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Future Expectancy of Technology Developments in some Types of Lipids

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Abstract. Lipids are biomolecules that are important research topics in biology, energy use, and engineering. As organic compounds, lipids play a crucial role in biological systems and human activities. This paper provides a comprehensive overview of the development of lipids in modern technologies (3D-printed food technology and biodiesel fuels) and prospects for future exploitation. It is shown that lipid-based 3D printing technologies enable customized food production, but face material and cost challenges. Biodiesel fuel blends offer environmental benefits, but struggle with low-temperature performance and high costs. Meanwhile, the combination of 3D printing technology with medical science offers great potential for personalized medicine and tissue engineering, but is also limited by protein stability and high-tech costs. By analyzing these technologies, this study provides a theoretical basis for advancing lipid-related technologies and addressing energy, food, and medical issues.

Keywords: Lipids, 3D food printing, Biodiesel Blended fuel, 3D protein printing

1. Introduction

Since scientists first isolated lipids in the 19th century, the study of these structurally diverse, water-insoluble organic compounds has grown exponentially. As important macromolecules in living organisms, lipids are core components of cell membranes (e.g., phospholipid bilayers form cellular barriers), efficient energy storage carriers, and key mediators of signal transduction. From the ubiquitous structure of biofilms in nature to the waxy waterproofing layer on paper cups in industry and edible oils in food processing, lipids have demonstrated extraordinary value in biological systems and human life due to their unique physicochemical properties, such as amphiphilicity and low polarity. The lipid family consists of more than 100,000 structural derivatives, which can be broadly classified into energy storage lipids (e.g., triglycerides), structural lipids (e.g., phospholipid), and functional lipids (e.g., sterols) based on their chemical composition and functional properties [2]. This study focuses on the two most promising types of energy storage lipids, fats and oils, and explores their direction in future technological development. These substances not only serve as energy reserves for living organisms, but also become a research hot spot in the fields of bio-energy, materials science and medical engineering due to their renewability, modification and bio-compatibility.

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This paper uses an integrated research approach combining literature review, case studies and exploration of technological principles to investigate the use of lipids in modern and future technologies. The aim is to reveal the current state of the art, advantages and challenges of lipid-based applications and to forecast future trends. The significance of this research is to provide theoretical guidance to promote sustainable development in the fields of food, energy and medicine, and to explore new solutions to global problems such as energy shortage and healthcare.

2. Modern technology developed of fat

2.1. Fat-based 3D printed food technology

2.1.1. Technology development and applications

In 2011, a team of researchers at Cornell University developed the first 3D food printer to print chocolate products containing cocoa butter using a fat-based material as the print substrate [1]. The study also found that by precisely controlling the melting point of the triglycerides (e.g. mixing the ratio of palm oil to tallow), the shear-thinning behaviour of the printing slurry could be adjusted to enable the lamination of complex structures. In 2013, the National Aeronautics and Space Administration (NASA) applied fat-based 3D printing to space food preparation and developed a printable material with a backbone of hydrogenated vegetable oils in combination with freeze-dried meat extracts. The problem of lipid oxidation in long-term storage was addressed, and precise protein-fat-carbohydrate nutritional regulation was also achieved through modular fat rationing [3].

The core technology of commercial devices such as Natural Machinery's Foodini (Figure 1) lies in the development of a fat-based binder, which forms a thixotropic gel matrix by compounding olive oil with modified soya lecithin. This allows the printing paste to maintain some fluidity during extrusion and to cure rapidly after moulding to maintain structural stability [4]. This technique is particularly well suited to simulating meat products with high fat content, where a fibrous structure similar to that of natural muscle can be constructed by stacking fat-protein composite pastes layer by layer, significantly enhancing the textural authenticity of plant-based patties.

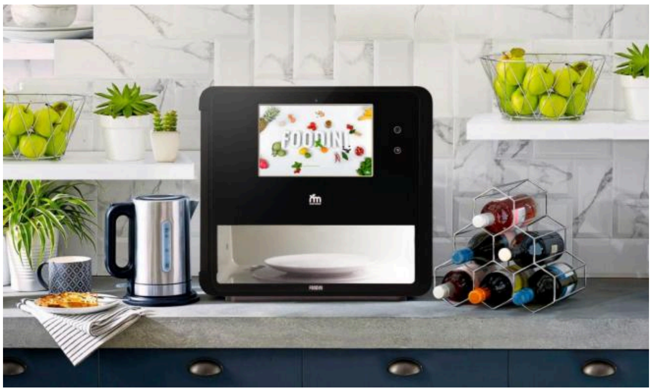

Figure 1. A concept map of the Foodini printing machine [5]

