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A Review on Food Printing

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Abstract: An emerging technology called 4D food printing has the ability to alter food design while ensuring nutritional security in an environmentally friendly manner. This type of 4D printing utilises a stimulus-responsive material, allowing a printed structure to undergo morphological or functional changes in response to environmental factors like temperature, pH, wind, water, or light. also, the food properties like colour, taste, aroma and texture. This Layer-by-Layer food concept of 4D food printing involves mixing and depositing different layers of ingredients that consumers can experience with different material combination. This specific 4D printing technology and their associate printing process for 4D customized food fabrications are reported for single and multilateral applications.
Keywords: 4D Printing, healthy foods, Stimulus-response

I. INTRODUCTION

A new additive manufacturing technique, four-dimensional (4D) printing has great promise for creating products with complicated shapes and desired features [17]. When an object is 3D printed utilising smart materials, it responds to external stimuli or appropriate artificial stimuli (such as temperature, pH, water, UV, light, etc.) by changing physically or chemically over time (the fourth dimension) [6].4DP is the extension of 3DP which create solidified digital data into three-dimensional form using smart materials. This current technology is piqueing the interest of academics and businesses worldwide due to its versatility as a manufacturing alternative and the potential for new growth chances.

II. 4D FOOD PRINTING

A unique and innovative food processing technique called 4D printing can create complicated and customised food. This enables us to create our own "art food" for consumers and stimulate their appetite. Food entrepreneurs will pay greater attention to 4D printed food as a result of which their market share will rise. Current applications of 4D printing in the food industry are reshaping the way that food is manufactured. Several industries, including healthcare, have found use for 4D printing. 4D printing has been successfully applied in a variety of fields, including medicine (Basak 2021; Melocchi et al. 2021; Xiao and Huang 2020), engineering [17].

III. FOOD PRINTING METHODS

The creation of food items utilising AM methods is referred to as 3DFP. The preloaded recipes in the 3D printers' software enable users to remote product design on their smart devices. Typically, syringes are used to hold the printing material, which is then stacked layer upon layer via a nozzle to generate the completed food product. This method offers the opportunity to include bioactive ingredients into meals to create a diet that is ideal for persons with particular dietary needs. As seen in, different meals are available in a variety of sizes, colours, and forms. The ability to generate a range of functional food items by including various components is another benefit of 3DFP technology.

A. Extrusion Technology

The idea behind extrusion technology is to use soft materials and control the temperature or use a fluid that is half solid and half liquid [13]. Material stays in a cartridge and is pulled through a nozzle, where it can be heated. The material is then put down layer by layer on the printer's platform by moving the nozzle horizontally and the platform vertically. In hot-melt extrusion (HME), a heating block or a syringe is used to heat the material to a high temperature. The viscosity of the material must be controlled so that it can flow through the nozzle. This is done by keeping the material at the right temperature [13]. plastics industry, healthcare and food extrusion for a variety of materials, foodstuffs, meat puree, dough, and chocolates that has already been tempered Figures made of potato starch gel have been printed with this method at different temperatures [13,16]. The samples printed best at a concentration of 14–23% starch suspension at 72 °C [20]. Fresh food products like fruits and vegetables that may be mixed and liquefied are potential components for the extrusion process. However, Mantihal et al. (2020) found that after extrusion, the freshly made smoothies were unable to maintain their precise shape. As a result, food additive hydrocolloids (such as starch, gelatin, xanthan gum, etc.) were required to improve printability, flow ability, and strengthening [13].

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B. Inkjet Printing

The most common applications for this technique are surface filling or food embellishment. Droplets of food ink are created and applied to the generally the surface of a cake, pastry, or confectionery to create an image from a CAD file. When it comes to printing food, inkjet printing is known as a non-contact method. By doing this While the image is being filled, the food is safeguarded from contaminants. Substances with low viscosity such as sauce or liquid pigments are suitable ingredients for this approach [14]. Several elements that are crucial to the inkjet printing process must be managed and controlled, including the material's qualities, which must be checked before printing, the edible ink's rheological characteristics, and the surface's characteristics. The speed of printing, size of the nozzle, height of printing, and temperature of printing are other processing variables that have an impact on printing precision. There is no post-processing involved with this procedure. The ink droplets used in this approach may contain a broad variety of colours, which gives designers the opportunity to create distinctive, individualised food graphics while also enabling quick production. This approach is only suitable for surface design or picture filling, all things considered [14].

