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Review Article

Application of 3D Printer in Food Packing and Technology

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Abstract: With increasing the human population and the advent of a machine-driven lifestyle, the use of modern technologies has created multiple ways to make human life easier. Among these, people are seeking to produce and consume food through various methods that minimize waste and pollution while ensuring safer and more convenient food production. One of these innovative solutions is the use of 3D printers in modern food technology and packaging production, which can significantly reduce pollution and waste. Initially, the focus will be on edible inks, their characteristics, and how 3D printers work with edible inks and extrusion. Then, the feasibility of essential components of food, including carbohydrates, proteins, and fats for 3D printing of food products will be discussed. Finally, the article will cover the production of food packaging and its various types using 3D printers. 3D printers represent advanced technology that has recently entered the food industry and food packaging. Also, this technology is particularly useful in the packaging sector. The aim of this paper is to enhance familiarity with the use of 3D printers in food packaging and food technology.

Keywords: Food Packaging, Food Technology, Edible Ink, 3D Printers, Extrusion.

INTRODUCTION

3D printers can be used successfully in the food industry for the production of 3D foods with complicated geometric shapes, personalized texture, and appropriate nutritional value. The first applications of 3D printers started in the early 2000s. The most important applications of 3D printing in the food industry, which is based on the technology of extrusion, involves some printable native materials such as cereal derivatives and chocolate. On the other hand, advantages of these printers include microbiological contamination, migration of toxic substances, color, and print clarity limitations due to printer components, and high costs of edible inks. However, sufficient cleaning and use of food-contact-approved materials make the printers comply with the necessary safety standards effectively [1, 2]. The major challenge is consumer acceptance, as these foods are 3D-printed and look strange. Regarding the legal view, 3D-printed foods have to be classified as "novel foods", which is considered a great opportunity to work on novel business strategies while increasing sustainability for the supply chain of food [1]. Great innovations in the food industry have been noticed concerning the printing and packaging of food. Edible ink is an innovative development that is changing the face of the food industry. It comes with a package deal for customized, aesthetically appealing, and safely printed foods. Edible ink consists of components that are food-grade and can be printed on cakes, cookies, and bread, among other food surfaces [2, 3]. This technology helps the food industry manufacturers to give unique designs, patterns, and logos to the foods, making it more visually attractive and communicative for the end consumer. Edible inks are special inkjet inks approved by the FDA for human consumption. They are deposited onto the surface of food through special printers, which print various designs onto layers of food [2]. From a functional point of view, 3D printing is the process to build complex solid geometries by layer-by-layer construction and then adequately bonding them together.

As the processing technology develops, this technology will give consumers a new taste experience [4]. In addition to these, packaging industries contribute much to environmental and economic burdens: packaging design, raw material procurement, and end-of-life processing. There are various definitions of packaging given in the literature, usually as a final product with appropriate structure to protect packaged items from harmful external factors and physical damage. Packaging improves freshness and shelf life of the product, facilitates transportation, storage, sale, and use. It also conveys aesthetic content information to consumers and involves economic features [5, 6] In this regard, the 3D printing process for making smart packaging and devices has developed multi-functional smart components that are highly sensitive using biocompatible and non-toxic materials with a lower cost compared to the traditional way of manufacture. Affordability offers better accessibility to smart food packaging for a larger audience, which can reduce food waste and prevent unsuitable food products from reaching the consumer [7]. In the last couple of years, 3D printers have been used in a broader way. Commonly, such printers rely on digital models where mechanisms print layer by layer from powdered materials to metals, plastics, and any other adhesive substance until the desired composition is attained [8].