2.1.2. Key mechanisms of action of fats

The thermoplastic properties of fats (melting point range of 40-60°C) make it an ideal substrate for 3D printing. At temperatures above the melting point, fats are liquid and ensure paste flow. After cooling to temperature, they solidify rapidly, providing mechanical strength for inter-layer bonding

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[3]. In addition, rather than being a carrier of fat-soluble vitamins (A/D/E/K), fats are an important source of food flavour through its oxidative degradation products (e.g., aldehydes, ketones). In space food printing, encapsulation of fish oil in a palm oil matrix by microencapsulation technology enables slow-release release of omega-3 fatty acids while avoiding rancidity caused by direct exposure to oxygen [6]. Meanwhile, by adjusting the fat crystal type and fatty acid composition (saturated/unsaturated ratio), the organoleptic properties of the printed food can be precisely controlled. For example, high oleic sunflower oil (unsaturated fatty acids > 80%) reduces nozzle clogging when used to print sauces, while lard (saturated fatty acids > 40%) is more suitable for constructing confectionery substrates that require a solid structure [3].

2.1.3. Advantages and challenges

'Print-on-demand' is achieved through the instant mixing of freeze-dried fat powders with liquid print carriers, extending the shelf life of high-fat food products from the 30 days of traditional processing to more than 6 months. The longer shelf life is particularly applicable to the use and storage of supplies in emergency disaster relief scenarios. Additionally, since printed ingredients are 1/5 the size of the finished product, it is possible to increase the quantity and efficiency of a single shipment in disaster relief scenarios. In terms of customized nutritional planning, the fat distribution of the printed layer can be algorithmically controlled for low-fat dietary needs so that the fat content in localized areas can be reduced while the overall taste remains unchanged [7].

However, there are limitations in the suitability of the printing materials. Currently, as the melting point of printing materials is 30-50°C, fat systems with 20%-50% solid fat content can be better suited for printing. However, fish oils, which are rich in polyunsaturated fatty acids, have a melting point of <-30°C and need to be modified by transesterification before they can be used, which increases the overall production cost [6]. In terms of flavor fidelity, higher-temperature printing processes (>60°C) may lead to fat oxidation, producing undesirable flavors. Studies have shown that the thiobarbituric acid reactivity values (TBARS) of meat fats increased by 23% compared to conventional cooking when printing temperatures exceeded 55°C, and therefore the flavor of the food could not be restored 100% [3]. Furthermore, in terms of energy consumption, high-precision fat printing requires a temperature control accuracy of ±0.5°C, which results in energy consumption that is three times higher than that of conventional 3D printers, and the cost of a single Foodini device is still more than $20,000 [4]. The Foodini device can be used for a variety of purposes, such as the production of meat fats and the production of meat products.

2.2. Biodiesel blended fuel

Biodiesel blends fuel are new fuel systems formed by blending biodiesel with conventional fossil diesel in specific proportions. As a typical fat-based energy conversion product, its core component, fatty acid methyl ester (FAME), is produced from vegetable oils (e.g., soybean oil, palm oil), animal fats (e.g., tallow, lard), or waste catering oils through transesterification reactions. This energy conversion technology based on the molecular structure of triglycerides not only realises the functional expansion of lipid molecules from energy storage carriers to power fuels, but also constructs a closed-loop economic model of 'waste fat recycling - chemical conversion - energy utilisation. Biodiesel blends can be classified into different types according to the concentration of biodiesel and conventional diesel, such as B5, B10, B20. B5 blends have a concentration of 5% biodiesel and 95% conventional diesel. B10 blends have a concentration of 10% biodiesel and 90%

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conventional diesel. As well as, B20 is a blend with a biodiesel content of 20% and a conventional diesel content of 80% [8].

2.2.1. Application

Biodiesel blended fuel have many application since it is economic, environmental friendly, lubricity. In deep-sea vessel applications, the use of biodiesel blends reduces pollution and biodiesel blends provide more energy than conventional fuels. Although the overall proportion of deep-sea vessels using blends is relatively small at present, this proportion will gradually increase. In Public transportation, an increasing amount of public transportation such as bus and trains start to use biodiesel blended fuel as an alternative to traditional diesel fuel. For example, up to 2017, around 34% of the bus in England use biodiesel blended fuel. Using biodiesel blended fuel can reduce the carbon dioxide released and increase the air quality. In addition, in diesel generator scenarios, B20 fuel exhibits unique advantages in that its higher cetane number (>50 vs. 45-50 for diesel) reduces the fuel ignition delay period, shortening the generator start-up time from 15 seconds to 8 seconds. Meanwhile, biodiesel's oxygen content (10%-12%) promotes complete fuel combustion, reducing carbon monoxide (CO) emissions by 35% in emergency power generation scenarios [9].

