Protein based edible inks for 4D and 5D food printing

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ABSTRACT

4D printing is the result of 3D printing intelligent materials that respond to different stimuli to produce new goods. 4D printing has so far been successfully used in a wide range of fields, including engineering, food processing, medical equipment, and computer components. Research investigations on 4D and 5D printing have significantly increased during the last two years. With the use of state-of-the-art technology, 4D Food Printing (4DFP) creates complex food structures with a range of flavors, textures, forms, and nutrients that may change their physicochemical properties across time and space in response to different stimuli. This article provides a quick overview of the various 4D and 5D printing technologies that could be used in the food sector. Next, the elements influencing the functional performance of edible inks based on proteins are examined. Techniques for enhancing these inks' functional performance such as protein changes that are physical, chemical, or enzymatic are also highlighted. Currently, creating 3D printed items with the right color, shape, flavor, and nutritional properties is the main objective of 4D food printing applications. This article reviews and discusses the principles and possible applications of the newest additive manufacturing technologies, including 4D and 5D printing. Up till now, 4D food printing applications have mostly concentrated on enhancing the nutritional value, color, texture, and form of 3D printed items. 5D printing has the ability to build incredibly complex structures with greater strength and less material use than existing 3D and 4D printing techniques. It is expected that these new technologies will lead to future developments in all areas, including the production of superior food items that are not achievable with the processing technologies now in use. Finding the industrial potential for 4D printing and advancing innovation with 5D printing are the main goals of this research. Nowadays, obtaining the appropriate nutritional properties, color, shape, and texture of 3D printed goods are the main objectives of 4D food printing applications. Notably, compared to 3D and 4D printing, 5D and 6D printing have the ability to create incredibly intricate structures with less material and more strength.

INTRODUCTION

In recent years, the needs of customized nutrition and food form have been effectively met by 3D printing technology. 4D printing for food adds a time component and associated stimuli sources in contrast to 3D printing, enabling the printed food to control its color, texture, and flavor in response to internal or external stimuli. This gives consumers more options and satisfies the needs of specific populations (Shen, Chen et al. 2023). A printer, printing software, printing ink, and stimulus are the essential components of 4D printing technology (Fig 1). Hydrocolloid starch, hydrogel, chocolate, dough, cheese, and a blend of fruits and vegetables are typically utilized to print customized food, however because of lack of intelligent materials in foods. The researcher hasn't done a lot of research (Patoliya, Vala et al. 2023). Food innovation manufacturing disciplines are currently utilizing a wide range of printing technologies, ranging from 2D, 3D, 4-D (4D), and 5-D (5D) printing, with remarkable advancements and opportunities across numerous industries (Nida, Moses et al. 2022). The evolution of three-dimensional printing, wherein an object's chemical and physical state is gradually changed over time by external stimuli including light, water, pH, and temperature, is referred to as the fourth dimension of four-dimensional printing (Nida, Moses et al. 2022). Semi-solid materials that flow through a nozzle and solidify after printing are ideal for edible inks. (Zhang, Li et al. 2022). Food proteins can be used for this since they can mix to form paste-like or gel-like substances. (Sridharan, Meinders et al. 2021)

The term 4DFP describes the controlled behavior modification of 3D printed food in response to a stimulus, resulting in a temporal physicochemical change (Kokane, Arora et al. 2024) The use of 4D printing revealed that the flavours of various fruit liquids, vanillin powder, beetroot and pumpkin powder, and soy protein isolates had changed (Nida, Moses et al. 2022). 4D printing has revolutionized the food business by bringing in new ideas. The fundamental components of 4D printing, of course, consist of 3D printing instruments, stimulus sources, materials corresponding to stimuli, and interaction mechanisms (Yu, Zhang et al. 2023). It is possible to customize more unique 4D printing products by combining digital cooking technology with food printing technology. For example, 4D printing enables the creation of floral structures that are suspended and unattainable with 3D printing (Yu, Zhang et al. 2023). By adding a time dimension and related stimulus sources to 3D printing, 4D printing for food has given consumers more options and can cater to the needs of specific populations by enabling controlled colour, texture, and flavour alterations brought caused by internal or external factors (Shen, Chen et al. 2023)