Edible Inks and Their Characteristics; How 3D Printers Work with Edible Ink and Extrusion

A. Edible Ink and Food Colors

Edible ink is normally formulated to work with a specific kind of printer, either an inkjet printer or a printer especially built for edible inks, and the formulation of edible ink itself depends upon the nature and type of printer and printing technique involved. However, there are some ingredients which are generally common in edible inks. Edible colors or food colors, according to Hakim *et al*., are some dyes and pigments used for adding color to food and beverages. Generally, it is used in small amounts to enhance appearance. The food industry is greatly impacted by edible colours, which make food products more appealing. Their use is extensively in a variety of food items, such as baked goods, confectionery, dairy products, beverages, and processed foods [2-9].

B. Extracting Natural Colour, Developing Edible Ink

Hakim *et al*., demonstrated that out of various methods, the solvent extraction method is the most appropriate technique of extracting natural colors. The various organic solvents used in this process include ethanol, methanol, acetone, chloroform, etc. The color source, which is usually a plant material, is chopped into small pieces, chipped, and then boiled at high temperatures with the aim of extracting the pigments from the plant material. Filtration is done through centrifugation.

The filtered liquid is concentrated in a hot air oven. After maintaining at -20°C for 24 hours, freeze-drying at -70°C gives the powder of the concentrated liquid, (as shown in Figure 1) [10].

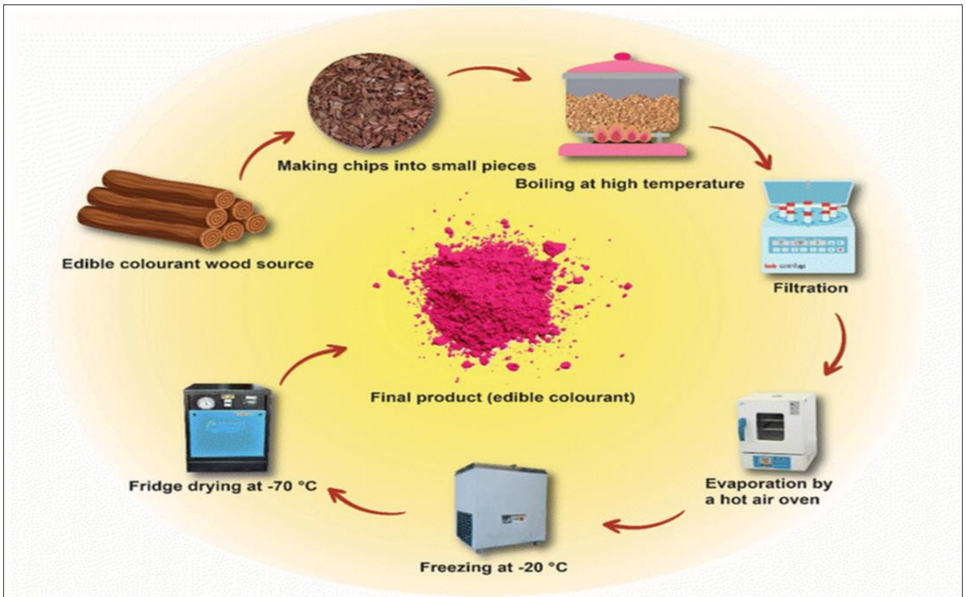

Figure 1: Steps involved in the extraction for color to produce edible ink

After extraction, natural colors can be used in the production of edible ink. However, there are many steps involved as reflected by the diagram below, Figure 2. Schematic diagram representing food color transformation into edible ink.

