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SYSTEMATIC LITERATURE REVIEW ON 3D PRINTING PERSONALISED FOOD FOR THE ELDERLY

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Abstract: Three-dimensional (3D) printing is currently a new technology being developed in the food industry due to its ability to design, customize, and fabricate a product with good precision and accuracy. Therefore, with regard to the mastication problems frequently faced by elderly people, this technology is utilized to design foods that can be consumed by them. Since there was limited published literature on the subject, the present study aimed to systematically review 3D printing personalized food for the elderly. The study used PRISMA as a guideline for report writing while integrating multiple research designs. This paper employed three databases to select the articles: Science Direct, Scopus, and Google Scholar. The study included five analyzed themes: 1) hardness; 2) moisture; 3) viscosity; 4) elasticity; and 5) printability. The study significantly contributed to several practical purposes and the body of knowledge. The findings provided the factors affecting the 3D printing of food, its mechanisms, and its significance.

Keywords: *3D Printing, personalized food, elderly*

1. Introduction

3D food printing is a newly developed method involving food manufacturing through the layering method of producing a 3D-structured model (Derossi et al., 2020a; Hamilton et al., 2018; Huang et al., 2019; Jonkers et al., 2020; Zheng et al., 2019). It requires special computer-aided design (CAD) software to create the shape and design of the product by using a specific digital fabricating machine and to print it mainly through the extrusion method (Huang et al., 2019; Liu et al., 2018; Maniglia et al., 2019; Oyinloye & Yoon, 2020). The printing system is comprised of a syringe that is filled up with viscous food material, which will be printed out through a nozzle that could move in any direction during the process (Chen et al., 2018). This method enables the production of a complex, detailed, and specific shape of a food product (Zheng et al., 2019). Due to its promising contribution to the food industry, research in 3D food printing has gained traction (Maniglia et al., 2019).

This review focuses on aspects including hardness, moisture, viscosity, elasticity, and printability. The customization can be made by adjusting the ingredients of the printed product, also known as the food ink of the machine, based on the product's rheological properties by incorporating structuring agents such as hydrocolloids (Derossi et al., 2020b). The base of the ink is made of edible matter, either nutritional food or snacks (Huang et al., 2019), enabling the development of personalized food for selected populations based on age, health condition, and specific nutritional demand (Dankar et al., 2018; Maniglia et al., 2019).

As for the challenges of 3D food printing, the product printability is affected by the physical appearance, nutritional value, or rheological properties (Maniglia et al., 2019). The printer properties, such as the nozzle size, distance between the nozzle and the printing bed, and speed of printing, can affect the precision of the printing process and end-product (Dankar et al., 2018). Moreover, the transient temperature, surrounding conditions, and ingredients used as the formulation also determine the printing accuracy (Garcia-Segovia et al., 2020; Oyinloye & Yoon, 2020). Some raw materials can be a challenge due to their unstable structure and difficulty integrating with other materials (Zheng et al., 2019). If an ingredient can be used, its homogeneous or heterogeneous form requires specific conditions to form an accurate shape and suitable rheological properties for consumption and to withstand the conditions of cooking and long-period storage (Dick et al., 2020; Hamilton et al., 2018).

This systematic review focuses on the details of the 3D food printing process relating to elderly consumers because they are well-known to experience several physiological

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changes, dysphagia, and require specific nutrition to maintain their well-being (Dankar et al., 2018; Derossi et al., 2020a). By using the right materials and conditions, a specific, nutritious, and easily swallowed printed food with acceptable rheological properties can be manufactured (Jonkers et al., 2020; Maniglia et al., 2020).

1.1 Research Gap – The Existing Research Conducted On 3D Food Printing for The Elderly

It is undeniable that 3D food printing has widely become an area of interest among scholars due to its promising future in the food industry (Dankar et al., 2018; Derossi et al., 2020a; Huang et al., 2019; Liu & Ciftci, 2019; Oyinloye & Yoon, 2020). Although there are many papers discussing this topic, there are limited studies that address a definite food design for specific populations, such as the elderly. Thus, this systematic literature review (SLR) was conducted to collect the data and specify the required characteristics to create 3D printed food for the elderly. The key to SLR was to create a research protocol to ease the process of searching for articles through a variety of databases before selecting and reviewing them (Shaffril et al., 2020a). Throughout the process, there was a classification, inclusion, exclusion, and critical selection using formulated questions to procure the best article for the selected topic.

This SLR was guided by the research question: How can 3D printing be applied to producing personalized food for the elderly? It was conducted to discuss the application of 3D printing to produce personalized food for the elderly based on their needs and acceptability. The technology of 3D food printing can precisely personalize their nutritional needs to improve their quality of life and address swallowing difficulties. Thus, the public or even researchers can determine the food characteristics that can be prepared by using this printing technology.

2. Method

2.1 The Review Protocol – PRISMA

The review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2009 checklist that contains items related to the systematic review content and serves as a tool to evaluate the comprehensiveness of the systematic review reporting (Liberati et al., 2009; Moher et al., 2009). The checklist consists of seven major sections: Title, Abstract, Methods, Results, Discussion, and Findings. Each must be accompanied by a rational elaboration, a pedagogical guide, and related examples (Page & Moher, 2017).

2.2 Formulation of Research Questions

To formulate the most suitable research questions, PICo (Population or Problem, Interest and Context) was used, which represents the primary concepts in a research review. For this study, the three major concepts in this review were elderly (population), personalized food (interest), and 3D printing (context) and were employed as keywords to develop the research questions. For example, “How can 3D printing be applied to produce personalized food for the elderly?”

2.3 Systematic Searching Strategies

Systematic searching strategies used in this study involved three main processes: identification, screening, and eligibility.

2.3.1 Identification

Identification was done by searching all the synonyms and related terms for the main keywords used in this study, which were elderly, personalized food, and 3D printing. The purpose of this process was to enable more choices of related articles to be included in the review from the selected database. As shown by Shaffril et al. (2020a), the research questions were used as a basis to develop these keywords. Meanwhile, the online thesaurus (Merriam Webster), the keywords suggested in the thesaurus of Microsoft Word, and common keywords used by past studies were the sources used to conduct this identification process. Two main databases were used to search for the related articles: Scopus and ScienceDirect (Table 1). The existing keywords were successfully enriched by the authors by selecting several synonyms related to this study before developing a full search string (using Boolean operators and phrase searching) to be used in the main databases. Additionally, the authors also selected Google Scholar to be the supporting database. Whereas a developed search string was used for the prior two databases, the authors created several appropriate combinations of keywords to be searched in Google Scholar. These combinations of keywords included elderly, geriatric, "3D printing", "personalized food", "customized food", "customized nutrition", "customized diet", "personalized nutrition", and "personalized diet" by using Boolean operators (AND, OR) and phrase searching functions. Haddaway et al. (2015) propose that Google Scholar has several advantages for use as an additional database in a systematic review. A total of 219 articles were obtained from the searching process in the three selected databases: Scopus, ScienceDirect, and Google Scholar.

Table 1. Database Selected and Search String.

Database	Search string
Scopus	TITLE-ABS-KEY (("Elderly" OR "geriatric" OR "old folks") AND ("personalized food" OR "personalized nutrition" OR "customized food" OR "customized nutrition") AND ("3D printing" OR "3D food printing" OR "additive manufacturing"))
Science Direct	TITLE-ABS-KEY (("Elderly" OR "geriatric") AND ("personalized food" OR "personalized nutrition" OR "customized food" OR "customized nutrition" OR “Personalized diet” OR “customized diet”) AND ("3D printing" OR "3D food printing" OR "additive manufacturing"))
Google Scholar	Elderly OR geriatric AND "3D printing" AND "personalized food" OR "customized food" OR "customized nutrition" OR "customized diet" OR "personalized nutrition" OR "personalized diet"

2.3.2. Screening

This study has set several inclusion and exclusion criteria to ease the process of article selection. The sorting function in each database sorted out all the 219 articles according to the inclusion and exclusion criteria (Table 2). The authors decided to review articles within a five-year period before the search was conducted, since it was impossible for them to review all the published articles available online, as corroborated by Okoli (2015). Furthermore, only English-based articles from 2016 until 2020 were included in this review to ease understanding. A total of 166 articles that did not meet the inclusion criteria were removed, and the remaining 53 articles were further screened for duplicates. Then, 11 duplicated articles were detected and removed, leaving 42 articles for the eligibility process.

Table 2. The Inclusion and Exclusion Criteria.

Criteria	Inclusion	Exclusion
Timeline	2016–2020	< 2016
Document type	Research article and thesis	Review article, conference, magazine, encyclopedias, books, chapter in books, book series, periodical, and others
Language	English	Non-english
Indexes	3D printing related to food printing	3D printing other than food printing

2.3.3. Eligibility

This process required the authors to retrieve all the published articles to be manually monitored so that the articles that were included in this review met the criteria. The eligibility process was carried out by going through the titles, abstracts, and conclusions of the retrieved articles. From this process, 27 articles were excluded due to the focus on ways to develop food models instead of using 3D printing for personalized food; focus on food presentation via 3D printing for children instead of the elderly; irrelevancy with 3D food printing; focus on 3D printing for nutraceutical delivery; focus on designing a 3D printer instead of designing food via 3D printing; focus on factors influencing 3D food printing instead of specifically on the characteristics of 3D food printing; focus on developing food equipment using 3D printers instead of developing food itself; focus on economic aspects of 3D food printers; focus on developing personalized food via other methods instead of via 3D food printing; focus on the development of systems to alter perception and illusions of 3D-printed food; and publication as thesis papers. As a result, only 15 articles remained to be reviewed.

