EXPLORING DYSPHAGIA-FRIENDLY PUDDING AS A VIABLE INK FOR 3D FOOD PRINTING: PRINTABILITY AND CHARACTERIZATION

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ABSTRACT

Dysphagia-friendly food requires texture modification to achieve homogeneity to ease of swallowing. 3D-printed food is perceived as one of the modalities to present dysphagia patients with an aesthetic, unique and presentable texture-modified food. This study aims to evaluate the rheological properties and 3D printability of nutritionally tailored pudding formulations An extrusion 3D food printer was used to verify the printability of the dysphagia-friendly pudding. The International Dysphagia Diet Standard Initiatives (IDDSI) framework testing methods were conducted to assess the potential of pudding as dysphagia food. The temperature and amplitude sweep of the pudding premix were measured to determine the characteristics of the pudding as the food ink. Printability was evaluated by comparing the stability of the printed material at T0, T10 and T30 after printing. The pudding premix exhibited viscoelasticity and shear thickening properties with n = 0.4742, K = 351.45. It was successfully printed three-dimensionally and was able to retain its shape after 30 minutes of printing. These findings demonstrate the potential for developing aesthetically pleasing, nutritionally tailored foods for specific dietary needs using 3D printing technology.

Keywords: 3D food printing, dysphagia, extrusion printing, food ink, rheology

INTRODUCTION

3D food printing is considered to be the most promising technology for serving personalized meals (Mirazimi et al., 2022). The construction of layer-by-layer pureed food into an aesthetically appealing presentation may promote the intake of pureed food among the tailored respondents. These specific individuals may be elderly with degeneration of their physiological age, or patients with difficulties in swallowing, commonly known as dysphagia. Dysphagia is any disorder related to the transportation of foods and beverages from the mouth to the stomach (Zargaraan et al., 2013).

Texture-modified food was commonly served for dysphagia management (Quinchia et al., 2011). Razalli et al. (2021) described texture modification of food as food that is soft, moist, elastic, smooth and easy to swallow. The study also concluded that overall plate waste for the texture-modified diet in Malaysian urban university hospitals was 47.5%, exceeding the 30% baseline. The blended diet was found to have the highest plate waste as it underwent the most changes in food consistency (Razalli et al., 2021). The proposal to reduce plate waste is to improve the appearance of the food and its varieties, however the traditional methods often fall short in providing variety and visual appeal. The usage of 3D printed food was proposed by Sarkar (2018) and the 3D printed food preparation for dysphagia diet was established by many, among others are Natural Machines (Machines, 2023) and Gastronology (Gastronology, 2023) to increase the food intake and avoid malnutrition by serving unique and aesthetically appealing food.

Nutrifit, a high-protein pudding jelly premix was formulated for the improvement of muscle mass recovery in the elderly (Hashim et al., 2022) was used in this study. According to Khalid et al. (2021), Nutrifit is a soft-textured custard, therefore it is appropriate for patients with dysphagia, thus it is categorized as a dysphagia-friendly custard in this study. In addition, the pudding was selected because it is uniquely formulated with local ingredients and has the potential to be used as food ink. While 3D printing offers a novel presentation for this pudding, the rheological characterization of this 3D-printable food formulation is required to predict the behaviour. This present work aims to characterize the dysphagia-friendly pudding made from native ingredients and evaluate its printability as a prospective food ink.

METHODOLOGY

SAMPLE PREPARATION

Nutrifit premixes of pudding were supplied by the Food Technology Research Centre, MARDI Serdang. The declared ingredients were sweet potato, pumpkin, spinach, fructose, stabilizing agent, chickpeas, whey protein concentrate, lecithin, isolated soy protein, wheat fibre, oat, calcium carbonate, vanilla flavour, vitamin D3, whey peptide, anti-caking agent, salt and lactase. The pudding premix, 62 g was mixed with 250 ml of full cream milk (Dutch Lady Malaysia, purchased from a local supermarket) and heated at 80°C in "Thicken" mode for 10 minutes using a multifunction cooker (Thermomix TM6, Wuppertal, Germany). The sample was then put in a container and kept chilled at 5°C until further testing.

THE INTERNATIONAL DYSPHAGIA DIET STANDARD INITIATIVES (IDDSI) FRAMEWORK TESTING METHODS

The International Dysphagia Diet Standard Initiatives (IDDSI) framework outlines the standardized testing approach that is user-friendly and affordable to categorize the classification of texture-modified food. This test was carried out in compliance with the dysphagia-friendly food for IDDSI. The pudding was expected to be extremely thick/pureed corresponding to the Level 4 IDDSI category. Therefore, a spoon tilt test was carried out to measure the cohesiveness and adhesion of the sample (Cichero et al., 2017; Hanson, 2021). The fork pressure test was carried out to measure the hardness of the food practically using any sophisticated mechanical equipment (Cichero et al., 2017). The measurements were carried out at chilled conditions to simulate testing at the points of service.