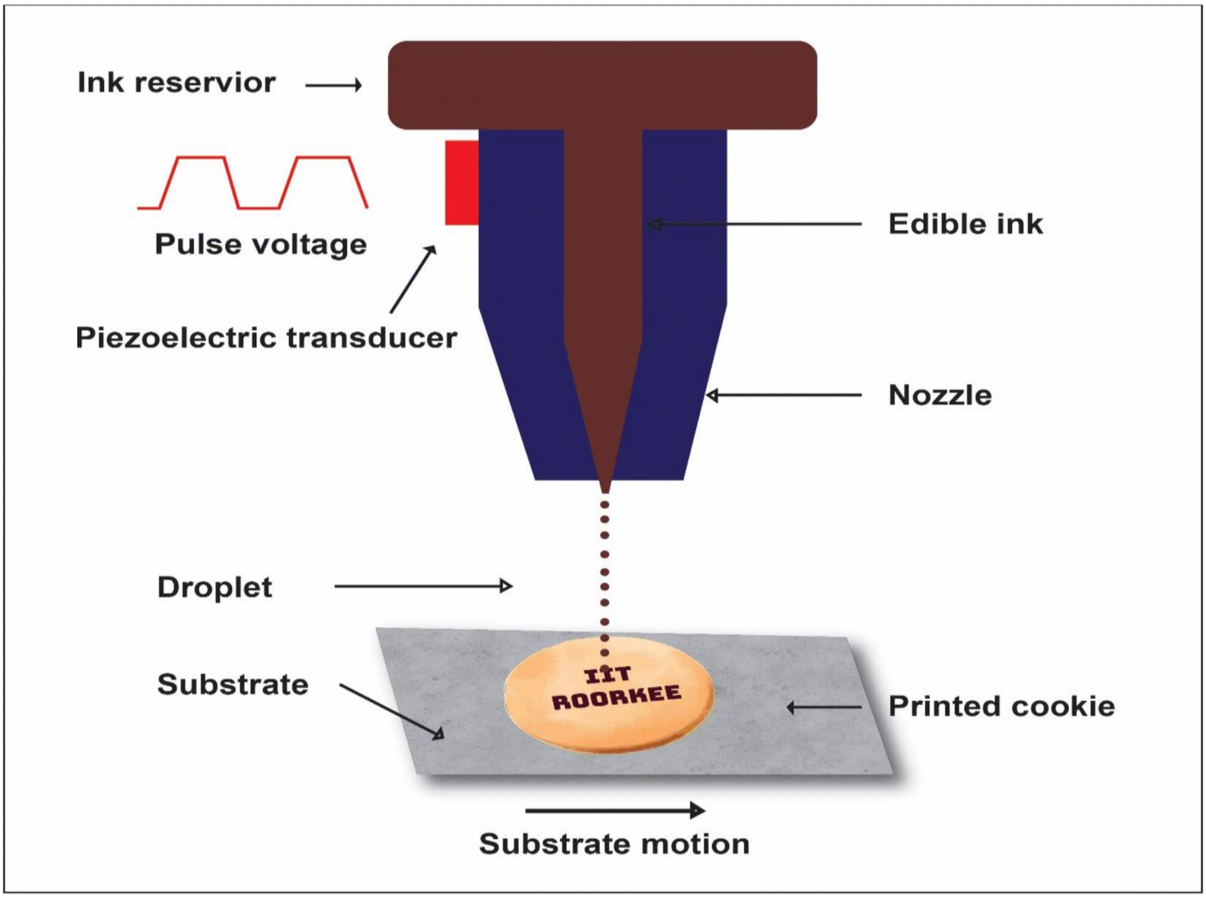

Fig. 1. Graphic representation of the procedure to use an inkjet printer to print edible ink onto a food substrate(HAKIM 2023)

4D PRINTING INKS

The most widely used production method for 4D printing is direct ink writing (DIW) technology, which is open source for a range of materials (Figure 2).

