

3D FOOD PRINTING OF FRESH VEGETABLES USING FOOD
HYDROCOLLOIDS FOR DYSPHAGIC PATIENTS

Cross-Reference to Related Application

5 **[0001]** This application claims the benefit of priority of Singapore Patent Application No. 10202010613X, filed 26 October 2020, the content of it being hereby incorporated by reference in its entirety for all purposes.

Technical Field

10 **[0002]** The present disclosure relates to an edible and 3D printable plant-based ink composition for consumption by dysphagic patients. The present disclosure also relates to a method of forming the edible and 3D printable plant-based ink composition.

Background

15 **[0003]** Three-dimensional food printing (3DFP) allows the creation of dishes by adding food layer by layer to construct edible three-dimensional (3D) structures from digital designs. 3DFP may offer several advantages, including personalized diets with individualized nutrition for health benefits, enhance visual appeal of alternative protein source, automate food preparation, and reduce food wastage. 3DFP may utilize four of
20 the seven established additive manufacturing processes, which are material extrusion, material jetting, binder jetting, and powder bed fusion. The most popular 3DFP technique may involve extrusion-based 3D printing. Food inks used for extrusion-based printing may have to exhibit shear thinning rheological properties and sufficient mechanical strength to maintain structural integrity of the deposited food structure.
25 Natively printable inks made from chocolates, hydrogels, cheese, dairy products may have been researched more extensively compared to non-natively extrudable inks e.g. meat. 3DFP may be able to deal with and fulfill a consumer's food purchase consideration, such as cost, taste, convenience, nutrition and experience. 3DFP may target the general populace as well as specific groups like prosumers (consumers who
30 produce), people with special nutritional requirements (e.g. in hospitals and nursing facilities, athletes), and defence and aerospace industries and spearhead digital gastronomy. One example of such groups may be patients suffering from dysphagia.

[0004] Dysphagia refers to the difficulty in swallowing food, which manifests as an abnormal delay in moving food in the form of an alimentary bolus, solid, or liquid during swallowing. Ageing and underlying medical conditions that affect motor or neurological functions, such as Parkinson's disease, stroke, dementia, head and neck cancers, are all risk factors associated with dysphagia. Oropharyngeal dysphagia (OD) causes coughing, choking, and difficulty in initiation of swallow because of food residue being left in the oral cavity. All these conditions may lead to poor nutrition, dehydration, and weight loss due to less food intake by patients. A report indicates that up to 41% of OD patients feel anxious during meal times and 36% of these patients avoid eating with others, leading to a feeling of isolation and social deprivation, which significantly impacts their quality of life. To prevent malnutrition and dehydration among patients, food is preferably made soft enough to chew and safe to swallow. This is done by changing textural properties of the food, e.g. making pureed foods that are soft and easy to swallow or modifying the viscoelastic properties of fluids to thicken them for better uptake. However, these pureed, minced, moist and mashed foods are visually unappealing, and therefore unappetizing to the patients (e.g. dysphagic patients), i.e. providing adequate nutrient-rich and safe diets becomes a considerable challenge. Efforts may have to be made to aid in the dignified feeding of these patients so as to significantly improve their mealtime experiences and enable them to socialise and consume meals that look, feel and taste like regular food. It has been shown that resemblance to daily food leads to willingness of consumption in these patients.

[0005] Despite all the above, current practice of using moulds and casts to shape purees for patients may offer aesthetically pleasing dishes but the practice places a high demand on specially trained manpower. While 3DFP may address this limitation, feasibility studies so far may have been limited to chocolates, dough, meat, sugar, and gels, and not nutritional foods specifically for dysphagic patients. For example, most 3DFP studies used dehydrated and freeze-dried food powders for extrusion-based printing. Freeze-dried foods suffer from vitamin C, vitamin E and folic acid losses. The water content during freeze drying is greatly reduced, which leads to a high calorie content per unit mass. Freeze drying is an energy-intensive process with high capital costs. Hence, it is a technique only suitable for high-value and low-volume foods. Freeze-drying tends to disrupt cell walls of vegetables and fruits due to increased

formation of ice crystals. Also, freeze-drying may need to utilize protective agents to minimize the effect of freezing on food quality so as to maintain ingredient stability and preserving food colour.