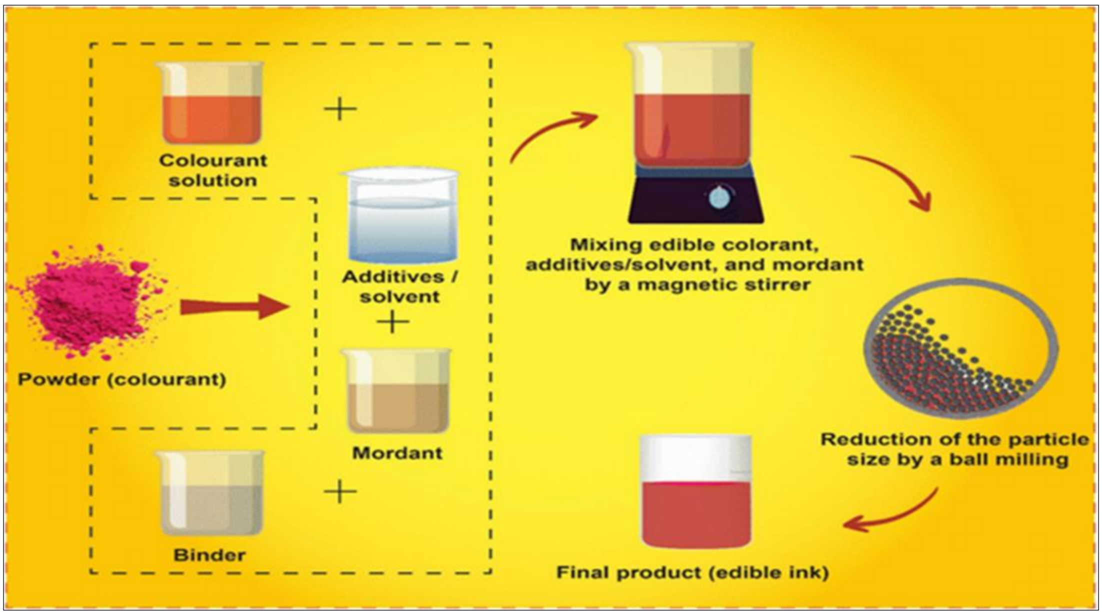

Figure 2: Schematic representation of the extraction and production process of 3D printer edible ink [2]

C. Antimicrobial Activity of 3D Printer Edible Ink

Antimicrobial activity is of great importance in active packaging because it tends to:

- Extend the freshness and shelf life of food,
- Prevent foodborne illnesses,
- Utilize appropriate packaging materials and techniques,
- Enhance food safety,
- Reduce production and consumption waste, and
- Formulate eco-efficient packing alternatives.

Experimental results signify that edible ink possessed great antimicrobial effect against microorganisms such as Escherichia coli and Staphylococcus aureus. Edible ink has many valuable qualities. It is non-toxic, cheap, accessible, and prolongs the shelf life of food by protecting it from microbial growth and oxidation. Red beet and cabbage are popular plants for producing natural ink and possess antibacterial features while being widely used in natural dyeing processes.

D. Working of 3D Printers with Edible Ink

The basic principle of inkjet printing is controlled deposition of droplets of the material. It also involves a powder-based technique wherein layers of solid particles are bonded together using the printer.

The printer head can be used in piezoelectric or thermal mechanism:

- Thermal Heads: The heating system develops enough pressure for the droplets to be ejected at the nozzle.
- Piezoelectric Heads: A piezoelectric actuator divides the liquid into droplets, ejecting them at precise intervals. This allows printing cookies, cakes, and pastries Figure 3 [4].

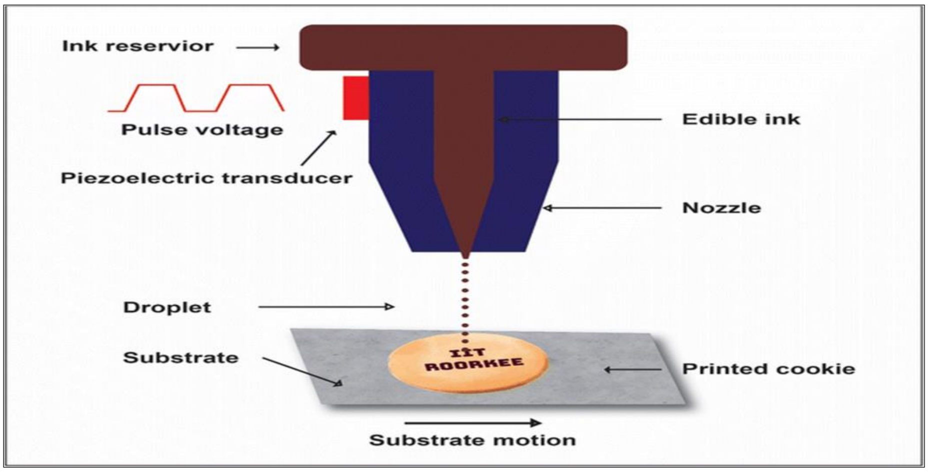

Figure 3: Schematic of a 3D printer using edible ink.