C. Binder Jetting

Binder jetting, a printing technique, is named for the adhesive liquid (glue) that holds the powder particles together when printing. Two major parts of the procedure are repeated until the thing is finished, utilising a map from a CAD file. Layer by layer, the re-coater coats the moulded compound (ingredients in a powdered form) in the first stage. High precision is used by the re-coater to precisely place the grains of the powdered material when they are applied to the construction area. The liquid binder is applied by the printhead in the second phase, and it is released, allowing it to bond to each particle of the mouldings. Radiation is often used to heat the surface, allowing for the deposition of the subsequent layer while improving the mechanical characteristics [15]. Until the required shape is constructed, these processes are repeated. Once the printing method is finished, the moulding material is withdrawn, and printed object can be obtained [15]. In contrast to traditional approaches, it is therefore simple to produce unique and sophisticated goods using this cutting-edge technology [13]. Only materials in powder form can be utilised with the technology of binder jetting, and the Chef Jet 3D printer can implement it. To bind powdered materials, such sugar, flavour- and colour-customized solutions can be used. Printing precision is impacted by a variety of factors, such as the properties of the material being printed (particle size, binder viscosity, and flowability), the characteristics of the printing process (nozzle size, printing rate, and layer height), and the characteristics of the postprocessing steps (baking, heating, and surplus removal) [9,15].Binder jetting has the ability to print intricate 3D food constructions rendered in multiple colors and featuring the possibility of a variety of flavour profiles. However, it can provide fewer nutrient-dense products due to the limited options in suitable materials acceptable for this procedure [16].

IV. PROPOSED SYSTEM

An effective technical solution is a key part of 4D printing because it makes it easier to make the product you want. When making and printing the 4D model, a number of software solutions and a management software solution were used. There is a separate solution for each of the five stages(fig.1) Stimulation, Modeling, Slicer, Host/Firmware, Monitoring, and one Printing Management software. Using a software program to simulate the behavior of an object or system is a way to study how it works. Most of the time, simulation software is used before a product can be made. This lowers the risk of failure before the product is actually made. It is based on using math formulas to describe real-world events. The user could indeed learn how to do everything without having to do it.

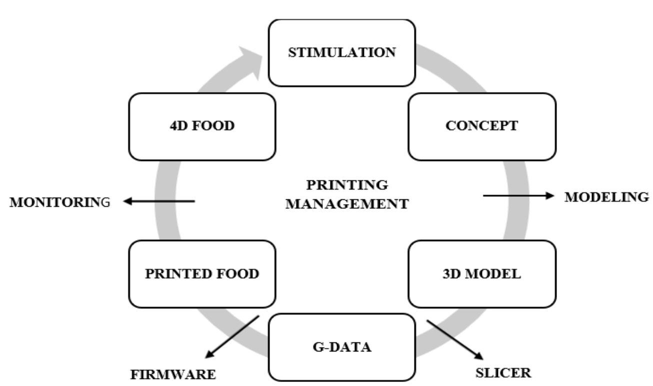

Fig. 1.4D printing software process-flow

An emerging technology, 4D food printing has the potential to permanently alter the way food is developed, especially in regards to dietary food safety and security. This type of 4D printing includes a stimulus-responsive product, enabling a published framework to change its development or operation in reaction to stimuli such as temperature, wind, pH, light, and structure. The 4D food printing approach of "layer-by-layer" involves combining and depositing different layers of active chemicals that customers may or may not taste depending on the product combination. The main objective of this assignment is to design a 4D food printer that can produce nutritious and well-balanced meals. Single and multi-material uses of this 4D printing technology and its associated printing process for 4D customised food fabrications are described.

V. STIMULI-INDUCED VARIATIONS IN 4D-PRINTED FOOD

A. Shape Alterations in 4d Food Materials

In order to provide flour-based sheets the potential to alter shape, the geometric qualities on the dough surfaces that can govern the swelling or drying rate of the food materials, which ultimately results in the shape of the pasta, were grooved. The majority of 4D printing research is mostly focused on the shape-change of non-edible materials such as the shape-changing of hydrogels [24], shape-memory polymers [11], alloys, and ceramics [25]. In recent years, a great number of investigations on the transformation of form in 3D-printed edible materials have been carried out [26]. Researchers at MIT have developed and unveiled the world's first application of the fourth-generation printing technology in the food industry [27].

B. Variations in the Colour of 4d Dietary Ingredients

The appearance of food products is largely determined by colour, which also has a considerable impact on whether or not consumers' appetites are sparked or suppressed. Color is therefore one of the major difficulties facing the food industry [19]. While foods with unappealing or undesirable colours lower food attraction and suppress hunger, foods with appealing colours increase food appeal and boost consumer appetite. Based on the capabilities of these materials, 4D food structures can evolve over time in a planned way.