[0006] Moreover, 3DFP with freeze-drying may be specifically viable for foods with high water content, and not for food with low carbohydrates and fats which may be difficult for solely 3DFP due to their rheological properties.

[0007] There is thus a need to provide for a solution that addresses one or more of the limitations mentioned above.

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Summary

[0008] In a first aspect, there is provided an edible and 3D printable plant-based ink composition for consumption by dysphagic patients, the edible and 3D printable plant-based ink composition includes:

- a vegetable puree and/or a fruit puree, wherein the vegetable puree and the fruit puree are not freeze-dried and contain one or more hydrocolloids; or

- a vegetable puree and/or a fruit puree, wherein the vegetable puree and the fruit puree are not freeze-dried;

- wherein each of the one or more hydrocolloids is present in an amount of 10 wt% or less based on the vegetable puree and/or the fruit puree.

[0009] In another aspect, there is provided a method of forming the edible and 3D printable plant-based ink composition described in various embodiments of the first aspect, the method includes:

- providing a puree of a vegetable and/or a fruit;

- sieving the puree to remove any solid particles which blocks a nozzle of a 3D printer; and

- cooling the puree to room temperature for 3D printing.

Brief Description of the Drawings

[0010] The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the present disclosure. In the following description, various embodiments of the present disclosure are described with reference to the following drawings, in which:

[0011] FIG. 1A shows plots of viscosity versus shear rate for food inks of peas, carrots, and bok choy (inks 1 to 5).

[0012] FIG. 1B shows plots of yield stress of food inks of peas, carrots, and bok choy (inks 1 to 5). * $p \leq 0.05$.

5 [0013] FIG. 1C shows recovery of food inks by measuring viscosity with changing shear rate over time.

[0014] FIG. 2A shows representative images of 3D printed shapes with five formulations of one food ink type, images with box drawn around them represent the optimized formulations of the inks.

10 [0015] FIG. 2B shows pictures assembled by 3D printed designs of garden peas, carrots and corn.

[0016] FIG. 2C shows storage modulus (G' , triangle) and loss modulus (G'' , square) represented as a function of applied oscillatory shear stress for carrot ink 4, black arrow depicts the linear viscoelastic region (LVER). Yield stress calculated from the cross
15 over point of G' and G'' .

[0017] FIG. 2D is a table indicating printability of food inks assessed by precision and shape stability.

[0018] FIG. 3A shows plots that demonstrate spreading of food inks measured in area covered by the liquid leaking from food inks on filter paper, * $p \leq 0.05$.

20 [0019] FIG. 3B shows representing image of carrot inks 1 and 2 depicting syneresis.

[0020] FIG. 3C shows spreading of carrot inks. Red square of $1 \times 1 \text{ cm}^2$ used as a reference for measuring area covered by the liquid spread.

[0021] FIG. 4A is a panel of four images depicting garden peas ink 1 (images i, ii) and ink 5 (images iii, iv). Images (ii) and (iv) are magnified images (1500x) of images (i) and (iii) (500x), respectively. Scale bar in images (i) and (iii) denote $50 \mu\text{m}$ and scale
25 bar in images (ii) and (iv) denote $10 \mu\text{m}$.

[0022] FIG. 4B is a panel of four images depicting carrots ink 1 (images i, ii) and ink 2 (images iii, iv). Images (ii) and (iv) are magnified images (1500x) of images (i) and (iii) (500x), respectively. Scale bar in images (i) and (iii) denote $50 \mu\text{m}$ and scale bar in
30 images (ii) and (iv) denote $10 \mu\text{m}$.

[0023] FIG. 4C is a panel of four images depicting bok choy ink 1 (images i, ii) and ink 4 (images iii, iv). Images (ii) and (iv) are magnified images (1500x) of images (i) and

(iii) (500x), respectively. Scale bar in images (i) and (iii) denote 50 μm and scale bar in images (ii) and (iv) denote 10 μm .

[0024] FIG. 5 shows the textural properties of 3D printed samples of garden peas, carrots and bok choy inks. Values are normalized against the highest value and reported
5 between 0 and 1.