2.4. Quality Appraisal

The quality appraisal was conducted to filter out low-quality articles from being included in this review. The remaining articles were assessed by reading all the articles thoroughly and executing the quality appraisal with the Critical Appraisal Skills Program (CASP) tool for systematic review. The authors modified several questions from the checklist accordingly to match the assessed research articles. The checklist was modified by omitting three out of ten questions, which were unrelated to the research articles. Only seven questions in the checklist were agreed to assess the quality of the articles’ contents. The marks obtained from the checklist were categorized as follows: 1 to 2 marks as low quality, 3 to 5 marks as moderate quality, and 6 to 7 marks as high quality. Only moderate and high-quality articles were included in this review. The articles would be reviewed if there was a mutual agreement between all the three authors that the articles must at least be classified as moderate quality. Any disagreement on the rank of any article was discussed among the authors, and the third author was the decision-maker. From this process, the authors ranked 10 articles as high quality and five articles as moderate quality to be included in this review (Fig. 1).

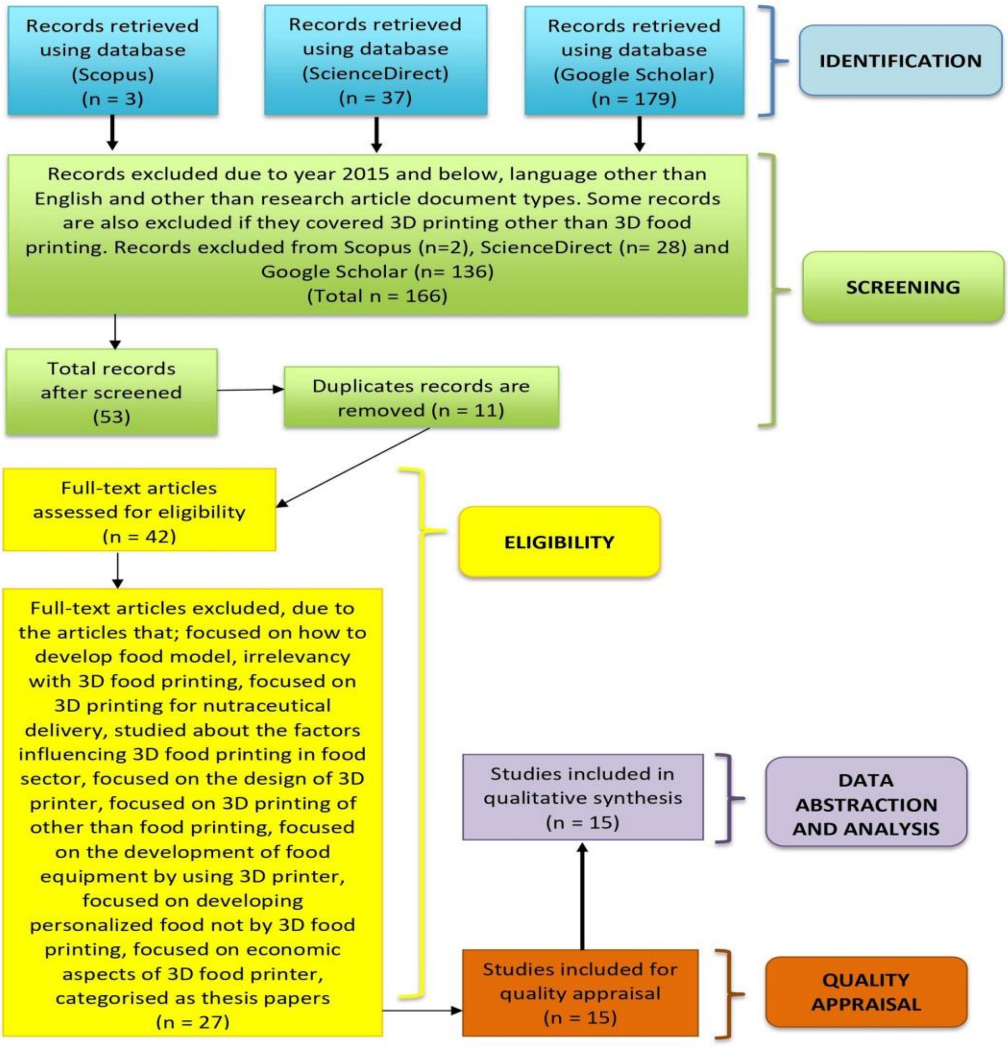

Figure 1. The Flow Diagram of Systematic Searching Strategies.

2.5 Data Abstraction and Analysis

This study used the qualitative synthesis technique. The entire 15 articles, especially the abstract, results, and discussion parts, were read thoroughly by the authors. The authors conducted data abstraction by abstracting any data from the included studies that could answer the research questions and was tabled. Then, the thematic analysis categorized all the data abstracted from all the reviewed articles into themes (Table 3). According to Shaffril et al. (2020b), the synthesis of data can be done either by qualitative synthesis, quantitative synthesis, or both. Thematic analysis is a part of qualitative synthesis that identifies important themes from the selected studies and groups them under the thematic headings (Braun & Clarke, 2006). According to Fleming et al. (2018), it is also the most suitable technique to synthesize a mixed research design, which started with the identification of similar patterns from all the selected studies and were grouped together. From this, seven main themes were discovered by the authors. Next, the accuracy of these themes was reviewed by all authors to ensure their suitability to present the data. The authors had excluded several themes unrelated to the research question, and the finalized themes were comprised of five main themes. The articles were divided among the authors for them to read, identify the patterns, and produce suitable themes. Afterward, the suitability of themes and the different interpretations of data were discussed until a mutual agreement was reached on the finalized themes.

Table 3. Data Abstraction Analysis of Reviewed Articles.

Study	Year	Food studied	Hardness	Viscosity	Moisture	Elasticity	Printability
Dankar *et al.*	2018	Potato Puree	/		/		/
Liu and Ciftci	2019	High-oil-content food pastes	/	/		/	/
Chen *et al.*	2018	Potato, rice and corn starches	/	/		/	/
Oyinloye and Yoon	2020	Mixture of pea protein and alginate	/	/		/	/
Derossi *et al.*	2020a	Cereal	/		/		/
Maniglia *et al.*	2019	Cassava starch		/	/		/
Dick *et al.*	2020	Pork	/	/	/	/	/
Huang *et al.*	2019	Brown rice	/	/		/	/
Zheng *et al.*	2019	Potato starch, corn starch, wheat starch	/	/	/	/	/
Derossi *et al.*	2020b	Cereal	/		/		/
Maniglia *et al.*	2020	Wheat starch	/	/			/
Jonkers *et al.*	2020	3D printed food with 50% native wheat starch, 40% maltodextrin, 10% palm oil powder				/	
Vieira *et al.*	2020	Cookies fortified with *Arthrospira platensis*	/	/	/	/	/
Liu *et al.*	2018	Milk protein incorporated with whey protein isolate (WPI)	/	/	/	/	/
Garcia-Segovia *et al.*	2020	Xanthan/Konjac gum		/		/	/

3. Results

3.1. Background of the Selected Articles

A total of 15 articles were obtained throughout the review process, and five themes were selected to be discussed: hardness, moisture, printability, viscosity, and elasticity. These themes were selected since they were emphasized and discussed deliberately in the studies. Furthermore, the themes affect the food structure to be tailored and consumed by the selected population. Hardness, printability, viscosity, and elasticity are crucial parts during the food extrusion and layering processes since inappropriate measures will result in failure. Meanwhile, moisture can affect all the other suggested parameters and primarily impact the shelf-life of the product. From the patient's acceptability perspective, hardness and elasticity must be within the acceptable range to be successfully printed and readily consumed by the elderly. From all the articles that were published in 2018 (3 journals), 2019 (4 journals) and 2020 (8 journals), the studies discussed the uses of potato puree, potato, rice, corn, wheat, cassava starch, cereals, pea protein, pork, and milk protein. They also included the effects of high oil content in food materials and biscuits incorporated with cyanobacteria.

3.2. Themes

The elderly population usually experience natural physiological changes as they age, such as swallowing difficulties (dysphagia) and reduced sensory perception that can lead to choking and aspiration. Texture-modified diets that consist of pureed, bite-sized, minced food and thickened fluids can help to reduce the risks of choking and aspiration in dysphagia patients (Dick et al., 2020). However, these foods are usually less appetizing to them (Dankar et al., 2018). Therefore, 3D printing allows the creation of food that resembles the original food but with modified textural properties (Dick et al., 2020).

3.2.1 Hardness

Most of the articles studied the hardness of different printed foods and the various parameters that affect it. Dankar et al. (2018) investigated the effects of extrusion parameters and additives on the specific mechanical energy (SME) of potato puree mixtures. They found out that SME was inversely proportional to the extrusion speed and that reducing the diameter of the hole also increased SME. Moreover, Huang et al. (2019) stated that the hardness of their printed sample was lowered significantly when the nozzle size, perimeter, and infill density were reduced. The smaller nozzle size produced a softer texture sample than the larger one. They also emphasized the benefits of controlling the infill levels to produce softer products that may be beneficial for elderly consumption.

Oyinloye and Yoon (2020) correlated the sample hardness with the ability of the materials to retain the shape and their extrusion characteristics after printing. They observed that increasing the concentration of pea-protein in their sample produced a harder printed product. Utilizing the combination of alginate and pea-protein as the basic material for 3D printing can positively improve texture, reduce hardness, and stabilize its shape. This was also supported by Dankar et al. (2018), who have shown that the SME increased with the addition of agar or alginate to potato puree. However, the SME decreased when the same concentration of lecithin or glycerol was added. Although potato puree, or a mixture of puree and glycerol or lecithin, created smoother extrusions, potato puree that was added with agar or alginate showed a more stable shape of extruded layers. Contrarily, the extrusion layers of potato puree alone and puree mixed with glycerol or lecithin easily collapsed and recombined post-extrusion (Dankar et al., 2018).