E. Working of 3D Printers Using Extrusion Technology

The printing based on extrusion is performed by loading the layers via a movable syringe nozzle that is filled with material. In this method, every layer is extruded and, after cooling, it bonds with the previously laid layer. This approach is user-friendly and can be used to print liquid and semi-solid materials. The motors coupled to the printer heads provide the motion for the syringe, while the hydraulic piston directs the material with enough force to deposit layer by layer. Some formulations require the individual layers to be bonded through post-deposition processes like baking, cooling, or hydrogel formation (Figure 4) [4].

Among the advantages of this type of printer in the studies conducted by Igor *et al*., are:

- Save time and energy,
- Enhancing the nutritive value of food materials.

However, the food safety of the products made by 3D printers is less explored. It was also pointed out that raw fruits and vegetables are not suitable for printing directly because they cannot be printed. To make them printable dough, flow behavior and viscosity have to be improved by using additives. Common additives used include hydrocolloids, hydrogels, and others [11].

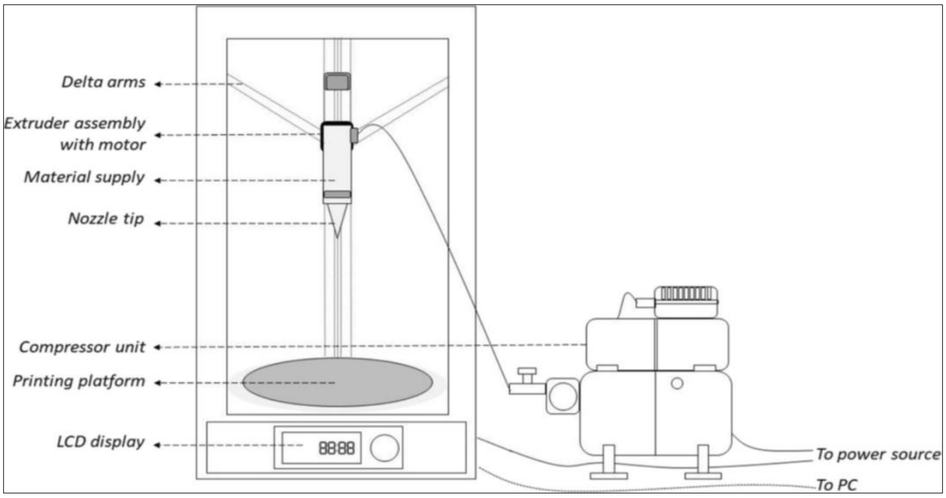

Figure 4: Schematic of an extrusion-based 3D printer [4].

Feasibility of Key Food Components for 3D Food Printing

According to Fernanda *et al*., the design of 3D food structures using the AM technique strongly depends on the properties of materials and the bonding mechanism. In recent times, considerable effort has been directed toward achieving desirable characteristics in 3D structures. Food materials should flow easily during deposition, with their structure maintained during or after the process. The change in the ratio of proteins, carbohydrates, and fats affects the melting behavior, glass transition state, and plasticization of food materials during liquid- or powder-based 3D printing processes [12].

Zhenbin *et al*., revealed three challenges in their research related to 3D food printing:

1. Print accuracy and precision,
2. Process efficiency,
3. Value addition of colourful and multi-flavoured products [13].