[0025] FIG. 6A demonstrates a fork pressure test on soft and bite sized 3D printed samples of food inks (pea ink 1, carrot ink 2 and bok choy ink 4) is carried out as per IDDSI (International Dysphagia Diet Standardization Initiative, 2019).

[0026] FIG. 6B shows a spoon tilt test on food inks of pea ink 1, carrot ink 2 and bok
10 choy ink 4 from top to bottom row images, respectively, as per IDDSI (International Dysphagia Diet Standardization Initiative, 2019).

[0027] FIG. 6C shows a fork pressure test as per IDDSI (International Dysphagia Diet Standardization Initiative, 2019) on soft and bite sized 3D printed samples of different food inks.

15 [0028] FIG. 6D shows a spoon tilt test as per IDDSI (International Dysphagia Diet Standardization Initiative, 2019) on different food inks.

[0029] FIG. 7A shows 3D printed structures using pea inks, control (pea puree with 80% water content) in left image versus ink 5 (pea puree with 80% water content and 0.3% XG and 0.3% KC) in right image.

20 [0030] FIG. 7B shows five food ink formulations where ink 1 (top row): pea puree with WC = 80%, ink 2 (2nd row): pea puree with WC = 85%, ink 3 (3rd row): pea puree with WC = 90%, ink 4 (4th row): pea puree with XG and KC = 0.1% w/w, ink 5 (5th row): pea puree with XG and KC = 0.3% w/w. Compositional details of the inks are also described in example 12A.

25 [0031] FIG. 8A shows plots of viscosity against shear rate and comparing the shear thinning for food inks of garden peas. Compositional details of the inks are described in example 12A.

[0032] FIG. 8B shows a plot of yield stress for the different pea food inks in FIG. 8A.

[0033] FIG. 9A shows syneresis measurement for food inks of garden peas using
30 Whatman filter paper grade 4. Compositional details of the inks are described in example 12A.

[0034] FIG. 9B is a table for syneresis measurement wherein distance spread of water is measured in cm for the pea inks of FIG. 9A.

[0035] FIG. 10A shows 3D prints of different formulation of carrot inks, including control print (ink 1 –left image) versus configured prints (ink 2, ink 3 – center and right images). Compositional details of the inks are described in example 12A.

[0036] FIG. 10B shows five food ink formulations where ink 1 (top row): carrot puree with WC = 90%, ink 2 (2nd row): Carrot puree with XG = 0.3%w/w, ink 3 (3rd row): Carrot puree with XG and KC = 0.3%w/w, Ink 4 (4th row): Carrot puree with XG = 0.5% and KC = 0.5%w/w, ink 5 (5th row): Carrot puree with XG =0.7% and KC = 0.7% w/w. Compositional details of the inks are also described in example 12A.

[0037] FIG. 11 shows syneresis measurement using Whatman filter paper grade 4 for carrot inks. Compositional details of the inks are also described in example 12A.

[0038] FIG. 12 is a table showing distance spread of water measured in cm for the carrot inks of FIG. 11.

[0039] FIG. 13A shows plots of viscosity against shear rate and comparing the shear thinning for carrot inks. Compositional details of the inks are described in example 12A.

[0040] FIG. 13B shows a plot of yield stress for the different carrot inks of FIG. 13A.

[0041] FIG. 14 shows 3D prints of different bok choy inks. Compositional details of the inks are described in example 12A.

Detailed Description

[0042] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the present disclosure may be practised.

[0043] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0044] The present method involves three-dimensional food printing (3DFP), which offers advances in digital gastronomy by targeting consumers' specific requirements for nutrition customization and visual appeal. Dysphagia, i.e. difficulty swallowing, may be prevalent in elderly people and patients suffering from debilitating illnesses.