Besides that, Dick et al. (2020) also studied the effects of varying the concentration of two hydrocolloids – xanthan gum and guar gum – that were mixed with pork towards the formulation's texture profile after a post-processing heating. It was noted that the pork pastes without any added hydrocolloids were the hardest, followed by the formulation with only guar gum added. Addition of either one or both hydrocolloids result in a formulation with lower hardness compared to the sample without any hydrocolloids added (Dick et al., 2020). Vieira et al. (2020) developed functional cookie formulations that incorporated different forms of Arthrospira platensis. The cookie dough with the addition of A. platensis biomass was the hardest among all cookie formulations. In contrast, when the dough was incorporated with its free or encapsulated extract, these formulations showed a significant decrease in hardness compared to the control cookie dough without A. platensis.

The mechanical properties of the food pastes are reflected by their hardness (Liu & Ciftci, 2019; Zheng et al., 2019). Zheng et al. (2019) showed that their printed samples' hardness increased gradually with storage, specifically after 24 hours of storage. According to Liu and Ciftci (2019), the hardness of the high-oil-content food paste that they studied was affected by the ratio of starch more than the ratio of whey protein isolate (WPI). Liu et al. (2018) also reported that introducing WPI can soften the protein paste mixture, benefiting the extrusion and stability of deposited layers. Generally, a hard and rigid paste is formed from pure MPC powder, yielding a dry, rigid, and brittle extruded product compared to when it is mixed with WPI, which produces a

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softer and flexible paste (a dose-dependent process) (Liu et al., 2018).

Meanwhile, Liu and Ciftci (2019) also reported that increasing the ratio of starch resulted in increasing gel strength. The same result was reported by Chen et al. (2018), in which higher starch concentration increased the yield stress (τy) and storage modulus (G’) of samples, reflecting their mechanical strength. However, the flow stress (τf) also increased with increasing starch concentration, and if it was too high, it could affect the smooth extrusion of the starch samples (Chen et al., 2018). Zheng et al. (2019) also compared the addition of wheat, corn, and potato starches. They observed that wheat starch was the most suitable for 3D food printing. Most of the selected articles studied the effects of different proportions of materials and printing parameters on the hardness of printed products. Meanwhile, Maniglia et al. (2020) conducted research on the effects of dry heating treatment (DHT) on the improvement of wheat starch properties for 3D printing. They reported that increasing the DHT heating period could significantly increase the hardness of printed samples.

Derossi et al. (2020a) showed that the size and position of pores influenced the hardness of 3D printed snacks. Different hardnesses of 3D printed cereal snacks could be produced by modulating the position and number of pores. Thus, they suggested the potential of producing cereals with the desired mechanical properties to meet the specific requirements of the elderly. Lastly, Derossi et al. (2020b) compared the difference between 3D printed food and hand-made food. They observed that the layer-by-layer deposition of 3D printing had contributed to the increase in the hardness of printed food compared to hand-made ones. Moreover, 3D printed food had reduced pores that were bigger in size, leading to a denser food formula than hand-made food. This property made the 3D printed food harder than the traditionally hand-made food.

3.2.2 Moisture

Different kinds of materials incorporated into the sample have different abilities to hold or to prevent the binding of water molecules, thus adjusting the content can be made to meet the requirement. For the potato puree, the measured SME was reduced when it was incorporated with 1% lecithin or glycerol at 51.9 ± 2.1 and 52.0 ± 0.6 kJ.kg-1, respectively. In contrast, 1% alginate or agar would increase the hardness, with SME of 162.4 ± 10.1 and 217.0 ± 0.3 kJ.kg-1, respectively (Dankar et al., 2018).

Another type of starch-based ingredient used was cassava starch. The research was conducted by using DHT at 130°C against the starch component for 2 and 4 hours. This method was designed to maintain the moisture level below 10%. As the control sample contained 13.2% moisture content, the results after 2 hours and 4 hours were only 6.2% and 6.7%, respectively. Furthermore, the starch properties changed after the process. Consequently, maintaining the proper moisture content is crucial in producing a printable hydrogel (Maniglia et al., 2019). Similarly, in another study, wheat starch with longer DHT produced larger granules and lower moisture content (Maniglia et al., 2020). Zheng et al. (2019) discovered samples with wheat, potato, and corn starch as the main ingredients became harder with reduced springiness upon storage for 24 hours.

Derossi et al. (2020a) found that the 3D printed wheat-based cereal snacks having increased pores or honeycomb structure led to a greater moisture loss than the concentric structure upon baking. The smallest surface area of the sample showed changes in pore size and sample volume at -14.94 ± 9.1% and -9.56 ± 3.79%, respectively. Meanwhile, the largest surface areas showed changes of -26.92 ± 11.6% and -17.33 ± 0.67%, respectively. Negative volume denotes reduction in measurement. Another similar study using the same base ingredient showed different moisture content in the 3D printed cereals compared to the conventionally prepared ones (Derossi et al., 2020b). The results showed that the method for 3D food printing could produce an insignificant difference between the crumb and crust, which were 30g/100g and 15g/100g of water content, respectively.

Dick et al. (2020) reported that when the initial moisture content of meat was at 74.51 ± 0.05%, all the cooked samples in the paste form, either control or experimental, showed no difference in moisture content. All of them showed moisture content in the range of 76-77% (Dick et al., 2020). For biscuits incorporated with A. platensis, the moisture content was critical in suppressing the growth of bacteria or any other pathogens and to maintaining their crispiness. The successfully printed biscuits contained an average water activity (aw) of 0.3, low enough to maintain their crispiness and to suppress pathogenic activities (Vieira et al., 2020).

3.2.3 Viscosity

Liu and Ciftci (2019) discovered that storing paste at a low temperature (4°C) for a longer period of time improved viscosity. The 24-hour cooled paste had lower viscosity and a more stable shape of the printed product compared to the 2-hour storage. The results showed a similar trend to the ones observed by García-Segovia et al. (2020), in which the xanthan/konjac gum samples had reduced viscosity when the printing temperature was increased. In addition, by using different types of starch, Zheng et al. (2019) found that wheat and corn starch were less viscous and more thermally stable for the pasting process compared to potato starch. The viscous potato paste can possibly block the nozzle; thus, it needs adjustment for printing. Additionally, wheat starch exhibited the greatest thermal resistance to viscosity breakdown under temperature exposure of 91.28°C. Moreover, DHT-treated cassava starch also displayed a reduction in its peak apparent viscosity with gel firmness, indicating that the treated samples were better than the native starch (Maniglia et al., 2019). In another study by Maniglia et al. (2020), the apparent viscosity dropped substantially as the period of DHT increased.

Chen et al. (2018) observed that at the same shear rate, increasing starch concentration directly increases its viscosity. Within the range of shear rate from 0.1 to 100 s-1, the viscosity of potato starch was the highest at a low concentration of 10%, while rice starch became the most viscous sample when the concentration was increased to 30%. As for synergistic effects between ingredients, Oyinloye and Yoon (2020) found that higher pea-protein content in the alginate samples yielded higher viscosity. However, the sample with 100% pea-protein displayed the lowest viscosity with increasing shear rate. Optimum viscosity was shown in a blending ratio of 80:20 between alginate and pea-protein and it was best suited for 3D printing (Oyinloye & Yoon, 2020).

Comparatively, shear rate is another vital factor that affects the viscosity of 3D printed products. In an opposite trend, the apparent viscosity of protein paste samples remarkably abates with the shear rate. Furthermore, rising WPI composition was shown to cause the same viscosity result (Liu et al., 2018). Huang et al. (2019) stated a similar trend for the viscosity of brown rice paste with escalating shear stress and shear rate. Dick et al. (2020) added that a decreased apparent viscosity was observed in pork samples mixed with xanthan and guar gum as the shear rate was high and closer to the extrusion step. The addition of hydrocolloid to the samples provided no significant effect to the apparent viscosity. Vieira et al. (2020) utilized the encapsulation method and obtained dough with a lower viscosity, while high viscosity was observed in biomass cookie dough.

3.2.4 Elasticity

The corn starch and WPI incorporated with oil, at any ratio of corn starch, water and canola oil in the study, constantly showed higher G' than G". The sample with reduced corn starch or WPI and increased canola oil resulted in a greater reduction of both G' and G". The result was also observed from the printed object, which could not withstand layering during the process. G' and G" could be increased with longer storage time. Reducing either starch or WPI would create a better print, but too low starch content would reduce the hardness of the product (Liu & Ciftci, 2019). For the study on brown rice, the researchers also stated that higher G' than G" contributed to the elasticity of the gel structure which could be beneficial for the extrusion process (Huang et al., 2019). Rice starch showed the lowest tan δ (below 0.1), and a more consistent value was observed with a starch concentration of 15–30%.

Chen et al. (2018) found that the elasticity of all starches (corn, rice, potato) remained low under low temperatures until they reached a specific point called glass transition temperature (Tg), which ranged from 60–70 °C. At this point, G' and tan δ rapidly increase and decrease, respectively. Besides, potato starch showed the lowest Tg, which started at 60°C. The maximum glass transition state (TG'max) for potato, corn and rice starch was 71.2 ± 0.9°C, 73.2 ± 1.1°C and 84.4 ± 1.0°C, respectively. At TG'max, the concentration of potato, corn, and rice starch was 10%, 30%, and 10%, respectively. However, further heating resulted in a rapid reduction in the G' value for all samples. The G' value of corn and potato starch declined when exceeding 10°C from their Tg, while 20°C in the case of rice starch (Chen et al., 2018).