A. Carbohydrates: First Major Essential Component of Food

According to the studies by Godoi *et al*., carbohydrates comprise a broad category of types, including simple sugars, such as glucose, and disaccharides, including sucrose and lactose, oligomers, and maltodextrins. Carbohydrates of high molecular weight are usually not printable, but their issues can be solved through modification or addition of water or gelling. In AM technology, particle systems used in powder-bed fusion processes are key components consisting of sugars. Using a heat source, which is dependent on the melting point range of the material, continuous interaction between layers is created. Nachal *et al.,* also noticed that, among carbohydrates, especially starches, contribute much to the extrusion and help to maintain structural integrity in the post-printing process, if their content exceeds their gelatinization point. Regarding carbohydrate fractions, Tg is one of the critical parameters for giving material stability. The high molecular weight carbohydrates, for example, maltodextrin have higher Tg compared to simple sugars such as fructose, Tg ~ 31°C [4-12].Mohammad *et al*., have stated in their work that, during glass transition, a phase change occurs from a glassy to a flexible and elastic state. Additionally, this transition temperature has a great influence on transport and physicostructural properties of foods [14, 15].

B. Proteins: The Second Major Component of Food

Food proteins consist of amino acids with both negatively and positively charged functional groups.

Protein polymers can carry positive or negative charges depending on the pH of the solution and the isoelectric point (pI) of the protein. Godoi *et al*., showed that the isoelectric point is where proteins tend to aggregate, a property quite useful for the AM processes influenced by particle-based gelation mechanisms and hydrogel formation. New textures will be able to be fabricated based on this approach by layering food proteins with polysaccharides such as gelatin and alginate. Nachal *et al*., underlined the role of proteins in the microstructural and textural properties of 3D-printed foods, highlighting protein aggregation, which assists printing processes controlled by mechanisms of gelation and hydrogel formation [4-12].

C. Fats: The Third Major Component of Food

Fats are composed of three fatty acid molecules and one glycerol molecule, also known as triglycerides. According to Godoi *et al*., the composition and structure of triglycerides have impacts on the AM material formulations and functional properties, including melting point range and crystalline structure. For example, the quality of meat, in terms of texture, color, and shelf life, is highly related to the composition of triglycerides. Nachal *et al*., discussed how fat composition influences the organoleptic and physical properties of 3D-printed foods. They also noted that solutions to prevent melting of printed products have been developed by modifying fats and using fat substitutes [4-12].

3D Printing of Food Packaging

3D printing can be considered one of the innovative technologies for the packaging of food. According to Witek *et al*., there are three important uses of 3D printing in packaging:

1. **Active Packaging:** It involves the addition of chemicals that absorb the unwanted elements, which will help the food products to stay fresh for a longer period. Antimicrobial and antioxidant agents or materials capable of absorbing gases or odors emitted by the food are commonly included in active packaging components.
2. **Smart Packaging:** Witek *et al*., and Zhou *et al*., Smart packaging consists of freshness indicators, sensors, and information carriers. Food spoilage may be manifested by changes in freshness indicators, such as the presence of metabolites of microbial growth, carbon dioxide, volatile nitrogen compounds, organic acids, pH value, or temperature fluctuations during storage.
3. **Thermal Insulation Packaging:** 3D printing could build thermally insulated packaging structures. The packaging feature keeps the frozen state of food throughout transportation. Porous printed structures filled with air or other gases could serve as efficient thermal insulation layers. Figure 7 illustrates this principle [5-16].