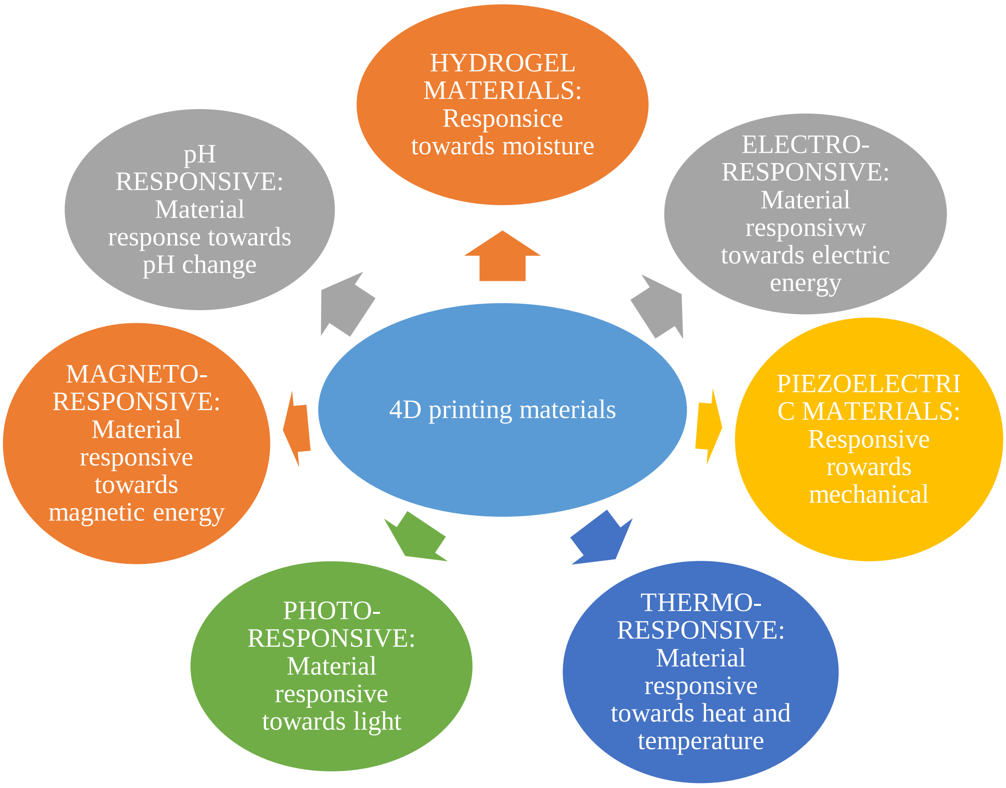

Fig. 2. A schematic illustration of the different kinds of materials used in 4D printing.

The DIW method is a computer-controlled printing technique that creates layer-by-layer geometries by applying pressure through a nozzle to transfer a dispenser filled with printed ink. DIW micro-nozzles could produce high printing resolution, which is promising considering the possibilities of radio frequency and unconventionally driven micro-devices (Wan, Luo et al. 2020). Liquid crystal elastomers (LCEs) undergo a quick, reversible shape change in response to stimuli by alternating between the liquid crystal (nematic) state and the isotropic state. From de Gannesin's initial mention of them in 1975, their potential uses have been thoroughly examined. Using 4D printing of two-way shape memory LCE in conjunction with straightforward preparation, printing, and activation techniques can enable innovative, quick manufacture of medical devices or flat-pack smart structures. (Roach, Kuang et al. 2018)

EDIBLE INKS BASED ON PROTEINS FOR 4D AND 5D PRINTING OF FOOD

Proteins have several uses in food items as functional ingredients due to their thickening purposes, gelling, emulsification, creating foam, binding, and nutritious qualities; these qualities also make them useful when utilized in edible inks .Plant proteins are more environmentally friendly and sustainable than animal proteins, which is why there has been interest in using them for this purpose recently (Wang, McClements et al. 2024). Using both additive and subtractive manufacturing processes, 5D printing is a hybrid technology. In addition to the two rotating axes, the three movement (X, Y, and Z) axes are used to print incredibly complicated shapes. Figure 3 shows that the two rotating axes represent the printing bed, while the X, Y, and Z axes represent the printer's printing head. (Nida, Moses et al. 2022)

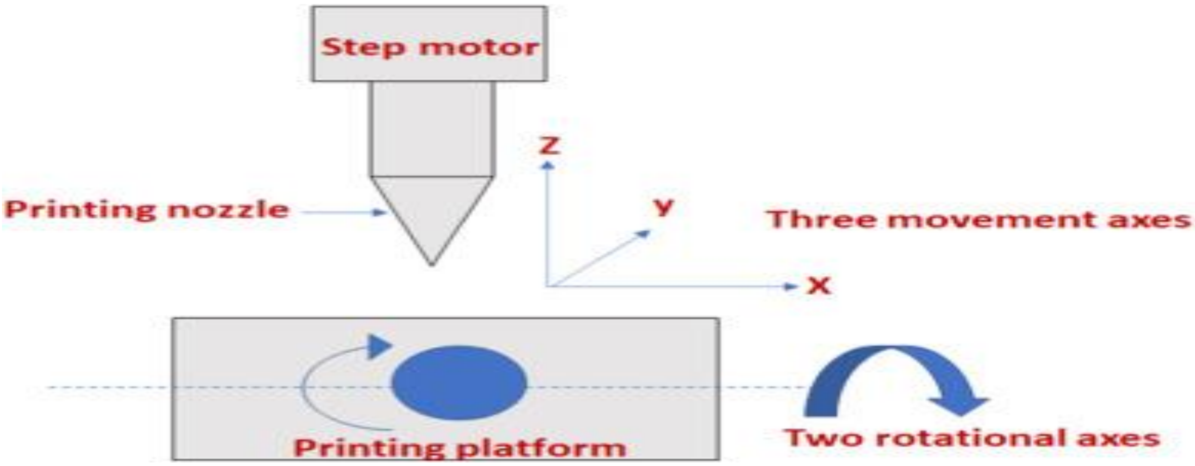

Fig. 3 Schematic diagram of 5D printing technique (Nida, Moses et al. 2022)