From a study conducted by Oyinloye and Yoon (2020), heating of all samples (pea-protein 100%, alginate 100%, alginate-to-pea-protein ratio of 90:10, 80:20, 70:30) with both heating rates (2°C/min, 5°C/min) showed increased G' and G" with G' constantly higher than G". Apart from that, the mixture of both ingredients showed higher G' and the highest G' was achieved with the 70:30 ratio using a 2°C/min heating rate. The increasing ratio of pea-protein increased the G', but the pea-protein and alginate alone showed lower G'. The G' value of 70:30 ratio was also the highest after the cooling process. All the samples showed a higher rate of increasing G' at 40–50°C (Oyinloye & Yoon, 2020).

Zheng et al. (2019) found that the samples of wheat and potato starch were more elastic than corn starch after being stored for 6 hours. After 24 hours, potato starch had slightly higher springiness compared to the others. However, corn starch constantly increased in springiness after a longer storage period. A study on a brittle sample of 50% wheat starch incorporated with maltodextrin (40%) and palm oil (10%) was conducted to characterize and measure plasticity and elasticity behavior. Elasticity was measured to differentiate it from plasticity by measuring the tension and compression when the model was compressed, showing the values of 1.0 MPa and -0.73, respectively. Moreover, the plastic deformation also resulted in a shear rate value of 1.0*10-3 s-1 (Jonkers et al., 2020).

In a test of 3D printed cookies incorporated with different preparations of A. platensis, Vieira et al. (2020) stated that all samples (control, biomass, free extract, and encapsulated extract) showed a tan δ value lower than 1 for all the temperatures tested. Besides that, the biomass-containing dough exhibited greater elasticity. This result was in contrast with the encapsulated extract. Elasticity decreases with increasing temperature after 40°C and remains constant until 105–110°C. Above this temperature, the elasticity profile rose again until it reached 120°C. The encapsulated sample had the lowest Tg (90°C), TG’max (110°C), and G’, while the biomass sample had the highest Tg (100°C), TG’max (120°C), and G’. Changes in elasticity parameters were similar for all types of samples (Vieira et al., 2020).

Pure MPC cannot be used for 3D printing because it does not have enough elastic semi-solid properties. Liu et al. (2018) prepared a few samples with different mixtures of MPC and WPI. They discovered that increasing the WPI ratio reduces G' in all samples. Adding one part of WPI to six parts of MPC greatly reduced tan δ. It showed that an MPC to WPI ratio of 4:3 had the highest G' and the lowest tan δ value (Liu et al., 2018). For the study which used the mixture of xanthan and konjac gum as the base, they found that the G' was more affected than the G" in respect to the printing temperature. For a mixture that has a melting temperature at 45°C, the lower printing temperature (25°C) resulted in greater G' (1006–1528 Pa) compared to the higher temperature, 50°C (390–644 Pa). The G' also be increased by reducing and increasing the concentration of syrup and gum, respectively. Moreover, the xanthan and konjac gum ratios played an important role in determining the elasticity, with the sample ratio of 2:1 showing the highest G' compared to the other ratios (Garcia-Segovia et al., 2020).

3.2.5. Printability

A lot of foods are printable with suitable modifications of certain parameters. According to Dankar et al. (2018), the best printability of potato puree is achievable with a 0.5 cm nozzle height and a 4 mm nozzle diameter with a range of alginate concentration of between 0.5% and 1.5% and an agar concentration of between 0.5% and 1%. Similarly, Huang et al. (2019) also showed that a smaller nozzle size improved their food samples’ printability.

Liu and Ciftci (2019) studied the relationship of paste composition and paste conditioning with the printability of food. Higher WPI content negatively affected the printability, while 24 hours of storage of the pastes at 4 °C improved the printability. However, Liu et al. (2018) showed different results. Their results showed that increasing WPI concentration had improved the printing performance of protein pastes. The best formulation for the successful printing of protein paste was the paste with an MPC to WPC ratio of 5:2. Besides, Chen et al. (2018) studied the influence of the rheological properties of corn, potato, and rice starch on their 3D printing performance. They proved that rice starch of 15% to 25% (w/w) concentrations at 80°C, corn starch of 20% to 25% (w/w) concentrations at 75°C and potato starch of 15% to 20% (w/w) concentrations at 70°C had the appropriate τf, τy, and G’ values for excellent printability, shape stability and resolution. Zheng et al. (2019) also approved the suitability of all starch gels in 3D printing, with wheat starch showing the closest dimension to the actual model.

Derossi et al. (2020a) believed that 3D printed cereal-based snacks with different hardness could be created via the modulation of position and number of pores. Derossi et al. (2020b) observed that the 3D printed food exhibited higher hardness, chewiness, and cohesiveness compared to the hand-made samples. Furthermore, Vieira et al. (2020) agreed on the potential of 3D printing technology as a great alternative to create cookies and other novel functional foods that can be incorporated with antioxidants, such as microalgae.

Besides that, Oyinloye and Yoon (2020) studied the different blends of alginate and pea-protein. They showed that the 100% alginate and 100% pea-protein samples might not be suitable for 3D printing. Some studies added hydrocolloid to improve the printability of food materials (Dick et al., 2020; Garcia-Segovia et al., 2020). Dick et al. (2020) examined the effects of adding xanthan gum and guar gum, either as individual components or in combination, on the printability of pork pastes. All the samples showed a shear-thinning effect, implying their suitability for 3D-extrusion printing. This suggests their possibility of becoming one of the transitional foods for people with swallowing problems (Dick et al., 2020). Meanwhile, Garcia-Segovia et al. (2020) observed that mixtures with higher xanthan gum and konjac gum content and a lower concentration of syrup exhibited greater values of G', G", and η*. Increased syrup concentration led to the reduction of Fmean, area, Fmax, and slope gradient.

Maniglia et al. (2019) evaluated the effects of DHT on the printability of hydrogels based on cassava starch. They concluded that DHT-treated starches, especially those that were treated for 4 hours, produced gels with better printability compared to native starch (Maniglia et al., 2019). Similarly, in their other work, Maniglia et al. (2020) observed that the best printability and better reproducibility were shown by the hydrogels treated with DHT for 4 h compared to 2 h at 130°C.

4. Discussion

Elderly people may require different nutritional requirements than normal people, which is often due to swallowing problems (dysphagia), which require specialized nutritious meals. Thus, 3D food printing could be one of solution to addressing the problems faced by the elderly by printing a suitable personalized food for them. Based on the thematic analysis, there are five parameters that can be modified to represent the research themes: hardness,

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moisture, viscosity, elasticity, and printability. This section will further discuss the themes (Table 4).

4.1 Hardness

Hardness is one of the important themes since it is related to the swallowing problems among the elderly. The hardness of printed samples can be controlled via printing parameters, such as nozzle diameter, infill density, and perimeters (Huang et al., 2019). The diameter of extrusion lines is determined by the nozzle size, while perimeters refer to the amount of layer at the outer part of the printed samples, and infill density refers to the solid proportion in the inner part of the printed samples. When using a 3D slicer to slice the designed food, more layers are sliced with the use of a smaller nozzle. Consequently, this helps to improve the texture of the printed materials (Huang et al., 2019). The SME of the sample can also be decreased with a smaller diameter hole. It will create more friction that leads to a higher applied force needed to extrude the samples (Dankar et al., 2018). Thus, reducing the nozzle diameter, infill density, and perimeters can help to reduce the hardness of the printed samples.

A combination of 80% alginate solution and 20% pea-protein solution as the printing material can create a softer texture food. This is due to their ability to increase the gel strength, which is caused by the calcium release from the alginate gel that can induce the coagulation of aggregated proteins (Oyinloye & Yoon, 2020). Dankar et al. (2018) showed that a lower SME was recorded in the potato puree mixed with lecithin or glycerol compared to the addition of alginate or agar. This is because of the moisture retention ability of lecithin or glycerol that can disrupt the starch granules' internal microstructure, thus softening the material. However, potato puree mixed with alginate or agar is preferred because it can retain the stability of shape after printing better than the mixture with glycerol or lecithin. Even though the mixture with glycerol or lecithin was smoother, its extruded layers collapsed after printing (Dankar et al. 2018).

Adding hydrocolloids can also produce a transitional food that is useful in addressing the swallowing problems faced by the elderly (Dick et al., 2020). It was reported that the ideal ratio of hydrocolloids in the pork pastes was the formulation with a xanthan to guar gum ratio of 70:30. This formulation is more flexible, presenting a less compact microstructure than the pork pastes without hydrocolloids. The less elastic formulation contributes to a higher hardness texture due to a more compact microstructure as seen in the pork pastes without hydrocolloids (Dick et al., 2020). Food thickeners, such as starch and xanthan gum, can act as rheology modifiers in food printing to improve the food materials to be printed (Huang et al., 2019).

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Table 4. Summary of Article Findings.