2.2.2. Advantages

Biodiesel blends are remarkably environmentally friendly, with blends emitting significantly less carbon dioxide compared to conventional diesel. This is mainly due to the fact that the biodiesel feedstock (e.g., vegetable oils, animal fats) absorbs carbon dioxide through photosynthesis during growth or metabolism, creating a carbon cycle. In addition, the higher oxygen content of biodiesel during the combustion process leads to a more complete combustion of the fuel, effectively reducing the emission of nitrogen oxides (NOx) and particulate matter (PM), thus contributing to the improvement of air quality. Meanwhile, biodiesel blends are renewable and sustainable. This is because the feedstock for biodiesel fuel comes from a wide range of renewable sources, including vegetable oils (e.g., soybean oil, rapeseed oil), animal fats, and so on.

Furthermore, biodiesel blended fuels are characterised by high lubricity, which effectively reduces friction loss between engine mechanical parts and prolongs the maintenance cycle and service life of the engine. Biodiesel blends have high compatibility with engines. Below a B20 concentration, biodiesel blends can be used directly without any modification to existing diesel engines. This feature greatly reduces the threshold of technology application and makes the transition from conventional diesel to biodiesel blends easier [10].

2.2.3. Disadvantage

The high proportion of long-chain saturated fatty acid methyl esters in biodiesel leads to the formation of crystalline networks at low temperatures, which significantly reduces fuel mobility. As a result, biodiesel blends have poor low-temperature performance and are prone to clogging of the engine oil circuit in cold regions. To improve this problem, anticoagulants or low saturated fatty acid feedstocks are usually required, but this undoubtedly increases the production cost and technical complexity.

As well, the production cost of biodiesel is relatively high because the raw materials required for the production of blended fuels are plants and animals. Taking soybean oil as an example, its price fluctuates considerably due to factors such as crop yield and market supply and demand, thus

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directly leading to price fluctuations in cost. In addition, energy consumption, catalyst costs, and by-product treatment during the production process further push up the overall production costs.

In addition, biodiesel has weak oxidative stability. The high content of unsaturated double bonds (e.g. methyl linoleate) in biodiesel makes it susceptible to auto-oxidation during storage, resulting in higher acid values and colloidal precipitation, which affects the quality and performance of the fuel. Normally, additional oxidation inhibitors have to be added to meet international standards, which undoubtedly increases production and storage costs. The addition of antioxidants may pose new environmental and health risks, which need to be further investigated and evaluated [10].

3. Future expect on the development technology of fat

3.1. Trends

Despite the challenges faced in the practical application of biodiesel blends, they have become an important development in the future energy system due to their remarkable environmental friendliness and clean combustion characteristics. Compared to the large amount of greenhouse gases and pollutants produced by conventional diesel combustion, biodiesel has gained a wider scope of development due to its carbon-neutral property, which means that the carbon dioxide produced during combustion does not add to the total amount of carbon dioxide in the atmosphere. The chemistry equation of the process of burning biodiesel is shown as [10]:

$$C19H36O2 + 27O2 \rightarrow 19CO2 + 18H2O \tag{1}$$

$$\Delta H = -11,000kJ/mol$$

The chemistry equation of the process of burning traditional diesel fuel is shown as:

$$2C12H26 + 37O2 \rightarrow 24CO2 + 26H2O \tag{2}$$

$$\Delta H = -7,510kJ/mol$$

Compared to equation 2, equation 1 produces lesser carbon dioxide and have a smaller ΔH which means that it produces more energy. Currently, the research and development of new diesel fuels focuses on two main directions, which are reducing greenhouse gas emissions and improving energy conversion efficiency. In order to reduce greenhouse gas emissions, multiple strategies are being used. The first approach is to change the type of fuel, for example, from the use of traditional diesel fuel ($C_{12}H_{26}$) to biodiesel fuel ($C_{19}H_{36}O_2$), which significantly reduces carbon dioxide, carbon monoxide and particulate matter emissions [9].

Secondly, by optimising the selection of feedstock and molecular design, the development of cleaner biodiesel costs to reduce greenhouse gas emissions. Taking methyl oleate (Methyl (9Z)-octadec-9-enoate) as an example, as a typical biodiesel fuel, methyl oleate is carbon-neutral, which means that combustion of this fuel does not have a large negative impact on the environment. This is because the raw vegetable oil absorbs carbon dioxide from the atmosphere during the growth process, and the carbon dioxide produced in the combustion of the resulting vegetable oil will be equal to or close to the carbon dioxide absorbed by the plant, making it truly carbon neutral [10].

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3.2. Prospect

In the future, the development of new diesel fuel will show three main technical characteristics, environmental protection, low cost, and high performance. On the basis of the continuation of the low-carbon advantages of biodiesel, the new fuel will further reduce the emission of nitrogen oxides and other harmful gases. Current research focuses on the development of biodiesel derivatives with higher oxygen content and more stable molecular structure, such as medium-chain fatty acid methyl esters (MCFAME) prepared by transesterification reaction. In addition, the use of nanocatalyst technology promotes complete combustion of fuels and reduces unburned hydrocarbon and carbon monoxide emissions for synergistic control of all pollutants.