5 Dysphagic diets tend to require textural modifications to render them soft and safe to swallow. Additionally, the diets may need to be visually pleasing to help in greater food uptake and prevent malnutrition in patients. 3DFP so far utilized only freeze-dried vegetable powders for shaping 3D designs. However, the present disclosure provides diets that include not only frozen, but also fresh vegetables, offering better nutritional

10 profile and low costs. Three different categories of vegetables are usable based on the number of hydrocolloids (HCs) required to render them printable. Garden pea, carrot and bok choy are chosen as representatives in each category, which may require no HC, one type of HC and two types of HCs, respectively. In the present disclosure, food inks may be prepared by the addition of HCs, e.g. xanthan gum (XG), kappa carrageenan

15 (KC) and locust bean gum (LBG) for texture modification. Rheological, textural, microstructural and syneresis properties of the inks are examined. International dysphagia diet standardisation initiative (IDDSI) tests can be done to assess potential of the present inks for dysphagic diets. The present ink formulations has excellent 3D printability, minimal water seepage, and dense microstructures with minimal amount

20 of HCs. Advantageously, fresh vegetables can be included, without solely relying on freeze-dried foods, thereby preserving flavour and nutrition just like real food. This in turn brings 3DFP of at least vegetables closer to being adopted in hospitals and nursing home kitchens.

[0045] Details of various embodiments of the present food ink composition and method, and the advantages associated with the various embodiments are now described below.

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[0046] In the present disclosure, there is provided an edible and 3D printable plant-based ink composition for consumption by dysphagic patients. For brevity, the plant-based ink composition is herein interchangeably referred to as "food ink composition", "ink composition", "ink formulation", "food ink", or simply "ink". The term "plant-based" herein means that the present food ink is absent of meat, seafood and dairy products.

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[0047] The present plant-based ink composition is advantageous in that it can maintain its printed structure for at least 15 minutes. Said differently, in the context of the present disclosure, a plant-based ink composition is deemed 3D printable if its printed structure can be maintained for at least 15 minutes.

5 [0048] The editable and 3D printable plant-based ink composition may include a vegetable puree and/or a fruit puree. The vegetable and/or fruit is pureed directly from fresh vegetables and/or fruits, respectively. In other words, the vegetable and/or fruit is absent of powdered or processed vegetables and fruits. The vegetable puree and fruit puree are not freeze-dried. The vegetable puree and fruit puree may contain at least 50%
10 of water, 80 wt% of water, at least 85 wt% of water, at least 90 wt% of water, at least 95 wt% of water, etc. The term “freeze-dried” herein differs from “freezed” in that freeze-drying involves removal of water but freezing does not.

[0049] In various non-limiting embodiments, the editable and 3D printable plant-based ink composition may be absent of hydrocolloids. In various non-limiting embodiments,
15 the editable and 3D printable plant-based composition may include one or more hydrocolloids. Each of the one or more hydrocolloids may be present in an amount of 10 wt% or less, 5 wt% or less, 3 wt% or less, 2 wt% or less, 1 wt% or less, 0.7 wt% or less, 0.5 wt% or less, 0.3 wt% or less, etc., based on the vegetable puree and/or the fruit puree. Such weight percentages, said differently, refer to concentration of a
20 hydrocolloid in the vegetable and/or fruit puree. In various non-limiting embodiments, the editable and 3D printable plant-based ink composition may include a vegetable puree and/or a fruit puree, wherein the vegetable puree and the fruit puree are not freeze-dried and contain one or more hydrocolloids, wherein each of the one or more hydrocolloids may be present in an amount of 10 wt% or less based on the vegetable
25 puree and/or the fruit puree.

[0050] In various embodiments, the vegetable puree and/or fruit puree may include a starchy vegetable, a root vegetable, or a leafy vegetable. In other words, the vegetables which the vegetable puree is directly obtained from can be divided into three categories depending on their water and starch content. Each category may undergo a different
30 treatment to be configured or enhanced for 3D printability into various shapes. Advantageously, the present plant-based food ink is better than traditional moulds that were employed for shaping purees for patients, as the present plant-based food ink

provides for 3D printed food that looks and feels aesthetically pleasing with higher replicability, no compromise in safety, lesser man hours required and hence a better alternative to moulded foods regardless of the types of vegetables. The three categories of vegetables may be (1) starchy vegetables with less water content and high starch content, e.g. potatoes, corn, peas, sweet potatoes, (2) root vegetables with high water content and moderate starch content, e.g. carrots, beets, turnips, and (3) green leafy vegetables with highest water content and least starch content, e.g. bok choy, spinach, kale. This categorization approach may be applied for fruits. The present plant-based ink composition is not limited to the vegetables mentioned above, and other vegetables and fruits may be configurable into the present plant-based ink composition.