Themes	Hardness	Moisture	Viscosity	Elasticity	Printability
Dankar et al. (2018)	- SME is inversely proportional to extrusion speed, in such a way that the SME decreases with increasing extrusion speed. - Reducing the diameter hole also increases SME.	- The use of water-binding agent increases moisture content, thus softens the starch-based puree. - The use of hydrocolloid increases molecular bonding, thus increasing the puree hardness.	Not discussed.	Not discussed.	A mixture of potato purees with a specific concentration range of agar or alginate can produce a more stable printed product that can retain their shape longer without deforming.
Liu and Ciftci (2019)	- The hardness of food pastes increases with or without storage when there is an increase in the total mass. - Reducing WPI ratio leads to a smoother printed pastes' surface and since they do not spread, the printed shape can be retained well. - Increasing the ratio of starch results in increasing gel strength.	Not discussed.	Increasing total mass, shear rate and storage period within 24 hours improves product viscosity.	Elasticity was increased with increasing percentage of corn starch used and longer storage period.	- Reducing starch or WPI concentration improves the printability of the hexa shape while reducing the starch content to print vase-shaped paste results in poor printability. - Starch acts as a thickening agent and plays a vital role in maintaining the height and weight of the vase-shaped paste.
Chen et al. (2018)	Higher starch concentration will increase the yield stress (τy) and storage modulus (G') of samples, which also reflects their mechanical strength.	Not discussed.	Within constant shear rates, the viscosity rises as the concentration increases.	Rice starch has good thermal stability, and it does not lose its elastic properties in wide range of temperature during printing process.	Starches' shear-thinning and strain-responsiveness behaviour make them suitable for and printable as 3D printing food materials.
Oyinloye and Yoon (2020)	- Increasing the concentration of pea-protein produces a harder printed product. - Combination of alginate and pea-protein as the basic material for 3D printing is beneficial to produce a sample with good texture and reduced hardness while stabilizing its shape.	Not discussed.	An optimum result of easy extrusion was found in a blending ratio of 80:20 (alginate to pea protein).	- Elasticity of pea-protein based food can be increased by using higher amount of pea-protein and slower heating rate. - The best model should have gelation temperature nearly similar to extrusion temperature.	A mixture of pea protein and alginate shows stable thermal properties and no endothermic peak is detected at lower temperature, indicating that the nutritional compositions in the mixture are well-preserved at the extrusion temperature, 45°C.

Derossi et al. (2020a)	- Different hardness of 3D printed cereal snacks can be produced by modulating the position and number of pores. - Cereals with desired mechanical properties can be produced to meet the specific requirements of certain populations such as the elderly people.	Increasing surface area will increase evaporation rate, which will make the sample lose moisture faster.	Not discussed.	Not discussed.	- Printed snacks are smaller than the virtual model, which may be caused by dehydration during the baking process. - There are additional pores developed throughout the dough deposition and baking, which resulting in higher porosity fraction in the printed sample.
Maniglia et al. (2019)	Not discussed.	Pre-treatment of sample with DHT greatly reduces the moisture content of the sample.	The product apparent viscosities drop when the treatment period increases. However, it must be altered at a level that is easy for extrusion.	Not discussed.	- DHT for 4 hours has produced the best printability compared to DHT for 2 hours at the temperature of 130°C. - DHT-treated starches are also presented with lower water absorption index (WAI).
Dick et al. (2020)	Addition of hydrocolloids to samples, either on its own or in combination, can create a formulation with lower hardness compared to the sample without any hydrocolloids added.	Hydrocolloid does not affect moisture content.	Overall, there are no changes in the apparent viscosity upon the addition of hydrocolloids.	Not discussed.	Adding samples with hydrocolloids, either in combination or on its own has shown an admirable textural and rheological properties of the end-products.
Huang et al. (2019)	- Hardness of their printed sample is lowered significantly when the nozzle size, perimeters and infill density are reduced. - Control the infill levels to produce softer products that may be beneficial for elderly consumption or people with mastication problems.	Not discussed.	Elevating both shear stress and shear rate leads to reduced viscosity of the brown rice paste.	Higher G' and lower G" indicate good elastic properties of sample	- Printing precision is significantly affected by the nozzle size due to the influence of gravity towards the deposition of extruded lines. - Smaller nozzle size minimizes the deviation in the dimensional properties of their samples.
Zheng et al. (2019)	- Printed samples' hardness increases gradually with storage, specifically after 24 hours of storage. - Wheat starch is the most suitable for 3D food printing.	- Lower moisture content will reduce springiness of the sample. - Wheat starch can hold the highest amount of water molecules.	Each species of the starches exhibits different level of viscosity. Moreover, higher viscosity would make extrusion more difficult during 3D printing.	Elasticity or springiness will reduce with extended storage period of the sample.	Wheat starch gel is the most suitable starch to be used as 3D food printing materials due to lowest viscosity, better extrusion ability and excellent storage properties.

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Derossi et al. (2020b)	- Layer-by-layer deposition of 3D printing has contributed to the increase in hardness of printed food compared to the hand-made ones.	With specifically similar method used, the sample with the same amount of moisture is reproducible.	Not discussed.	Not discussed.	The samples’ microstructures vary in 3D samples, affecting their mechanical properties and resulting in less favourable textures compared to the hand-made samples.
Maniglia et al. (2020)	Increasing DHT heating period can significantly increase the hardness of printed samples.	Reducing moisture content without changing the physical properties can be done by using low temperature DHT with longer period.	Long period of DHT reduces apparent viscosity significantly.	Not discussed.	Yield stress of DHT-treated starch increases with increasing DHT time, which is an important characteristic of the food material to retain its shape under gravity and stresses from the deposited layers. - Syneresis is also reduced when the wheat starch is modified with DHT.
Jonkers et al. (2020)	Not discussed.	Not discussed.	Not discussed.	For 3D food printing, its elastic properties do not relate to plasticity.	Not discussed.
Vieira et al. (2020)	- Cookie formulations incorporated with addition of A. platensis biomass is the hardest among all cookie formulations. - Dough that is incorporated with A. platensis free extract or A. platensis encapsulated extract showed a significant decrease in hardness compared to the control cookie dough without A. platensis.	The method used by the researchers can produce a cookie with aw level as low as 0.3. This moisture level is low enough to suppress any growth of microbes.	Dough containing antioxidant extract has unstructured network that leads to reduced viscosity, which consequently lowers its resistance to deformation.	- The sample exhibits gel-like material when $\tan \delta < 1$. - Sample incorporated with biomass extract shows the highest elastic properties and the most heat stability since it has the highest TG’max.	By using a diameter close to the opening of the nozzle, all the formulation present consistent dimensional properties post-deposition. - Using the antioxidant extract in encapsulated form is preferable to improve the stability of 3D printed cookies towards different environments.

Liu et al. (2018)	- Using pure MPC alone is too hard to be extruded from the nozzle, thus yielding a dry, rigid and brittle extruded product. - The ideal ratio of MPC to WPI is 5:2. This mixture is easily extruded from the nozzle and it successfully maintains its shape post-extrusion.	Not discussed.	The addition of WPI lowers the apparent viscosity and it is prepared at ratio of 5:2 (MPC/WPI), providing mechanical strength for deposition and adhesion.	MPC to WPI ratio of 5:2 shows the best elastic properties which enable the sample to be printed and layered properly without affecting its confirmation.	- Increasing WPI concentration helps to improve printing performance of protein pastes. - However, increasing too much WPI concentration can result in a protein paste possessing weaker mechanical strength, which can lead to collapse.
Garcia-Segovia et al. (2020)	Not discussed.	Not discussed.	Viscosity serves as a parameter to study rheological and viscoelastic behaviour.	- Higher gum percentage results in greater elasticity. - The printing temperature that is higher than its melting point will reduce elasticity and increase flowability.	- Increasing concentration of xanthan gum and konjac gum and lowering the concentration of syrup lead to higher values of G', G", and η*, influencing textural properties.

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Liu and Ciftci (2019) observed that the gel strength could be increased by increasing the starch concentration. There is a higher number of starch molecules per unit volume when the starch concentration is increased. This increases the possibility of more intermolecular hydrogen bonding, resulting in a more compact structure that can increase the gel strength. Furthermore, it is recommended that the printing paste be stored at a cold temperature (4°C) to incorporate more oils into the paste. Higher mechanical and gel strength are noted with increasing storage time, providing shape stability of the printed paste after extrusion (Liu & Ciftci, 2019). However, Zheng et al. (2019) showed that their printed samples' hardness increased after 24 hours of storage, possibly due to the higher likelihood of getting dehydrated after cold storage.

Besides that, Liu et al. (2018) suggested the addition of WPI to soften protein pastes. The higher proportion of WPI contributes to a significant reduction in the hardness of protein pastes, as reflected by the alternating interactions shown by the macromolecules of the protein and other small molecules. However, a further increase in WPI proportion will create a smoother texture but with lower shape fidelity (Liu et al., 2018). Reducing relative density is also crucial to lowering the hardness of printing samples, which is also related to porosity, as portrayed by Derossi et al. (2020a). Derossi et al. (2020b) reported that 3D printed food exhibited lower and bigger-sized pores compared to hand-made food, which is may be due to the imbalanced printing conditions.

4.2 Moisture

Moisture content is an important characteristic to be addressed because it can affect various properties of the product, including the extrusion or post-extrusion process. Moisture content may affect the hardness of extruded materials (Dankar et al., 2018), printability (Maniglia et al., 2019), springiness (Zheng et al., 2019), crispiness, and bacterial stability (Vieira et al., 2020). Besides that, moisture content can be affected by the surface area of the printed object (Derossi et al., 2020a). Dankar et al. (2018) revealed that the incorporation of lecithin and glycerol could reduce the SME of the puree. Both lecithin and glycerol can bind with water molecules, reducing the microstructural integrity of starches, and thus, making it softer. In contrast, when incorporating alginate and agar of the same percentage, the material becomes harder since its hydrocolloid properties cause the formation of random, multiple, and continuous bonds with starch molecules. Although alginate has a lower SME compared to puree alone, the shape of the extruded product has better integrity and shape. Consequently, adding alginate softens the materials while, at the same time, increasing their integrity.