In terms of production cost competition, the high production cost of biodiesel severely restricts its large-scale application. The cost of producing biodiesel fuel is about two to three times that of conventional fuel, which costs about $1.39 per gallon, compared to $5.53-$6.38 per gallon for biodiesel. New fuels will reduce costs through innovative feedstock sources and production processes.

The new diesel fuel will have enhanced lubricity and higher energy density. Optimisation of the fatty acid chain structure through molecular engineering technology will improve the lubricity of the fuel and significantly reduce the wear and tear of engine parts. At the same time, the introduction of high energy density biosynthetic fuel components will increase the calorific value of the fuel, which will significantly improve engine power output and range.

The new diesel fuel of the future will be a perfect blend of environmental friendliness, economic viability, and high performance. Through interdisciplinary technological innovation and the integration of cutting-edge achievements in bioengineering, materials science, and chemical engineering, it is expected to break the technological bottleneck of traditional fuels and provide sustainable energy solutions for green transformation.

3.3. Combination of 3D printing technology with medical science

Continuous breakthroughs in 3D printing technology and rapid development of biomaterials science have pushed protein 3D printing from theoretical conception to clinical practice. As the core functional molecules of life activities, proteins are endowed with highly specific biological functions by their four-level spatial structure (primary sequence, secondary helix/folding, tertiary structural domains, and quaternary multimer). Currently, by analysing the three-dimensional crystal structure data of proteins and combining it with 3D printing technology, the precise construction of tertiary protein structural units has been achieved [11].

3.3.1. Application

Personalised drug customisation In tumour-targeted therapy, 3D protein printing technology can fuse monoclonal antibodies with nanoliposomes, and form composite protein carriers with gradient release characteristics by regulating the printing parameters. In addition, for rare diseases, specific enzyme proteins can be customised according to the patient's genetic defects, solving the adaptability problem of traditional mass-produced drugs.

More cutting-edge applications include the printing of ‘bioinks’ containing protein-nucleic acid complexes, enabling the spatially specific delivery of gene editing tools (e.g., CRISPR-Cas9 proteins) and opening up new pathways for gene therapy. In addition, nutritional medicine and precision health target the nutritional needs of special populations, 3D protein printing can

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customise functional protein powders enriched with specific amino acid sequences. For people with food allergies, safe nutritional supplements can be developed by printing ‘desensitised proteins’ with the structural domains of allergenic proteins removed [12].

3.3.2. Advantages and challenges

Industrial-grade 3D protein printers can produce gram-scale customised proteins within 24 hours, dramatically shortening the production cycle. Also, by changing print templates and bioink formulations, protein products can be quickly switched to produce different functionalities. At the same time, 3D printing enables structural reproduction with nanometer precision, ensuring the biological activity of the printed protein. With a footprint of less than 1.5 square metres, the modular 3D printing device is particularly suitable for space-constrained clinical laboratories and remote sites.

However, the thermal sensitivity and conformational fragility of proteins make them difficult to store. At room temperature, the half-life of printed proteins is only 2-3 days. Even at ultra-low temperatures of -80°C, prolonged storage results in a 15-20% loss of activity. Current solutions include the development of glassy protectants and lyophilisation-recombination techniques, but this also significantly increases production costs. Moreover, the high acquisition cost of a single high-precision bio-3D printer, together with the high cost of the accompanying structural analysis equipment and the raw materials required for printing, limits the widespread adoption of the technology [13].

4. Conclusion

This review summarises the multifaceted applications of fats and oils in emerging technologies, highlighting their transformative potential in food science, energy and medicine, while acknowledging the ongoing challenges. Fat-based materials utilise the thermoplastic and emulsifying properties of triglycerides to 3D print food products, enabling innovations in lipid-based foods. However, limitations in lipid types and cost issues have restricted the popularity of this technology. In addition, biodiesel blends can better reduce greenhouse gas emissions and drive towards carbon neutrality compared to conventional fuels. However, due to technical barriers such as poor low-temperature fluidity and high production costs, future breakthroughs in feedstock innovation and catalytic processes are necessary. In terms of future directions, the convergence of 3D printing and medical science holds promise for personalised protein therapies. However, the instability and excessive cost of proteins pose a huge obstacle.

In conclusion, lipids are multifunctional precursors for sustainable technologies, but realising their full potential will require concerted efforts to overcome technical and cost barriers. By fostering cross-cutting innovation, lipids can drive a paradigm shift towards circular, low-carbon solutions in food, energy, and healthcare.

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