[0051] In various embodiments, the one or more hydrocolloids may include xanthan gum, kappa carrageenan, and/or locust bean gum.

[0052] In certain non-limiting embodiments, the vegetable puree may include pea (e.g. a garden pea), and the one or more hydrocolloids may include xanthan gum and/or kappa carrageenan. In certain non-limiting embodiments, the xanthan gum and the kappa carrageenan may be respectively present in an amount of 0.1 to 0.3 wt% based on the vegetable puree (e.g. pea puree). For example, the xanthan gum and the kappa carrageenan may be respectively present in an amount of 0.1 wt%, 0.2 wt%, or 0.3 wt%, based on the vegetable puree.

[0053] In certain non-limiting embodiments, the vegetable puree may include carrot, and the one or more hydrocolloids may include xanthan gum and/or kappa carrageenan. In certain non-limiting embodiments, the xanthan gum and the kappa carrageenan may be respectively present in an amount of 0.3 to 0.7 wt% based on the vegetable puree (e.g. carrot puree). For example, the xanthan gum and the kappa carrageenan may be respectively present in an amount of 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, or 0.7 wt%, based on the vegetable puree.

[0054] In certain non-limiting embodiments, the vegetable puree may include bok choy, and the one or more hydrocolloids may include xanthan gum and/or locust bean gum. In certain non-limiting embodiments, the xanthan gum and the locust bean gum may be respectively present in an amount of 0.5 to 2 wt% based on the vegetable puree (e.g. bok choy puree). For example, the xanthan gum and the kappa carrageenan may

be respectively present in an amount of 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, 1.0 wt%, 1.5 wt%, 2.0 wt%, etc., based on the vegetable puree.

[0055] In various embodiments, the edible and 3D printable plant-based ink composition may have yield stress ranging from 20 to 360 Pa, 24.8 to 355 Pa, etc.

5 [0056] In various embodiments, the edible and 3D printable plant-based ink composition may have a viscosity profile which decreases with increasing shear rate. That is to say, the viscosity decreases when shear rate increases. In various embodiments, such a viscosity profile may be exhibited with the shear rate in a range of 0.001 to 1000 s⁻¹. The viscosity profile may include a viscosity range of 1000 to
10 100,000 Pa.s, 2900 to 16700 Pa.s, 2992.1 to 16607.47 Pa.s, etc.

[0057] The present disclosure also provides a method of forming the edible and 3D printable plant-based ink composition described in various embodiments of the first aspect. Embodiments and advantages described for the plant-based ink composition of the first aspect can be analogously valid for the present method subsequently described
15 herein, and vice versa. As the various embodiments and advantages have already been described above and examples demonstrated herein, they shall not be iterated for brevity.

[0058] The present method may include providing a puree of a vegetable and/or a fruit, sieving the puree to remove any solid particles which may block a nozzle of a 3D printer, and cooling the puree to room temperature (e.g. 20 to 30°C, 22 to 26°C, etc.)
20 for 3D printing.

[0059] In various embodiments, providing the puree may include boiling or steaming the vegetable and/or the fruit, and blending the vegetable and/or the fruit after the boiling or the steaming to form the puree. Blending may be carried out by hand mixing
25 or using a mechanical food blender.

[0060] In various embodiments, the method may further include mixing the puree with one or more hydrocolloids. In certain non-limiting embodiments, the one or more hydrocolloids may include more than one hydrocolloid. (e.g. two hydrocolloid). In various embodiment, the method may further include dry mixing of the more than one
30 hydrocolloid prior to mixing with the puree. In other words, two or more hydrocolloids may be directly mix without adding any liquid before contacting the vegetable or fruit puree.

[0061] In various embodiments, the method may further include incubating a mixture at a temperature of 65 to 75°C (e.g. 70°C or 72°C, 70 to 75°C), wherein the mixture may include the puree and the one or more hydrocolloids, and wherein the one or more hydrocolloids may include kappa carrageenan. In various embodiments, the the method
5 may further include incubating a mixture at a temperature of 85 to 95°C (e.g. 90°C, 90 to 95°C), wherein the mixture may include the puree and the one or more hydrocolloids, and wherein the one or more hydrocolloids may include locust bean gum. The incubation may take around 20 to 40 minutes (e.g. 30 minutes). Such incubation may advantageously hydrate a hydrocolloid, improving its gelling effect and control the
10 microstructure of the 3D printed plant-based ink composition.