The gelling, emulsifying, and foaming properties of proteins such as whey protein, casein, and soy protein isolate make them essential to 4DFP. Soy protein isolate, which creates heat-induced gels, can be used to shape food printing. (Phuhongsung, Zhang et al. 2020, Chen, Zhang et al. 2024). Due to its gelling qualities, whey protein, a by-product of cheese production, improves food item's texture and stability (Shen, Chen et al. 2023). Casein, the main protein in milk, can form durable gels and foams that maintain the skeletal strength of printed items, it is used. (Chen, Zhang et al. 2022). Fig. 4 shows the most widely used and popular colorant extraction method. A plant that has been broken up into tiny fragments is the source of the color. After that, the chips are cooked at high temperatures until the wood has lost all of its coloring components (Hakim, Deshmukh et al. 2024).

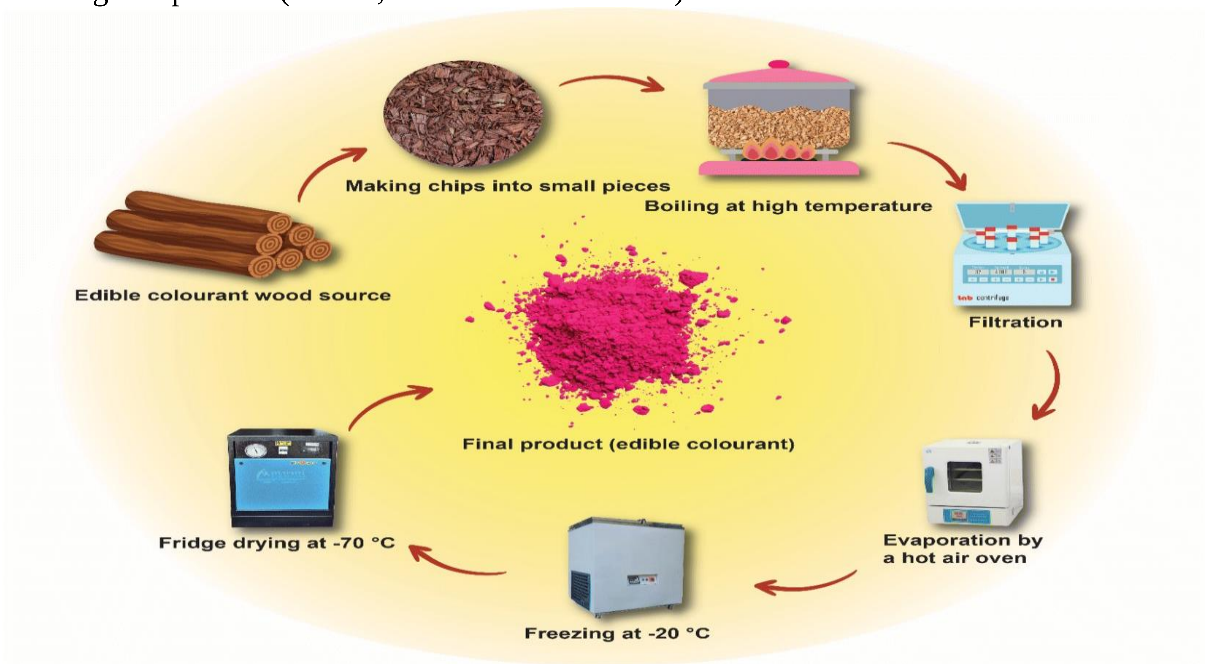

Fig. 4. Extraction of colorants and dyes (Hakim, Deshmukh et al. 2024)

Whey protein

The performance of WPI gel in 3D printing was not affected by the addition of NaCl, and the gel created by partially substituting MWP for WPI exhibited stable shape and good rheological characteristics (Wang, McClements et al. 2024). Micro particulate whey protein (MWP) was used in place of whey protein isolate (WPI) to improve the creation of viscoelastic gels, printability, and shape retention of three-dimensional objects after deposition. (Liu, Tan et al. 2023). When WPI was present, the MPC paste's apparent viscosity reduced and it became softer, making the printing process easier. (Liu, Tan et al. 2023). More whey protein isolate softens the yoghurt complex gel and suitably lowers yield stress, enabling continuous and smooth extrusion during printing. (Cheng, Fu et al. 2022). As a by-product of producing cheese, whey protein improves food items' texture and durability by gelling (Shen, Chen et al. 2023). Casein, the main protein in milk, is used to reinforce the structural integrity of printed items because of its ability to form stable gels and foams. (Cheng, Fu et al. 2022)