RHEOLOGICAL MEASUREMENT TEMPERATURE SWEEP AMPLITUDE SWEEP

Oscillatory measurements under the linear viscoelastic region (LVR) were carried out using a rheometer (Rheometer MCR302e, Anton Paar, Austria). Oscillation amplitude sweep using a parallel plate 25 mm diameter, PP25, 1 mm gap, with varying stresses from 0.1 to 1000 Pa were performed to determine the Storage Modulus, G' and Loss Modulus, G'. The power Law equation was used to describe the behaviour of the pudding at 25°C. A Power Law equation was described as equation 1 below:

$$\tau = K\gamma^n \quad (1)$$

as τ is shear stress, K is consistency index, γ is shear strain and n is flow behaviour index.

All the rheological measurements were performed in duplicate at 25 °C to ensure reproducibility. Data were exported from RheoCompass software and analyzed using Microsoft Excel. The exported data were used to calculate the mean viscosity and standard deviation for each shear rate. Additionally, the coefficient of variation was determined to assess the variability of the measurements. The linearity of the shear thinning behavior was assessed using the coefficient of determination (R^2) calculated from the data.

3D FOOD PRINTING CONDITIONS AND PRINTABILITY

An extrusion-based 3D food printer, Foodini by Natural Machines was used for the 3D food printing verification. The pudding mixtures of 100 ml were filled in the capsules and printing was carried out using a nozzle size 40 (4mm ϕ). The 3D printing design was using a default library in the dish gallery of Foodini Creator and a 'flower tower' design was chosen. The design was six layers and the estimated printing time is four minutes. The design was calculated to require an approximate volume of 67.36 ml according to the Foodini printer. The printing process was carried out at an ambient temperature, of 27°C. Preliminary trials were carried out before establishing the final printing design.

The printability of the design was evaluated by comparing the stability of the printed material at T_0, T_{10} and T_{30} after printing.

RESULTS AND DISCUSSIONS

THE INTERNATIONAL DYSPHAGIA DIET STANDARD INITIATIVES (IDDSI) TEST

The spoon-tilt test revealed that there is minimal residue on the spoon and nearly all the food falls off after a gentle flick to the spoon. This means that the pudding is not sticky and cohesive enough to hold its shape. The delicately textured pudding also required minimal to no chewing abilities. During the fork pressure test, the pudding was compressed and failed to regain its original shapes (Hanson, 2021). This demonstrates that this pudding is acceptable for a dysphagia diet.

Fig. 1. The spoon-tilt test and fork pressure test that was employed to the pudding

Spoon -tilt Test

Fork Pressure Test

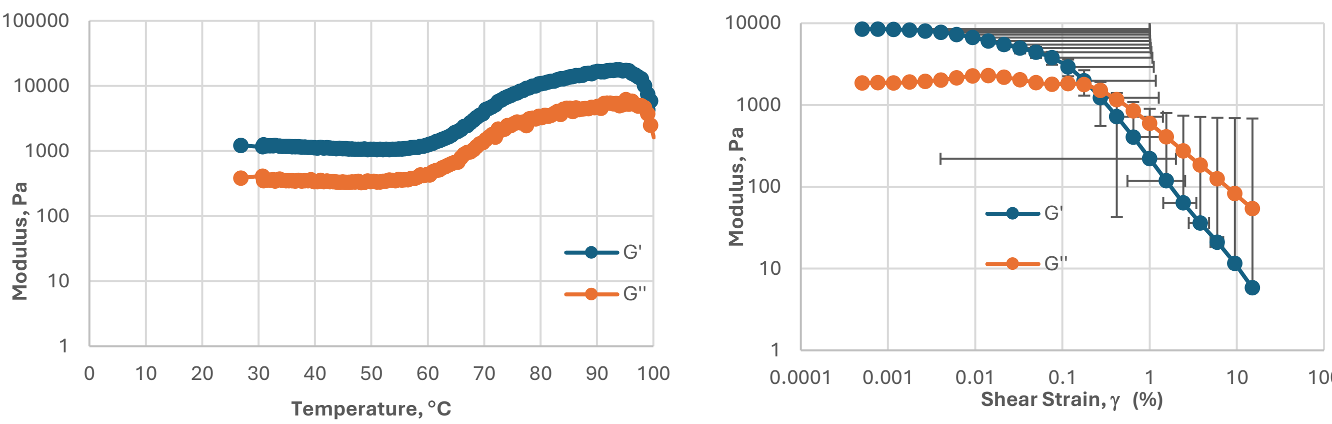
RHEOLOGY

The result of the temperature sweep is shown in Figure 2a. The pudding showed an increase in G' at 60° C after 6 minutes of heating, indicating a solidification or gelation occurs at this temperature. As the pudding will naturally thicken after heating and solidify after the chilling process, this may indicate the gelation temperature of this pudding premix. The amplitude sweep of the pudding was demonstrated in Figure 2b. The solid-like character of the pudding was obvious with G' appeared dominant until the mean yield point occurred at G'1506.98 Pa.