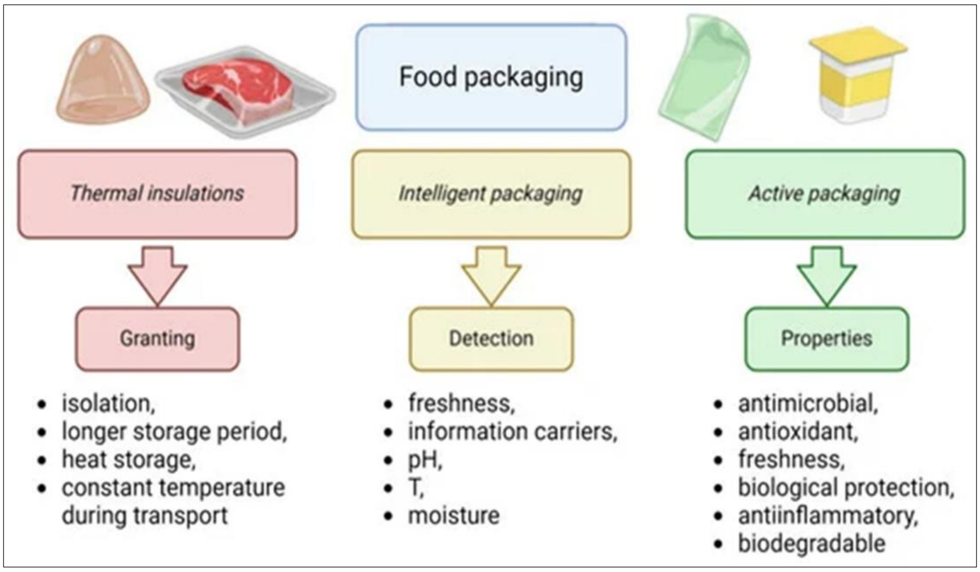

Figure 5: Effects of various types of packaging [5]

Fruits and vegetables are quite prone to mechanical damage caused by several factors during transport. Static pressure, shock, vibration, and collision may cause irreversible deteriorations in their quality. Zhou *et al*., explained that antibacterial packaging is needed for preserving fruits and vegetables to reduce irreversible loss in qualities during transportation of the produce as depicted in Figure 6. Besides, the smart aerogel packaging was fabricated using 3D printers with good flexibility, showing antimicrobial activity against Escherichia coli and Staphylococcus aureus [17].

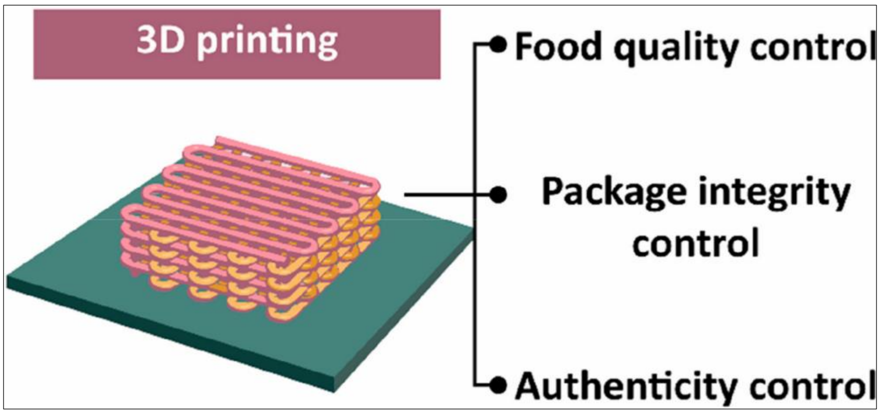

Figure 6: Advantages of 3D printers in food packaging [7]

In research by Nida *et al*., peels of banana were used for conversion into packaging material using 3D printers. In this set of studies, banana peel and guar gum at a concentration of 1% w/w were used; the printability is influenced by properties of particles and the concentration of hydrocolloids. Such types of printing may also allow other agricultural waste to be printed and transformed into biodegradable packaging [18].

CONCLUSION

The use of 3D printers has gained immense popularity these days, and this technology has shown its growth in the food processing industry with the passing of time. The development of new foods and contemporary packaging developed this technology. Although 3D printing is still in research and development, with some complications such as print accuracy, process efficiency, and the realization of a colorful, multi-flavor product, further studies and experiments may have much to contribute to changing the face of the food industry in the future.

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