Pea protein

Inulin and pea protein isolate (PPI) were used as raw materials for the coupling preparation procedure, which involved ultrasonic/pH translocation and glycosylation. (Jiang, Li et al. 2023). For sustainable management, a large number of the food industry's byproducts may be recycled. Take a look at the following instances: (3) pig plasma protein (PPP), a by-product of slaughterhouses that may be made from blood; (2) pea protein concentrate (PPC), a by-product of the industrial extraction of soy oil; and (3) soy protein isolate (SPI). These three protein sources—PPP, SPI, and PPC—are frequently utilised as thickeners or emulsifiers in the food sector. (Álvarez-Castillo, Oliveira et al. 2021). The incorporation of pea protein enzymatic hydro lysate xylose Maillard Reaction Products (xMRPs) might significantly improve the formability, structure, and physical properties of 3D printed items. Six grammes of xylose were incorporated in the most effective xMRPs. (Zhao, Wang et al. 2021). The effectiveness of the 3D printing technique was evaluated in relation to the rheological characteristics of protein-based doughs made from blood plasma, peas, and soy. In the end, the designs resulted in products that were easily manufactured or that approximated the planned pattern. Rheological methods were used to assess the printability of dough with different concentrations of porcine plasma protein (PPP). It was discovered that dough with a PPP concentration between 42.5 and 47.5 weight percent printed well. Soy Protein Isolate (SPI) or Pea Protein Concentrate (PPC) were used to replace the leftover PPP, maintaining the dough's overall biopolymer content at 45 weight 36 percent. (Álvarez-Castillo, Oliveira et al. 2021)

Milk protein

To create milk protein composite gels, milk protein concentrate MPC was dissolved in sodium caseinate solution. The milk protein gels with a total protein concentration of 400–450 g/L had the greatest printing performance. (Liu, Zhang et al. 2024). Milk protein concentrate (MPC) was mixed in sodium caseinate solution to produce milk protein composite gels. (Liu, Zhang et al. 2024)

Cod protein

By creating a concentration, dependant percentage of adsorbed proteins, and a cross-linked network, oil-in-water HIPE becomes more stable and, after seven days of storage at 4 °C, creates a uniform, self-supporting structure. When stabilised with 50 mg/mL cod protein gel strength, resolution, toughness, cling, and chew ability during 3D printing, HIPEs displayed good print quality. (Li, Xu et al. 2020)

Soy protein

Using the free radical grafting technique, three polyphenols—the polyphenols from basil, thyme, and rosemary—were individually grafted onto soy protein isolate. This was done with the aim of formulating a precursor ink that would facilitate the 3D printing of plant based cheese (Mohammadi, Kashi et al. 2023). Three separate polyphenols that are polyphenols found in thyme , rosemary and basil, were distinct grafting onto isolate from soy proteins using a free-radical using grafting technique on make a forerunner plant-based cheese that can be 3D printed with downloadable ink (Mohammadi, Kashi et al. 2023). SPI and deionized water were used to prepare the soy protein isolated (SPI) dispersions. The SPI/SSPS dispersions were supplemented with varying amounts of soybean soluble polysaccharides (SSPS) at 0%, 1%, 2%, 3%, 4%, and 5%. A sessile water drop technique using an automated microscopic contact angle metre was used to find the largest contact angle (24.17) in 3% SSPS xerogel during hydration. The observed bending degree is in the range of 3% > 2% > 1% > 0% (Li, Wang et al. 2022).

Heat-induced gels made with soy protein isolate can structure printed foods (Phuhongsung, Zhang et al. 2020). Guo et al.'s (2023) investigation examined the impact of soy protein isolate (SPI) content on oat flour when employing microwave heating as an external stimulus. The ideal form distortion was seen when the object was treated in a microwave oven with an oat flour to SPI ratio of 1:0.7 (Guo, Zhang et al. 2023). The SPI is abundant in residues of amino acids found in large concentrations in plant-based proteins, including glutamic acid, aspartic acid, leucine, serine, glycine, alanine, and proline (Qin, Wang et al. 2022). Additionally, SPI is vegan-friendly and aligns with the general population's current dietary consumption trends move towards plant-based food proteins as a result of the substantial health advantages and reduced environmental impact of plant-based diets (Qin, Wang et al. 2022). The gelling, emulsifying, and foaming properties of proteins such as whey protein, casein, and soy protein isolate make them essential to 4DFP. Printing related meals can be structured by soy protein isolate, which can create heat induced gels (Kokane, Anjaly et al. 2024). Heat-induced gels made with soy protein isolate can structure printed foods (Phuhongsung, Zhang et al. 2020). Whey protein, a by-product of making cheese, gels food to enhance its texture and durability. (Shen, Chen et al. 2023). Casein, the main protein in milk, is used to reinforce the dimensional stability of printed items because of its ability to form stable gels and foams. (Cheng, Fu et al. 2022). Porous shells made from soy protein have been successfully printed and might be used as biomaterial implants in regenerative medicine applications. Soy protein has adequate physicochemical or functional qualities and a fair amount of both essential and non-essential amino acids. Soy protein as well as sodium alginate are mixed together to help gel and form a sturdy structure. (Chen, Mu et al. 2019, Chen JingWang, Mu TaiHua et al. 2019)