VI. INGREDIENTS USED FOR 4D FOOD PRINTING

Stimulation is the primary requirement for meeting the prerequisites for causing changes in the properties, functionalities, and shapes of materials that have been 4D printed(fig.2). A stimulus can take place in a variety of ways, including physically, chemically, or physiologically, amongst others. Alterations in factors such as temperature, humidity, light, magnetism, and electric energy are examples of physical stimuli. The existence of chemicals, in addition to pH and ionic strength, are all elements that contribute to the chemical stimulation. Under the biological stimuli, glucose and enzymes are classed [28].

CHANGES	MATERIALS	STIMULI USED	REFERENCES
SHAPE CHANGES	• Protein, ethyl-cellulose, and starch • Flour based dough • purple sweet potato purees	• Water (via cooking) • Dehydration (via baking) • Microwave dehydration	• wang et al. (2017) • tao et al. (2019) • He, Zhang, and devahastin (2020) • Z. liu et al. (2021)
COLOR CHANGES	• Anthocyanin-potato starch gel and lemon juice-potato starch gel • sago starch with turmeric blends	• pH solutions • pH solutions	• Ghazal, Zhang, and liu (2019) • He, Zhang, and Guo (2020)
FLAVOUR CHANGES	• Soy protein isolates, pumpkin powder, beetroot powder • soy protein isolates with k-carrageenan and vanilla flavour.	• pH solution • Microwave heating	• Phuhongsung, Zhang, and devahastin (2020) • Phuhongsung, Zhang, and Bhandari (2020)
NUTRITIONAL VALUE CHANGES	• Edible plant seeds, organism's spores or yeast, and bacterial cells were incorporated into an edible nutritional matrix (fruits, vegetables, nuts, etc.)	• Sunlight • UV-C irradiation	• rutzerveld (2014) • Chen, Zhang, and devahastin (2021)

Fig. 2.Food printing relying on physical or chemical transformation

VII. GLOBALIZATION OF CUSTOMIZED FOOD

The consumer has direct control over the food composition process. Food personalization offers opportunities to raise people's quality of lifestyle in food. Foods that are customized have proliferated, especially in the later half of the 20th century. With rising personalized values of food consumption, price, packaging, flavour, and nutritional benefits, food and food products have been added a new drift in this consumer inclination. Beyond their nutritional worth, many foods provide health advantages. Because the idea has even more potential to divide the entire population into several groups based on biomarker investigations, we call this approach "personalized nutrition. "Individually customized nutrition and personalised nutrition have similar meanings but take a step further by seeking to provide individualized nutritional intervention or guidance.

It emphasizes the individual over social groups. We can develop individualised suggestions of the healthiest foods for people by understanding their particular responses. People were more likely to improve their diets when they received tailored nutrition advice than when they did when they received more broad recommendations. Using a combination of 3DP and digital gastronomy technologies, 3D food printing may create foods with individualised characteristics such as size, colour, flavour, texture, and even nutritional value.Techniques can enhance the nutrient availability of customised meals [29]. It can be able to produce food in the desired forms and use a person's unique traits to generate individualised nutritional advice, Similar terms include "personalised nutrition" and "individually customised nutrition," however the latter term goes a step further by seeking to provide dietary interventions or advice that is appropriate for each individual [12] Specifically, personalised nutrition is the use of the related individual's genetic, phenotypic, medical, nutritional, and other key information to provide tailored recommendations for optimal eating and nutrition based on their unique needs. Nutritional interventions will use food type, biochemical measures, physical activity, and genetic variability to predict a person's metabolic diet.

VIII. PRINTING TECHNOLOGY APPLICATIONS IN FOOD PROCESSING

This technology has the potential to be a game-changer in the areas of food personalization, nutrient profiling, and the creation of prototype tools for the production of novel designs [30].It is used for individualised nutrition and for creating nutrient-rich snack options. Nutrient enriched food or snacks can be served for patients. The raw food materials turns into attractive and marketable products. It boosts the shelf life of food products. By using 4D printing it can reduce laborious effort and it saves time. Applications provides an emerging technology through the nutritional content required by specific diet.4D printing consists of colour, flavour, nutrition, shape changes. In the food industry, 4D printing is an established form of additive manufacturing.