Proper moisture content is also important for the printability of materials. The use of DHT before the extrusion process significantly affects the moisture properties of materials after being printed (Maniglia et al., 2019). The longer the period of starch under DHT, the lower the moisture content due to vaporization. The starch properties have also been observed to change, with the granules becoming larger upon DHT. However, using a lower temperature while targeting for a similar moisture content resulted in no changes in granule size, indicating that high temperature is responsible for the properties change (Maniglia et al., 2019; Maniglia et al., 2020). Thus, to maintain the starch properties, a lower temperature can be used while increasing the duration of process. Apart from that, the springiness of the object can be related to moisture content, with lower moisture contributing to less springiness (Zheng et al., 2019). Wheat starch had been shown to hold water molecules better upon storage up to six hours, but it greatly declines after 24 hours. Consequently, the loss of springiness can be attributed to the dehydration during storage. Therefore, observations need to be conducted at a shorter interval, especially on the 12th hour, to identify if wheat starch can hold water molecules for an intermediate storage period.

Derossi et al. (2020a) created a 3D printed food model with a similar size but different numbers of pores. Increasing pore numbers will proportionally increase the surface area. In turn, the increased surface area will significantly increase the evaporation rate, thus greatly reducing the moisture content. Therefore, the honeycomb structure has greater pore size and sample volume reduction upon baking compared to the concentric structure (Derossi et al., 2020a). The study conducted by Derossi et al. (2020b) concluded that a 3D food printing method could produce the same water content in the same snacks made with the same basis if they were processed specifically according to the author's research.

Hydrocolloid is used to increase water dispersion throughout the matrix. Hydrocolloids have been indicated to not affect the moisture content of the matrix since the control sample, incorporated by single or both hydrocolloids, has not changed the moisture content upon heating. However, the incorporation of both hydrocolloid guar gum and xanthan gum improved the pork paste texture, enabling it to be consumed by dysphagia patients (Dick et al., 2020). Although hydrocolloids do not significantly affect moisture content, their incorporation can improve the texture. The chewiness of pork pastes alone reached 37.19 ± 2.13 N, while incorporating xanthan gum and guar gum at a ratio of 1:1, 7:3 and 3:7 had significantly reduced the chewiness (Dick et al., 2020). This result can be achieved by using a higher guar

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gum percentage than xanthan gum since it is cheaper and it offers nearly similar textural properties.

In the study of microbial growth in the food manufacturing process, aw is a crucial factor to be monitored to prevent growth (Vieira et al., 2020). The aw is a measure of water molecules that participate in enzymatical, chemical, or biological reactions. The study stated that the suppression of bacterial and mold or yeast activities would be suppressed if aw was below 0.8 and 0.6, respectively. The 3D printed biscuit managed to maintain a low aw, which was below 0.3 even after being stored for 30 days. Therefore, 3D food printing can produce a microbiologically stable product as well as maintain its crispiness (Vieira et al., 2020).

4.3 Viscosity

Liu and Ciftci (2019) mentioned that low water content can reduce viscosity and gel strength as it limits the starch swelling ability and amylose leaching. The gel that was made up of corn starch and WPI required a low amount of water to allow smooth flowability through a small diameter nozzle. The viscosity level must be below the extrusion pressure before being printed into a paste. Upon being stored for 24 hours, the viscosity was observed to increase slightly, yielding a better paste shape.

The behavior of viscosity can also be impacted by shear rate as adopted by the non-Newtonian fluid with shear-thinning properties that vary according to the nature of the material. For example, elevations in both shear stress and shear rate lower the viscosity of brown rice paste (Huang et al., 2019). Chen et al. (2018) added that all starch samples fell under a similar category. Utilizing starch from corn, rice, and potatoes, increasing its concentration improves the viscosity, although the same shear rates are applied. Moreover, the peak viscosity is different for each material depending on their concentration. In the shear rate ranged from 0.1 till 100 s^{-1}, potato starch reached the highest viscosity value at concentrations of ≤ 10% (w/w) while the peak viscosity of rice starches required 15 to 30% (w/w) (Chen et al., 2018).

Dick et al. (2020) observed that a similar relationship between viscosity and shear rate existed in cooked pork paste. However, the utilization of hydrocolloids in the pork paste samples did not yield any significant effect on the apparent viscosity except for the control sample. The hydrocolloids affected the stability of the sample matrix, resulting in reduced apparent viscosity. The peak viscosity refers to the maximum ability of a material to retain its structure while swelling during the gelatinization process. To be precise, the resistance is observed as the starch granules swell before disintegration (Gou et al., 2019).

In a study related to protein, Liu et al. (2018) highlighted that viscosity affected the extrusion process. Successful printing requires a certain correct ratio of specific materials used to produce the right viscosity. For instance, MPC and WPI were combined in a 5:2 ratio to provide adequate mechanical strength for layer deposition and adhesion. Besides, the WPI particles react to water molecules, reducing the apparent viscosity and easing the extrusion of protein pastes. The viscosity had remained low during the process to improve flowability and became high after the process to allow adherence of the printed layers between one another. The observation was corroborated by Liu and Ciftci (2019) and Garcia-Segovia et al. (2020). Conversely, products with high viscosity will stick on the wall and block the nozzle that will lead to inaccurate shape of the printed product (Oyinloye and Yoon, 2020; Zheng et al., 2019). Garcia-Segovia et al. (2020) observed that the product's viscosity is enhanced by decreasing the ratio of syrup while increasing the ratio of both materials.

Meanwhile, Zheng et al. (2019) found that wheat starch gel has the lowest viscosity, better extrudability, and better storage properties but low thermal stability compared to corn starch. This is due to the granule size and shape. Besides, Oyinloye and Yoon (2020) found that increasing the percentage of pea-protein in the sample mixed with alginate resulted in greater viscosity due to the hydrophilic nature of pea-protein that absorbs moisture. The result was similar when the pea-protein was exposed to a higher temperature. However, the 100% pea-protein sample recorded the lowest viscosity. After applying a high temperature of 40°C, the sample turned into a gel with a high viscosity, but it was not favorable for 3D printing. Hence, the blending ratio of alginate to pea-protein for 3D printing was set optimally at 4:1.

Besides, some studies have utilized DHT to alter the product viscosity and firmness. The molecular and granular structures of the sample are modified based on the temperature and the treatment storage time. A cassava starch sample appeared to be the strongest gels with the least peak apparent viscosity under all the evaluated conditions after being treated at 130°C for 2 and 4 hours (Maniglia et al., 2019). Maniglia et al. (2020) further explained that DHT lowered the peak apparent viscosity by cleaving the glycosidic linkage between the starch particles, a process known as depolymerization. This process weakens the granules and diminishes their integrity through thermal degradation of the crystalline structures. Longer treatment time is associated with greater reduction of the peak apparent viscosity.

4.4. Elasticity

The matrix should exhibit pseudoplastic and shear-thinning behavior to ease the printing process. It should also ideally be able to withstand its own weight upon completing the process. Plus, thermoelastic value analysis helps to form good layering during the printing process (Oyinloye & Yoon, 2020). This value can be measured by the mechanical strength, where a higher value shows the ability to retain its structure. Higher G' with lower G" indicates the high elastic property of the matrix and it will have a gel or gel-like behavior (Huang et al., 2019; Liu & Ciftci, 2019). Besides that, Chen et al. (2018) stated that tan δ < 0.2 might indicate good elasticity property.

Liu and Cifti (2019) reported that all the samples showed G' is higher than G", indicating a matrix with gel-like properties. On the other hand, a reduction in corn starch percentage in the sample reduces elasticity. Corn starch acts as the water-binding agent, forming a crosslinking of the gel that strengthens the bond. Reducing corn starch can reduce the bond formation, thus reducing elasticity and vice versa. Storage time can also increase G' and G" due to more time being allowed for the agent to form more bonds (Liu & Ciftci, 2019).

The study on the effects of temperature on starch elasticity showed that at a specific level (Tg), the elasticity would rapidly increase as denoted by the rapid incline of G' and the decline of tan δ. The researchers stated that a good elastic starch suspension will have G' > 500 Pa and tan δ < 0.2 upon increasing the temperature. Tan δ is the measurement of its elasticity, with lower values indicating a greater ability to withstand plastic deformation. At Tg, the starch granules start to swell and form interactions with other ingredients. TG’max is the temperature when the sample has the highest elasticity value. Further temperature rises reduce G', indicating that the starch molecules start to degenerate and break their molecular interaction (Chen et al., 2018). Rice starch offers the widest range of Tg compared to other starches used, indicating that it has better thermal stability. The concentration of starches used does not correlate with TG’max, thus further research needs to be conducted to determine the absolute cause.

In the study conducted on alginate and pea-protein, the elastic properties were different due to the interaction between the two materials with respect to heating. Through heating, the mixture shows an increase in G’ with an increasing ratio of pea-protein. The calcium ions of alginate react with the protein molecule to enhance the covalent bond, thus describing the change in elastic properties as it behaves as a gel. The rate of heating can also affect the G' value. A slower heating rate (2°C/min) resulted in greater G' compared to a higher heating rate (5°C). A longer period allows the protein molecules to rearrange and create a more structured network. Increasing the pea protein-to-alginate ratio can yield stronger bonds, thus resulting in a higher G' compared to pea-protein and alginate alone. Apart from that, all the samples’ Tg ranged from 40 to 50°C due to the higher increase in the rate of G’ in this range. Due to the increased elasticity, a too low gelation temperature will increase the pressure required during extrusion. Therefore, the pea-protein amount needs to be adjusted so that it reaches a gelation temperature nearly similar to the extrusion temperature, which is 45°C (Oyinloye & Yoon, 2020).