Peanut protein

When carrageenan and gum gelling were added at a rate of 1.5%, the composite's hardness and storage modulus (G′) Hydrogel reached 104 Pa and at least 700 G, respectively, with better 3D model printing performance. (Li, Feng et al. 2023). The semi-interpenetrating peanut protein-polysaccharide matrix was constructed to improve the gelling and printing properties of the composite hydrogel. (Wang, McClements et al. 2024). It has been demonstrated that consumers favour and trust printing inks derived from peanut protein isolate more than they do other inks. Peanut protein isolate not only develops a new printing material but also increases awareness of the development of protein composite ink systems and other proteins (Chen, Zhang et al. 2021)

PROTEIN HYDROGELS

Hydrogel’s primary method for undergoing shape transformation in 4D printing is internal tension within printed objects, which can be induced by a variety of sources (Liu, Chen et al. 2020). Among the substances used in 4D printing, hydrogels have drawn considerable interest due to the availability of several smart hydrogels (Champeau, Heinze et al. 2020). Hydrogels, which may be used as edible inks, can be made from a wide range of dietary proteins. (Sharma, Nath et al. 2024). Multiple routes may be engaged in protein interaction, contingent upon the molecular characteristics of the proteins. For instance, gelatin can produce reversible cold-set gels because these proteins can transition from coil to helix when chilled below a threshold temperature. (Dai, Zhao et al. 2021). Hydrogen bonds bind the different gelatin molecules together, and the helical regions that are formed act as crosslinks between them. Alternatively, globular proteins—like those in eggs, soy, or whey—form irreversible heat-set gels. (Frydenberg, Hammershøj et al. 2016). 4D printed hydrogel can be broadly categorized into three types: pure hydrogel, hybrid hydrogel, and hydrogel composite, depending on the hydrogel composition and the actuation method (Liu, Chen et al. 2020). When a stimulus is applied to 4D printed hydrogel structures, the reversible shape-morphing is caused by a stress mismatch that results from the various degrees of swelling in the structure's components (Champeau, Heinze et al. 2020). In 4D printing, hybrid hydrogel that is, hydrogel that combines multiple types into one object has also been examined (Liu, Chen et al. 2020)

OPTIMIZATION OF 4D AND 5D PRINTERS

Using the appropriate computer modelling tools, a 3D model of the meal is first created. The food item is printed layer by layer using this model, which controls the printer's mechanical movements. (Waghmare, Suryawanshi et al. 2023). Compared to other 3D printing technologies, extrusion 3D printing has a number of advantages, such as quick turnaround times, inexpensive printing costs, user-friendliness, and a large selection of materials that may be utilised as edible inks. (Le-Bail, Maniglia et al. 2020). Cold-set extrusion methods employ edible inks, such as biopolymers (like agar, gellan, or gelatin) and certain lipids (such coconut oil, cocoa fat, and palm oil), which are solid at low temperatures but fluid at high ones. Here, after printing, the nozzle is heated to melt the edible ink, and the printing platform is chilled to solidify it. (Rando and Ramaioli 2021). Heat-set extrusion methods need to make utilisation of edible inks, such as globular protein solutions or starch suspensions, which are solid at high temperatures but fluid at low ones. (Dankar, Haddarah et al. 2018). Extrusion does not require temperature control methods like heating or cooling, which harden the edible ink. Materials with textural properties akin to plastic as room temperature, including mashed potatoes or starch pastes, can be used for this kind of extrusion. (Rane 2023). These substances behave similarly fluids in the nozzle under pressure, yet they behave like solids when printing is completed and pressure is released. As such, they display rheological behaviour akin to plastic. Biopolymers are used in ion-set extrusion that, when certain types of mineral ions are present, gel (Jeong, Lee et al. 2020)