The graph in Figure 2b showed the behavior of the pudding measured at 25°C using a rotational rheometer. Error bars represent the standard deviation of the measurements. The R^2 value indicates the goodness of fit for the shear thinning behavior model. The pudding showed a non-Newtonian behaviour, with n = 0.4742, K = 351.45, R^2 = 93%, indicating a shear thickening behaviour. While most starch-based puddings showed shear thinning behaviour (Quinchia et al., 2011), the diverse ingredients in the premix may promote a synergistic effect between multiple ingredients that leads to shear thickening behaviour. Martínez-Monzó et al. (2019) also obtained n and K values within a similar range of this finding in the printing of different formulations of potato puree. However, they characterized the behaviour using the Herschel-Buckley model. Tejada-Ortigoza and Cuan-Urquizo (2022) extensively described the various rheological relationships with the printability of the food inks. Many researchers agreed that an extrusion-based food ink should have shear-thinning characteristics, and be able to resist layer-by-layer load upon printing (Gholamipour-Shirazi et al., 2020; Huang et al., 2019). Tejada-Ortigoza and Cuan-Urquizo (2022) reaffirmed that different food ink should be handled differently due to their distinct rheological characteristics and food composition. Generally, most of all suitable food ink is always that the G' values are higher than the G'', implying the presence of viscoelastic and the dominance of solid-like behaviour.

Figure 2. a) temperature sweep of the premix at 0-100 □C at constant shear rate b) amplitude sweep of the premix at shear rate

a) b)



PRINTABILITY ASSESSMENT

The printability of a prospective food ink is closely related to the material viscosity and rheology (Godoi et al., 2016). The printability is determined if the material can hold its structure post-deposition after 30 minutes.

Figure 3. The images of the 3D printed pudding at 15 minutes intervals post-printing

T_0 *T_{15}* *T_{30}*

Layer heights: 23.77 cm | Layer heights: 20.42 cm | Layer heights: 19.81 cm

Figure 3 presents the 3D printed flower of the pudding over 30 minutes post-printing. The shape of the pudding was retained without any obvious deformation. Masbernat et al. (2021) considered a good quality 3D-printed food ink if the structure dimensions remained unchanged after 5 minutes. Nevertheless, while measuring the height of the printed custard, a reduction in the height of the layers was seen. This suggests that the material might not have the capacity to support the weight of the upper layer, causing it to disperse towards the lower levels after a certain time. According to Chow et al. (2021), one of the obstacles to 3D food printing technology is the wide diversity in the physicochemical and compositional complexity of food materials. Initial experiments in this study revealed that the custard premix could not be immediately printed after cooking because of its very thin and runny consistency unless a thickening agent was incorporated. Once the custard premix had been cooled for a few hours, it became ready for printing, without the need to add any thickener. Hydrocolloid is frequently employed to achieve the desired viscosity before printing, as demonstrated by several studies such as Chow et al. (2021) and Pant et al. (2021). It is also common for the management of dysphagia diet to incorporate thickeners to decelerate the swallowing process ensuring safety and efficiency (Moret-Tatay et al., 2015). The pudding premix also was not able to be printed with smaller nozzle diameters (8 and 15) due to blockage at the printer capsule likely caused by the large particle size, resulting in no extrusion.

CONCLUSION

The dysphagia-friendly pudding was successfully fabricated through three-dimensionally food printing methods. The printed pudding can maintain its printed shape for more than thirty minutes without any noticeable deformation. The pudding exhibited the viscoelastic character and the dominance of G' over G''. The finding proves that dysphagia-friendly pudding can be served aesthetically using emerging technology like 3D food printing. This technology could be particularly beneficial in settings such as nursing homes and care facilities, enhancing the quality and appeal of meals for individuals with specific dietary requirements. Future research should explore the overall acceptance of this 3D printed pudding in real-world settings.

ACKNOWLEDGEMENT

The author would like to express gratitude to Mr Lin Hee Law and Mr Kiel Tan of Anton Paar Malaysia for their assistance with the rheology measurements.
This research was funded by a Mechanization & Automation Grant from the Ministry of Agriculture & Food Security (KRM 263).

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