Elasticity can also be measured through the springiness of the mixture. Springiness is determined by the water content; more water escape results in a less elastic, hard, and compact structure. The study showed that the samples incorporated with potato and wheat starch were highly elastic in the 6th h but reduced after the 24th h (Zheng et al., 2019), indicated that the water started to leave the samples 6 h later. Thus, this mixture can be produced due to its high elasticity, but it cannot be stored for a long period of time. Apart from that, the base that uses corn starch can be stored for a longer period since its elasticity does not deteriorate after 24 h, but it is naturally harder and less elastic from the beginning.

Through stress-strain tests on several brittle models with different geometries, Jonkers et al. (2020) observed that the plasticity did not correlate to elasticity. This is because plasticity is measured through the macroscopic stress-strain response, showing signs of deformation before a fracture stress is reached. The sample’s plasticity, measured as shear rate, was 1.0*10-3s-1 while the elasticity was so small and insignificant that both did not correspond to each other (Jonkers et al., 2020). Thus, the studied model showed that the elasticity of the brittle model did not correspond to plasticity. With the sample having a tan δ lower than 1, all the cookie dough exhibited a gel-like property (Vieira et al., 2020). The dough that uses biomass had the largest G’ because its free composition created more networks with other materials in the dough. Compared to encapsulated extract, their content was trapped, and consequently no additional or strengthening of the bond could be created. All samples decreased in elasticity upon reaching 40°C due to the melting of butter used during the preparation of the dough. The biomass also indicated that it was the most heat stable compared to other preparations due to the highest TG’max. The reduced elasticity profile after such a temperature indicates that the bond starts to break because of molecular deterioration (Vieira et al., 2020).

The pure form of MPC is stiff and cannot behave as a semi-solid. Since it needs a very high extrusion force, it cannot be a candidate to be used in 3D printing. However,

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the incorporation of WPI manages to reduce its G' value, allowing it to behave as a viscoelastic material. WPI can hold water particles, incorporating them together with the sample. Increasing the water content will soften the materials, reducing their G' from their original sturdy state. However, excessive WPI will greatly reduce G' due to excess water content, making the mixture too soft, less elastic and exhibiting high flowability. The 4:3 ratio of MPC to WPI has been shown to have the lowest G' and highest tan δ. However, in this condition, the mixtures were too soft, showing failure in the layering process. Thus, the best MPC-to-WPI ratio to produce a suitable elastic material for smooth extrusion and good layer adhesion while withstanding external pressure is 5:2 (Liu et al., 2018). Consequently, very high G' and very low tan δ are bad for elasticity and printing process.

Garcia-Segovia et al. (2020) studied the effects of printing temperature on the elasticity of gel material using xanthan and konjac gum. The xanthan gum used has a melting point of 30–45°C. When the printing temperature is higher than the melting point, the elastic property of a gel is reduced. This observation correlated with the test since 50°C printing temperature resulted in a significantly lower G' compared to 25°C (Garcia-Segovia et al., 2020). Increasing the gum concentration also increases the G' or elasticity, since the gum itself contributes to the elastic properties of the mixture. Consequently, printing at a higher temperature than the melting point of substances can greatly reduce elasticity and increase flowability due to the melted samples (Garcia-Segovia et al., 2020). Besides that, the correct proportion of gel materials is necessary to produce good elastic properties during printing.

4.5. Printability

The 3D food printing technology has some limitations in building the 3D structure of the food and retaining the shape of the printed food post-printing. The composition of the food ink to be printed and the printing parameters of the 3D food printers highly affect the performance of the end products (Çakmak & Gümüş, 2020). Therefore, all the reviewed studies have focused on achieving good printability of food materials by modulating certain parameters that can affect the texture and rheology of the studied food. Before concluding that the ideal nozzle height was 0.5 cm, Dankar et al. (2018) tested the effect of a ≥ 1 cm nozzle height and irregular material flow. Irregular material flow was caused by the delayed deposition, which led to brittle extrusion layers. The surface roughness and precision of the samples were also affected by the nozzle diameter (Dankar et al., 2018).

Huang et al. (2019) reported that smaller nozzle size could improve 3D food printing precision. Printing precision was significantly affected by the nozzle size due to the influence of gravity on the deposition of extruded lines throughout the printing process. They concluded that smaller nozzle size should be used to greatly minimize the deviation in the dimensional properties of their samples. The type of substrate is also crucial during the printing process. Dankar et al. (2018) concluded that the mixture of potato purees with a specific range of agar or alginate concentration could produce a more stable printed product that could retain its shape longer without deformation. This is possibly due to the higher internal strength and higher SME shown by the formulation incorporated with agar or alginate. Thus, they suggested the possibility of substituting unappealing meals for people with swallowing difficulties by developing foods in a more innovative way.

Liu and Ciftci (2019) observed a negative effect of increasing WPI concentration on their samples' printability. WPI acts as a water and liquid oil emulsifier, which is co-applied with starch, a thickening agent. Successful printing also depends on the optimum weight of the pastes. Consequently, reducing starch or WPI concentration improves the printability of the hexa shape while reducing the starch content to print vase-shaped paste, results in poor printability. This is because the starch acts as a thickening agent and maintains the height and weight of the vase-shaped paste. The gel strength has been observed to increase with reduced starch content, but due to the absence of sufficient thickening agent, the end-product collapsed after printing (Liu & Ciftci, 2019). Besides that, 24 h of storage at 4°C has improved the printability of the pastes by increasing the gel strength. However, the gelation time and swelling are different with different gelling agents (Kim et al., 2018). Gelling agents that reduce the gel strength of the printed pastes during storage are not suitable to be used in 3D food printing since this technology needs consistent rheological properties (Liu & Ciftci, 2019).

Contrarily, Liu et al. (2018) observed that increasing WPI concentration helped to improve the printing performance of protein pastes. They stated that pure MPC paste was fragile, dry, and rigid upon extrusion from the nozzle, and it could not be shaped via extrusion-based printing. When they increased the MPC/WPI ratio to 6:1, the protein paste was easily extruded, but was still highly brittle and prone to collapse after printing. They further increased the WPI content and noted a smooth extrusion of protein paste with a more stable shape. However, excessively increasing WPI concentration can result in a protein paste with weaker mechanical strength, which can lead to collapse due to the inability to support its own weight. Consequently, protein paste with an MPC/WPI ratio of 5:2 was the best mixture since it provided excellent textural properties (Liu et al., 2018). Thus, it is imperative for the printed material to have optimum mechanical strength to support the weight of the deposited layers.

Zheng et al. (2019) and Chen et al. (2018) supported the use of starch-based food materials in 3D food printing technology. Chen et al. (2018) claimed that starches' shear-thinning and strain-responsiveness behavior made them suitable as 3D printed food materials. To ensure excellent starch printability, the desired starch-based printing materials should possess the optimal τy and G' values since these parameters are important in shape retention by being able to support their own weight. Other than having the appropriate τy and G' values, low τf values are also important to ensure smooth extrusion from the nozzle. Both τy and τf values are dependent on the concentration of the starch (Chen et al., 2018). Meanwhile, Zheng et al. (2019) concluded that wheat starch gel was the most suitable starch to be used as the 3D food printing material due to its lowest viscosity, better extrusion ability, and excellent storage properties. Thus, researchers can include wheat starch in future 3D food printing research within the concentration ranges that have appropriate G', τy and τf values to ensure successful printability of starch-based materials.

Derossi et al. (2020a) suggested the possibility of printing cereal-based snacks with different textures by controlling the numbers and sizes of pores. Even though the 3D printed snacks exhibited high shape fidelity without deformation even after the baking process, there was an 8% size reduction in the printed sample. Therefore, the snacks were smaller than the virtual model, which might be caused by dehydration during the baking process (Derossi et al., 2020a). The 3D printed samples studied by Derossi et al. (2020b) have a bigger pore size and a reduced number of pores caused by the screw-extrusion system and essential food compression in the 3D printing system. However, the main cause that creates most of the pores is the imbalanced printing conditions–printing speed and extrusion rate. The samples' microstructures vary greatly in 3D samples, affecting their mechanical properties and resulting in less favorable textures compared to the hand-made samples (Derossi et al., 2020b).

Furthermore, Vieira et al. (2020) studied different forms of A. platensis and their effects on the rheological properties of the 3D printed cookies. Their results have confirmed the suitability of all the formulations for extrusion. By using a diameter close to the opening of the nozzle, a homogenous filament was formed, and all the formulations presented consistent dimensional properties post-deposition. They also explained that using the antioxidant extract in the encapsulated form was much preferable to improve the stability of the 3D printed cookies in different environments.

Besides that, a mixture of pea-protein and alginate showed stable thermal properties, and no endothermic peak was detected at a lower temperature, indicating that the nutritional compositions in the mixture were well-preserved at the extrusion temperature, 45°C (Oyinloye & Yoon, 2020). Even though the mixture does not retain for a long time in the extrusion chamber, thermal stability is still important because it reflects the ability of the mixture to retain its nutrients from heat degradation at the printing temperature. Higher denaturation temperature of the mixture allows it to retain its nutritional components throughout the printing process (Oyinloye & Yoon, 2020).