OPTIMIZATION OF PRINTING CONDITIONS

For high-quality printing of proteins, choosing the right temperature range is crucial.. In certain applications, globular proteins may be denatured and aggregated due to high temperatures, however this is not always desirable (Ahmadzadeh and Ubeyitogullari 2022). On the other hand, a low temperature could be necessary for gelatin to solidify into a semi-solid state is employed to make edible ink. A consistent structure of networks with the necessary textural qualities may be ensured by maintaining the correct temperature. (Nieuwland, Geerdink et al. 2014). When the printing and extrusion rates are maintained within a suitable range, the printed material produces excellent form stability and a high resolution. This results in print lines that are consistent, continuous, and smooth. Should the extrusion speed have exceeded the print speed. As a result of stretching and narrowing, the extruded line may break. In contrast, if the extrusion speed is excessively high in comparison to the print speed, pace, thus there isn't enough time for the extruded lines to curl into packages (Severini, Derossi et al. 2016)

MODIFICATION OF PROTEIN INKS

The ability to travel through a nozzle, stick to a printed surface, and produce high-resolution outputs are all requirements for edible inks, yet single proteins seldom meet these requirements. As a result, these proteins usually need to be altered chemically, physically, or enzymatically in order to function better. Additionally, they can be mixed with other substances, such lipids or polysaccharides, to enhance their printing properties. (Dananjaya, Chevali et al. 2024). An overview of the several methods that may be used to improve the printing performance of protein-based edible inks is provided in this section. (Dananjaya, Chevali et al. 2024)

Physical modification

Protein particle size, shape, and physicochemical properties may now be changed thanks to physical modification techniques, which include both heat and non-thermal processing methods. Heat treatment promotes the thermal denaturation of globular proteins, which increases the number of sulfhydryl and non-polar groups on their surfaces. (Sager, Munk et al. 2020). To create whey protein-based emulsion gels that work with 3D printing, researchers have used controlled heating procedures. (Sager, Munk et al. 2020). Furthermore, further research has shown that soy protein pastes with advantageous printing properties may be created by thermal denaturation. (Chen, McClements et al. 2024). Whey protein isolate gels made by heat induction show higher strains than other gel formulations, according to creep recovery rheological evaluations. (Sager, Munk et al. 2020). Additionally, studies have shown that adding tannic acid to soybean proteins improves their printing properties. Food proteins' printing capabilities can be improved by using high-intensity ultrasound methods. (Sridharan, Meinders et al. 2021). Both non-covalent and covalent connections in proteins can be disrupted by this technology's severe and highly localised changes in temperature and pressure inside a material. (Hu, Chen et al. 2023). Consequently, this results in changes to their functional properties and structure. For instance, it has been shown that ultrasonic treatments significantly reduce the particle size of protein aggregates made from peanuts, black beans, and peas by interfering with the physical forces that keep them cohesive. (Hu, Wu et al. 2013). Food proteins' printing capabilities can be improved by using high-intensity ultrasound methods. (Sridharan, Meinders et al. 2021) This technique creates sharp, highly localised changes in temperature and pressure inside a substance, which can disrupt protein covalent and non-covalent connections. (Hu, Wu et al. 2013)

Chemical modification

The surface of proteins contains a variety of functional groups that can undergo various chemical changes. These chemical alterations usually lead to better printing results for protein-based edible paints. (Mu, Sahoo et al. 2020). The protein-particle-free emulsions (pH 7) were viscoelastic soft solids that only interacted with one another via drop-drop interactions. Conversely, emulsions made with protein particles (pH 3) demonstrated elastomeric material properties, including relatively strong adhesive drop-drop interactions. (Sridharan, Meinders et al. 2021)

Enzymatic modification

Protein-based edible inks can also be made more effective by using different enzyme treatments. For instance, the cross-linking enzyme transglutaminase (TGase) may catalyze the formation of covalent connections between lysine and glutamine residues in polypeptide chains to generate ε-(γ-Gln)-lysine isopeptide linkages. Stronger, more stable structures can be produced via covalent crosslinking between or inside molecules (Yu, Yang et al. 2022). In a different investigation, surimi was gelled during the 3D printing process using TGase and concentrated microwave radiation. Researchers concentrated heating mode (MW3DP) microwave 3D printing to accomplish self-gelation of surimi, TGase works in concert with method of printing (Zhao, Wang et al. 2021). At microwave power levels lower than 60 W/g, surimi showed shear thinning. Regarding the solid gel's form integrity, more favourable when 40 and 50 W/g of TGase were introduced(Zhao, Wang et al. 2021). Additional studies demonstrated that TGase might be utilized to bolster the toughness of the pea-based 3D-printed meat substitutes alginate and protein (Leelapunnawut, Ngamwonglumlert et al. 2022)