[0062] In summary, the present ink composition and method provides for the use of fresh vegetables in 3D food printing. The present disclosure establishes a versatile approach for configuring different vegetable types for 3D printing, wherein each vegetable type can have different water and starch content to form self-supporting 3D
15 printed structures. There is a lack of 3D printed fresh food ink formulations for dysphagia diets. The present disclosure broadly identifies the vegetables as three different categories and not specific vegetables for 3D printed food for dysphagia patients. The present ink composition and method utilize fresh vegetables and not vegetable powders, thus providing more nutritional benefits of the respective
20 vegetables. There is minimal or no additives (other than hydrocolloids) added to make food 3D printable. For example, in certain instances, the present ink composition of garden peas (having less water and higher starch content) can be 3D printed without even using hydrocolloid. In certain instances, only one hydrocolloid may be used to prevent syneresis (e.g. carrot inks with high water and moderate starch content). In
25 certain instances, only two hydrocolloids may be needed to prevent syneresis and provide structural stability (e.g. bok choy inks relatively having the highest water and least starch content).

[0063] The present method can be applied to other vegetables and fruits having similar starch and water content. Garden peas may represent the starchiest vegetable of the food
30 chosen in the present disclosure as a non-limiting example for demonstrating 3D printing of vegetables having the least water content at around 80%. As demonstrated in the examples further hereinbelow, the peas could be printed after boiling and grinding

and adjusting water content to form nice and stable shapes via a FOODINI printer, absent the use of any stabilizers or thickeners. Water leakage was observed to be minimal on the prints and viscosity was also suitable for printing.

5 [0064] Carrots having inherently higher water content of around 90% were configured differently in the present method. Experiments with addition of xanthan gum, which prevents syneresis, resulted in stable 3D prints and the water leakage from control samples having no xanthan gum was also prevented. With the addition of two hydrocolloids, e.g. xanthan gum and kappa carrageenan, desirable prints could also be achieved but the need for additional HC can be obviated by xanthan gum addition only.

10 [0065] In the case of bok choy inks, even when the water content was very high ($\geq 96\%$), the present method can still configure the bok choy inks to be 3D printable. This was achieved with addition of two different hydrocolloids (e.g. xanthan gum and locust bean gum at 1 wt%, respectively).

15 [0066] The word "substantially" does not exclude "completely" e.g. a composition which is "substantially free" from Y may be completely free from Y. Where necessary, the word "substantially" may be omitted from the definition of the present disclosure.

[0067] In the context of various embodiments, the articles "a", "an" and "the" as used with regard to a feature or element include a reference to one or more of the features or elements.

20 [0068] In the context of various embodiments, the term "about" or "approximately" and the symbol " $\approx$ " as applied to a numeric value encompasses the exact value and a reasonable variance.

[0069] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

25 [0070] Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

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Examples

[0071] The present disclosure relates to food ink compositions which are plant-based. The present disclosure also relates to a method of processing fresh vegetables and/or

fruits. The food ink compositions and the method consider the starch and water content of the fresh vegetables and/or fruits, rendering 3D printable inks that is at least consumable (e.g. for dysphagia patients) using minimal food additives while preserving flavour and nutrition. The vegetables and/or fruits can be categorized into three categories, and the present food inks and method even when based on these categories are still versatile in that different approaches can be adopted in terms of processing with hydrocolloids to render self-supporting 3D printable shapes.

[0072] The present method, which involves 3DFP, offers an advantageous solution to standardize and automate the preparation of visually appealing pureed food with a high consistency and repeatability. It provides an avenue by shaping texturally modified foods for a wholesome mealtime experience. Texture modification can be accomplished through the addition of food additives, stabilizers, thickeners, viscoelasticity modifiers like agar, gellan gum, locust bean gum, pectin, kappa carrageenan, and xanthan gum among others.