Adding samples with hydrocolloids has shown an admirable textural property of the end-products (Dick et al., 2020). After heating, these samples displayed lower hardness, cohesiveness, and chewiness compared to the pork paste without any hydrocolloids. Cryo-SEM micrographs showed textural changes in samples with hydrocolloids due to the additional retention of water by the hydrocolloids, resulting in the formation of less dense matrix (Dick et al., 2020). Garcia-Segovia et al. (2020) implied that different compositions of gels could influence the textural properties. Reducing other components in the mixture also led to the reduction of Fmax, Fmean, area, and slope gradient due to the reduced synergistic interactions between xanthan gum and konjac gum (Garcia-Segovia et al., 2020). Thus, adding hydrocolloids helps to improve the texture of food materials, consequently improving their printability.

Lastly, results from Maniglia et al. (2019) and Maniglia et al. (2020) showed that longer DHT treatment had produced the best starch printability at the temperature of 130°C. Maniglia et al. (2019) explained that starch treated with DHT for a longer time had a larger granule size and higher carbonyl content. Water vaporization during the DHT treatment might contribute to the expansion of the granules and, hence, the larger granule size (Maniglia et al., 2020). Moreover, the higher carbonyl content presented in DHT-treated starches was caused by the oxidizing capability of DHT towards the starch molecules, and this was observed with increasing DHT period (Maniglia et al., 2019). The molecular structural changes indicate the effectiveness of DHT in modifying starches.

Furthermore, Maniglia et al. (2020) reported that the τy of DHT-treated starch increased with an increasing DHT period. It is an important characteristic of the food material to retain its shape under gravity and stresses from the deposited layers. Moreover, the tendency of undergoing amylose crystallization causes water to be released from the gels, also defined as syneresis, leading to an unfavorable condition for 3D printing (Maniglia et al., 2020). However, Maniglia et al. (2020) observed that the syneresis was reduced when the wheat starch was modified with DHT, which was a crucial element for a successful 3D printing process. Therefore, DHT treatment helps to improve the printability of hydrogels based on different starches. In general, both works supported the use of the DHT process to improve the hydrogels' rheological properties, providing a suitable food ink for 3D printing.

5. Recommendation

This review listed several recommendations that could be focused on for future studies. The primary recommendation for future studies is regarding the nutritional value of the food. Most studies have thoroughly focused on the food's physical properties. However, too little attention is paid to the nutritional content of food after it has been 3D printed. There were 15 journal articles found using strategic and systematic search, but only an article by Vieira et al. (2020) mentioned the beneficial properties. Besides that, the scholars may stress the portion of the printed food that is deemed suitable for the geriatric group according to the weight, size, concentration, calorie or nutritional value of the food. This latter will influence the variation of food design, the development of 3D printer technology, customization of healthy food, food industry dependency and the local economy.

6. Conclusion

This study systematically reviewed 3D printing of personalized food for the elderly. It provides some insights and practical knowledge that are applicable in nurseries, homes, and healthcare settings. To conclude, the level of food hardness must be maintained in a suitable range that suits the needs of the elderly with mastication problems. Besides that, maintaining moisture content at certain ranges prevents bacterial growth, thus increasing the food storage period. 3D printing food also requires the use of materials with the right which may affect the extrusion process. Furthermore, each food has its own optimum ratio in combination with other materials to form products with the desired viscosity. Throughout the review, the elastic modulus has been measured for both pre-printed and printed samples, including samples tested for storage. G' and tan δ need to be maintained within a suitable range since it may affect the extrusion process. Also, personalized food for special populations can only be produced if the food ingredients used are printable. Therefore, it is vital for researchers to study the factors that influence the printability of materials to develop suitable food inks that can be printed into functional foods.

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Declaration Of Competing Interest

The team declares that there is no association within their knowledge relating to financial interests or personal relationships or any means that affect the work reported in the study.

8. References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101.

Çakmak, H., & Gümüş, C. (2020). 3D Food Printing with Improved Functional Properties: A Review. International Journal Of 3D Printing Technologies and Digital Industry, 4(2), 178–192.

Chen, H., Xie, F., Chen, L., & Zheng, B. (2018). Effect of rheological properties of potato, rice and corn starches on their hot-extrusion 3D printing behaviors. Journal of Food Engineering, 244, 150–158.

Dankar, I., Pujolà, M., El Omar, F., Sepulcre, F., & Haddarah, A. (2018). Impact of Mechanical and Microstructural Properties of Potato Puree-Food Additive Complexes on Extrusion-Based 3D Printing. Food and Bioprocess Technology, 11(11), 2021–2031.

Derossi, A., Caporizzi, R., Oral, M., & Severini, C. (2020b). Analyzing the Effects of 3D Printing Process Per Se on The Microstructure and Mechanical Properties of Cereal Food Products. Innovative Food Science & Emerging Technologies, 66, 102531.

Derossi, A., Caporizzi, R., Paolillo, M., & Severini, C. (2020a). Programmable Texture Properties of Cereal-Based Snack Mediated by 3D Printing Technology. Journal of Food Engineering, 289, 110160.

Dick, A., Bhandari, B., Dong, X., & Prakash, S. (2020). Feasibility Study of Hydrocolloid Incorporated 3D Printed Pork as Dysphagia Food. Food Hydrocolloids. Food Hydrocolloids, 107, 105940.

Flemming, K., Booth, A., Garside, R., Tunçalp, O., & Noyes, J. (2018). Qualitative evidence synthesis for complex interventions and guideline development: clarification of the purpose, designs and relevant methods. BMJ Global Health, 4(1), e000882.

García-Segovia, P., García-Alcaraz, V., Balasch-Parisi, S., & Martínez-Monzó, J. (2020). 3D printing of gels based on xanthan/konjac gums. Innovative Food Science & Emerging Technologies, 64, 102343.

Gou, M., Wu, H., Saleh, A. S., Jing, L., Liu, Y., Zhao, K., ... & Li, W. (2019). Effects of Repeated and Continuous Dry Heat Treatments on Properties of Sweet Potato Starch. International Journal of Biological Macromolecules, 129, 869–877.

Haddaway, N., Macura, B., Whaley, P., & Pullin, A. (2018). ROSES Reporting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. Environmental Evidence, 7(1). 1–8.

Hamilton, C. A., Alici, G., & in het Panhuis, M. (2018). 3D printing Vegemite and Marmite: Redefining “breadboards”. Journal of Food Engineering, 220, 83–88.

Huang, M. S., Zhang, M., & Bhandari, B. (2019). Assessing the 3D Printing Precision and Texture Properties of Brown Rice Induced by Infill Levels and Printing Variables. Food and Bioprocess Technology, 12(7), 1185–1196.

Jonkers, N., van Dommelen, J. A. W., & Geers, M. G. (2020). Experimental characterization and modeling of the mechanical behavior of brittle 3D printed food. Journal of Food Engineering, 278, 109941.

Kim, H.W., Bae, H., Park, H.J., (2018). Reprint of: Classification of the printability of 310 selected food for 3D printing: Development of an assessment method using hydrocolloids as 311 reference material. Journal of Food Engineering, 220, 28–37.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., ... & Moher, D. (2009). The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. Journal of Clinical Epidemiology, 62(10), e1–e34.

Liu, L., & Ciftci, O. N. (2020). Effects of High Oil Compositions and Printing Parameters on Food Paste Properties and Printability in A 3D Printing Food Processing Model. Journal of Food Engineering, 288, 110135.

Liu, Y., Liu, D., Wei, G., Ma, Y., Bhandari, B., & Zhou, P. (2018). 3D printed milk protein food simulant: Improving the printing performance of milk protein concentration by incorporating whey protein isolate. Innovative Food Science & Emerging Technologies, 49, 116–126.

Maniglia, B. C., Lima, D. C., Junior, M. D. M., Le-Bail, P., Le-Bail, A., & Augusto, P. E. (2019). Preparation of Cassava Starch Hydrogels for Application in 3D Printing Using Dry Heating Treatment (DHT): A Prospective Study on The Effects of DHT and Gelatinization Conditions. Food Research International, 128, 108803.

Maniglia, B. C., Lima, D. C., da Matta Júnior, M., Oge, A., Le-Bail, P., Augusto, P. E., & Le-Bail, A. (2020). Dry heating treatment: A potential tool to improve the wheat starch properties for 3D food printing application. Food Research International, 137, 109731.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Plos Medicine, 6(7), e1000097.

Okoli, C. (2015). A Guide to Conducting a Standalone Systematic Literature Review. Communications of The Association for Information Systems, 37(1), 879–910.

Oyinloye, T., & Yoon, W. (2021). Stability of 3D printing using a mixture of pea protein and alginate: Precision and application of additive layer manufacturing simulation approach for stress distribution. Journal of Food Engineering, 288, 110127.

Page, M. J., & Moher, D. (2017). Evaluations of the Uptake and Impact of The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement and Extensions: A Scoping Review. Systematic Reviews, 6(1), 263.

Shaffril, H., Samsuddin, S., & Abu Samah, A. (2020b). The ABC of systematic literature review: the basic methodological guidance for beginners. Quality & Quantity, 1–28.

Shaffril, H., Ahmad, N., Samsuddin, S., Samah, A., & Hamdan, M. (2020a). Systematic literature review on adaptation towards climate change impacts among indigenous people in the Asia Pacific regions. Journal of Cleaner Production, 258, 120595.

Vieira, M. V., Oliveira, S. M., Amado, I. R., Fasolin, L. H., Vicente, A. A., Pastrana, L. M., & Fuciños, P. (2020). 3D printed functional cookies fortified with Arthrospira platensis: Evaluation of its antioxidant potential and physical-chemical characterization. Food Hydrocolloids, 107, 105893.

Zheng, L., Yu, Y., Tong, Z., Zou, Q., Han, S., & Jiang, H. (2019). The Characteristics of Starch Gels Molded by 3D Printing. Journal of Food Processing and Preservation, 43(7), e13993.