PROTEIN APPLICATION FOR 4D AND 5D FOOD PRINTING WITH INK

In the food packaging sector, edible ink is of utmost importance because to its non-toxicity. Because edible ink is inexpensive and readily available, it has also been successfully employed in the food printing and food coating industries (Hakim, Deshmukh et al. 2024). Food products with edible ink on their coatings seem more upscale, are stronger, have less particle segmentation, have better tactile and visual attributes, have a longer shelf life, and are protected against oxidation and microbiological development. (Han 2014). In the food packaging sector, edible ink is of utmost importance because to its non-toxicity. Because edible ink is inexpensive and readily available, it has also been successfully employed in the food printing and food coating industries (Hakim, Deshmukh et al. 2024). Food products with edible ink on their coatings seem more upscale, are stronger, have less particle segmentation, have better tactile and visual attributes, have a longer shelf life, and are protected against oxidation and microbiological development. (Han 2014).

Personalized nutrition

Foods enriched with protein might be printed for people with high protein demands, including youngsters, athletes, the elderly, the sick, and pregnant women. The proteins used in these applications should have the required functional and sensory performance, as well as a balanced essential amino acid profile and sufficient digestibility. (Sun, Zhou et al. 2015). Producing specialized food items suited to each person's unique nutritional requirements will be feasible with 4D printing (Patoliya, Vala et al. 2023)

Fortified foods

Using emulsion-based edible inks stabilised by fish proteins and EGCG, astaxanthin, a carotenoid, and algal oil rich in omega-3 fatty acids have been successfully encapsulated and transported. (Zhang, Zhou et al. 2023)

Sustainable foods

In an attempt to mitigate the negative environmental impacts of the global food system, such as pollution, freshwater depletion, greenhouse gas emissions, and biodiversity loss, there is a growing movement to substitute alternative protein sources for animal proteins in food and beverage products. (Springmann 2020). In particular, there has been interest in creating plant-based alternatives to meat, fish, dairy, and eggs. (Ramachandraiah 2021). By adding insoluble dietary fibre (IDF) to soy protein isolate (SPI)-wheat gluten (WG) plant-based diets, the researchers found that they might improve the 3D printing capabilities of plant meat. Water retention and tensile strength reach their maximum values when the IDF concentration reaches 10%. (Cheng, Qiu et al. 2024). Rice starch (RS), xanthan gum (XG), and soy protein isolate (SPI) were utilized as food dyes (Shi, Li et al. 2023). When the printing parameters were changed, the filaments were successfully produced within the range of actual fish muscle fibres (width 97.36 μm). Its structural geometry was changed to produce a fish that resembled the genuine fish in terms of texture (Sharif, Zafar et al. 2021). Plant-based meat substitutes with the flavour and texture of genuine meat but without the negative effects on the environment could be made via 4D printing. It is also used to manufacture food in a way that uses less resources and is more sustainable, cutting down on waste (Ahmad, Qureshi et al. 2022)

Others

Printing on tablets and capsules: By utilising edible ink to print information such as the name, dose, and expiration date of the medication directly onto tablets and capsules, patients may make it simpler for them to identify and monitor their medications. The usage of edible ink in medical packaging is growing as it is completely safe and delicious. A migration problem is associated with commercial ink. (Ding, Hu et al. 2020). In addition to food, edible ink may be applied on paper, edible films, and direct-contact food packaging. Printing on paper using edible ink reduces costs and prevents issues. (Deshmukh, Kumar et al. 2022)

CONCLUSION

One of the few sectors in India where 4D printing is still in its infancy is the food industry. The food industry has a lot of potential for 4D printing. Digital models, food inks, post-processing, and printing technology are all crucial components that influence the effective use of 4DFP. Some efforts are being made to look at the possibilities for this technology in the production and packaging of food. The production of space food is another application for this technology. One of the nation's top research institutes, the Indian Institute of Food Processing Technology (IIFPT), is actively investigating the application of 4D printing in food. An edible sensor that is 4D printed and capable of determining the freshness of packaged foods has been created by the institution. This method holds promise for lowering food waste and enhancing food safety in India, where rotting of food is a major problem. India, where food deterioration is a major problem. Different dietary components respond to environmental stimuli in different ways and undergo diverse modifications based on their structures and qualities. With 3D printing technology, it might be difficult to create some of the more complex structures that can be produced via 5D printing. With this method, additional support materials might not be needed while printing food. Buildings with a 25% lower material content and higher mechanical strength should be able to be constructed thanks to this approach. This is now being used to create curved-shaped caps and may be used in food packaging materials printing as well.

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