IX. CONCLUSION

New smart materials, stimuli, and mechanisms might be discovered in the future, and these might be used in conjunction with existing smart food materials to bring about the needed changes in various qualities and enable substantial progress in 4D food printing. According to the most recent report by Emergen Research (Market Research for the Emerging Technologies | Emergen Research), the global market for 3D food printing is projected to reach US$1.0155.4 billion by 2027 and achieve a double-digit compound annual growth rate (CAGR) over the forecast period. Both of these outcomes are expected to occur during the period of the study [9]. Despite these benefits, there are a few downsides to 4D printing that increase the processing time, such as the need for support materials and the lack of additional printing degrees of freedom.. Shape, colour, taste, and texture are just few of the characteristics that could change in 4D-printed food. So far, potato puree, soy protein, and starch hydrogel are the only foodstuffs that have been tested for use in 4D food printing. In most studies, researchers attempt to stimulate a response by manipulating the pH level or by heating the sample in a microwave. Color shifts in 4D-printed food as a result of various stimuli are investigated in depth. Developing a mechanism to track the strength of 4D changes could pave the way towards achieving regulated shifts in

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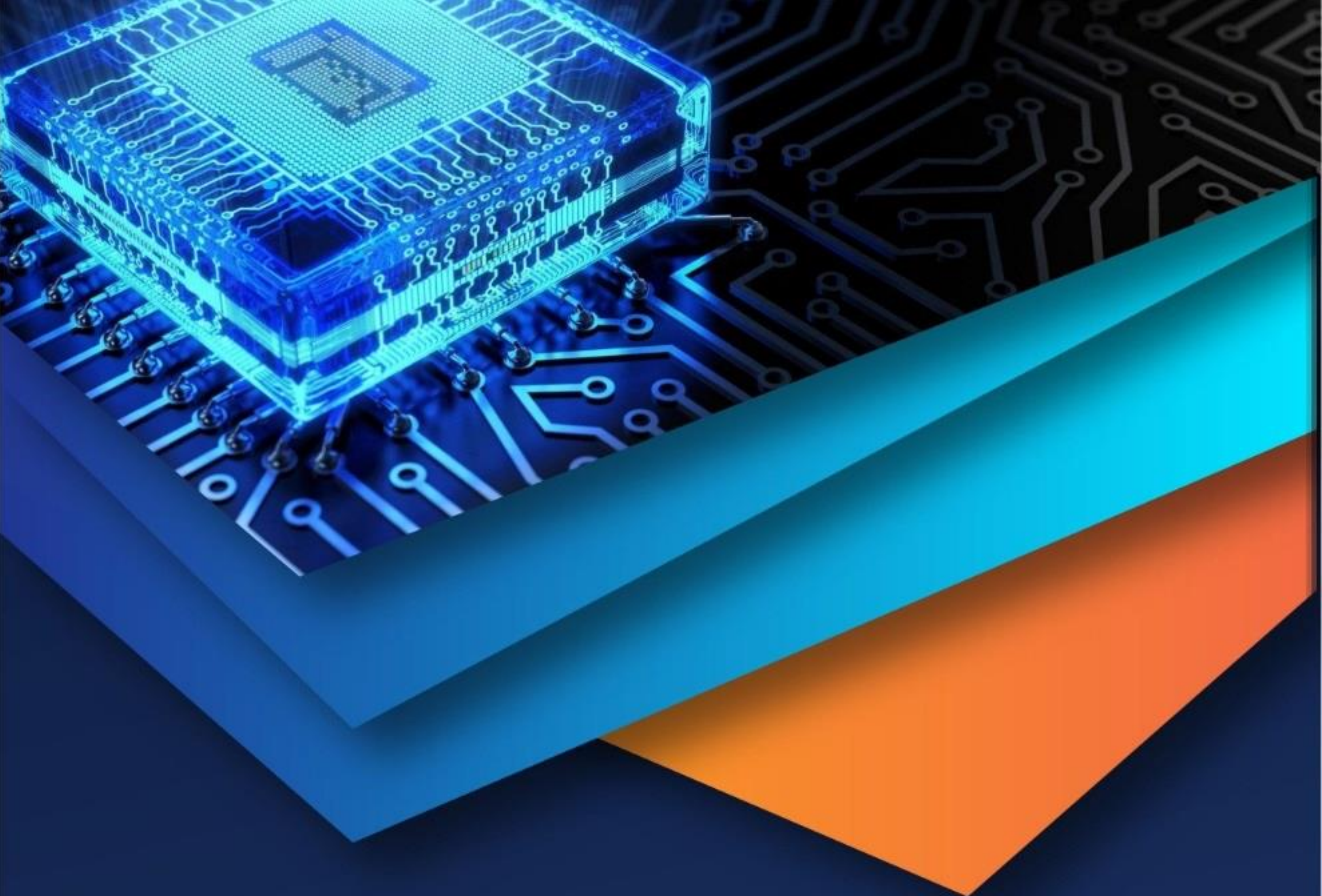

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