers or retailers. In addition, companies can directly receive feedback from consumers through comments, opinions, and suggestions, which can be sent via post or telephone, such as a dedicated customer hotline. Additionally, it is important to analyze customer complaints using the Deming PDCA cycle and the model proposed by Kano in 1984 [107]. In his book, Kano investigated the correlation between the level of expectation, performance, and the resulting satisfaction when it comes to food products (Figure 3). These expectations vary over time and depend on many internal and external factors. New products appearing on the food market are located in a three-dimensional space of satisfaction, expectation, and performance.

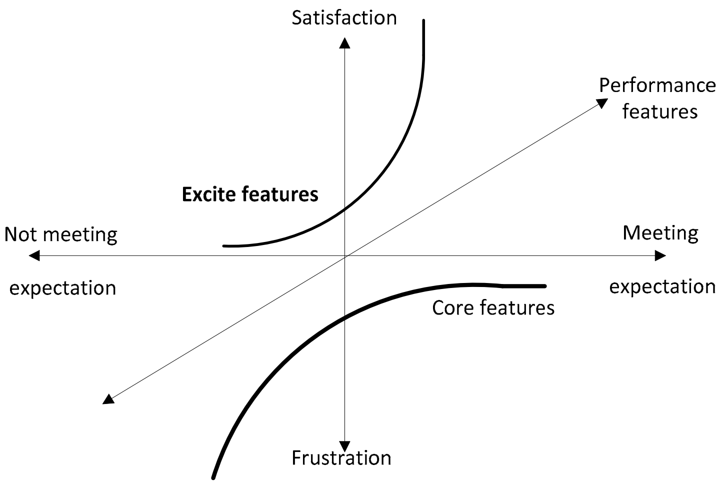

Figure 3. Kano model of the relationship between customer satisfaction, expectation, and frustration. Source: own drawing based on [107].

The classic PDCA cycle can be used to improve and better tailor a new product to the needs of customers [108]. The product idea and strategy undergo both informal and formal verification processes. Expert panels, consumer tastings, and sensory analysis specialists test the best variants, which are then subject to further studies. The evaluation includes measures of consumer acceptance, uniqueness, and expected sales frequency defined by the manufacturer, as well as sensory qualities such as taste, smell, and overall experience.

Sensory attributes of food have been and still are [109,110], intrinsically linked to its attractiveness and, to a large extent, to its healthiness and are absolutely necessary at all times when evaluating the concept of a new product and in the different phases of its implementation. According to Moskowitz [87], the sensory analysis should be used in the following instances: in preliminary work to identify the sensory attributes that create the image of a product; to demonstrate the imperfection or sensory mismatch between currently produced food, the preferences, and needs of the consumer in a given market; to create a product formulation that corresponds to the concept or intended image; or to capture the combination of conceptual elements that correspond to the product. According to Schifferstein [111], in order to attract customers in markets with high competition, products should not only be of good quality and visually attractive, but they should also offer interesting and engaging experiences. Therefore, it is important that research on sensory evaluation is connected to research on product aesthetics, meaning, and emotions. Last but not least, trust is a crucial element when it comes to accepting new products, especially food. A strong level of trust in the producer or brand, along with established systems for tracking the ingredients and products (traceability), is essential for increasing the acceptance of the product. According to research, higher levels of trust are directly proportional to higher levels of product acceptance [62].

During the development phase, it is crucial to experiment with the product on a small scale. This involves formulating the product to ensure optimal nutritional value, shelf life, and packaging proposal. Sensory tests are conducted during this phase, using trained individuals, as well as consumer tests, to ensure the product meets their expectations [109,110]. The objective is to develop a product that satisfies consumer expectations in a particular market. During this phase, various aspects such as taste, appearance, consistency, and smell are fine-tuned by making small adjustments to the composition, concentration of components, and production and technological conditions. Before finalizing mass production, a prototype of the product is put through a marketing test to gauge consumer response to factors such as price, packaging, advertising, promotion, distribution, and to assess its shelf life [112]. The response of the test markets is a good indicator of how the market as a whole will receive the new product. Completing all the above stages successfully is necessary before deciding to move forward with production. Depending on the previously chosen strategy, the manufacturer will need to spend money on technology and marketing, prepare for production, and launch the product on the market. This marks the beginning of the new product's life cycle.

5. Conclusions

Energy security and conservation are crucial topics for sustainable development. With the growing world population and the food sector already accounting for a significant amount of energy usage, there is a clear need for a deeper understanding of how new foods can enhance energy security. The review delves into the potential impact of new food products on enhancing energy security in line with the Sustainable Development Goals (SDGs). Specifically, the current state of research on the interplay between technical progress and know-how in creating and developing novel food products has been examined and factors for consumer acceptance and market success for new foods presented.

It has been found that novel foods and innovative production techniques can reduce the need for energy at various stages of the food production chain while also leading to an increased diversity of production and better product quality. In the last ten years, AI has significantly impacted the agri-food industry by promoting crop sustainability, optimizing processing, devising effective marketing strategies, boosting food sales, and analyzing eating habits and preferences. It has also played a crucial role in food design, new product development, maintaining health and safety systems during transportation, managing food and energy waste, and predicting health problems associated with food consumption.

Although some authors believe AI can or will soon be able to design new food products, we present a more comprehensive and human-oriented overview of design and development methods for novel foods and reducing energy consumption and propose a model for stimulating the development of novel foods, along with scenarios for practical application.

It is important to note that the vast majority of new food products do not succeed on the market, with consumer acceptance being the critical factor. Low acceptance can be attributed to various aspects, including food neophobia, rejection of new technology, suboptimal stimulation levels, poor sensory/consumer research, and inadequate marketing support. Therefore, the food industry must consider these factors and invest in trustworthy food information systems and brand-building to gain consumer favor and trust. Another challenge in designing and launching novel energy-efficient food products is the need for collaboration between academia, laboratories, technology experts, marketing specialists, food agencies, and various governmental and non-governmental organizations involved in legal and promotional aspects of food production.

The findings support that novel food products have the potential to improve food and energy security. Upon conducting a systematic review of secondary sources, little research was found regarding the use of AI to lower energy consumption in novel food. Each author's study proposes a unique solution, leaving the research problem open. With many authorities, research centers, and food and energy producers interested in the subject of novel food, there is a need for further research on the impact determinants of these new food products on energy security and their marketability. This research should consider economic, technological, social, and environmental aspects in order to gain a more comprehensive understanding of the potential offered by novel food.

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