[0073] The present food inks and method also address issues of using food powders, as the present food inks and method are able to 3D print unprocessed vegetables (whether fresh or frozen). Food inks prepared from fresh or frozen vegetables are used to automatically print food that are visually stimulating and texturally safe for consumption by dysphagic patients. Vegetables and fruits are an important source of vitamins, minerals, water, and antioxidants in our food, making them an excellent and necessary choice for dietary inclusion. However, they are difficult to print (non-natively extruding inks) due to their high water content with very low carbohydrates and fats. In the context of food ink preparation in the present disclosure, the vegetables and fruits may be broadly classified into three categories, and each category may require a different treatment to be printable. One representative vegetable from each category is selected for demonstration – garden peas (*Pisum sativum*) with high starch and low water percentage, carrots (*Daucus carota*) representing median starch and water percentage, and bok choy (*Brassica rapa*) with a low starch and a high water percentage. Rheological properties and textures are modified with hydrocolloids (HCs), which can include but are not limited to, xanthan gum (XG), kappa carrageenan (KC) and locust bean gum (LBG). The printability, rheological, textural and microstructural properties of these inks are characterized extensively. International dysphagia diet

standardization initiative (IDDSI, 2019) tests are performed to evaluate the suitability of the ink formulations for dysphagia patients.

[0074] The present food inks and method are described in further details, by way of non-limiting examples, as set forth below.

5 **[0075] Example 1: Formulation of Food Inks**

[0076] Vegetables (garden pea, carrot and bok choy) were purchased from local supermarkets, refrigerated at 4°C (carrot and bok choy) for a maximum of two days or frozen (garden pea) till used. Vegetables were peeled when required, washed and manually diced. Garden peas and carrots were washed and boiled in water for 15
10 minutes (or allowed to sit in hot water for additional 5 minutes), and bok choy was steamed for 15 minutes till tender. Water was drained, and boiled/steamed vegetables were blended thoroughly for 5 to 10 minutes to a puree-like consistency in a food processor. The pureed vegetables were then sieved to avoid the inks from blocking the nozzle of the printer, and the resulting sieved puree was measured for its water content
15 (WC).

[0077] Example 2: Moisture Content Measurement

[0078] One gram of sieved puree was spread on aluminum foil and dried at 150°C in a convection oven until the weight no longer decreased. The weight of the sample before and after drying was measured using a digital weighing balance, and the water content
20 percentage (WC %) was calculated accordingly.

[0079] According to the vegetable type, the WC % for each vegetable was adjusted to a standardized value, i.e. garden peas (*Pisum sativum*) adjusted to 80%, carrot (*Daucus carota*) adjusted to 90%, bok choy (*Brassica rapa*) adjusted to ≈ 96%. The WC % was calculated by the following formula:

25
$$\text{WC \%} = \frac{\text{Weight of sample before drying} - \text{weight of sample after drying}}{\text{Weight of sample before drying}} \times 100$$

[0080] Food grade HCs were purchased from a local food store. Different amounts of HCs, namely xanthan gum (XG), kappa carrageenan (KC) and locust bean gum (LBG), were added to the purees at desired concentrations. HCs for each formulation were
30 measured based on the weight of the puree, dry mixed if more than one HCs were used, then added to the puree, and homogenised thoroughly by a handheld blender. Beakers containing the inks were sealed with food grade clingwrap to avoid loss of moisture due

to evaporation during incubation. The beakers were then kept in a water bath for 30 minutes at the hydrocolloid gelation temperature of 72°C and 90°C for inks containing KC and LBG, respectively. The inks were then cooled to room temperature before being printed or stored in refrigerator for future use. All inks that were kept in the fridge were brought to room temperature before the experiments. Inks formulated from raw food ingredients for 3D printing through extrusion were termed as food inks. Different food ink formulations prepared are shown in Table 1.

[0081] Table 1 - Food ink formulations of garden peas, carrots and bok choy differing in water content (WC) and hydrocolloids (HCs), i.e. Xanthan Gum (XG), kappa Carrageenan (KC), Locust Bean Gum (LBG).

Food inks	Ink 1	Ink 2	Ink 3	Ink 4	Ink 5
Garden peas	WC = 80%	WC = 85%	WC = 90%	WC = 80% with each of XG and KC = 0.1% w/w	WC = 80% with each of XG and KC = 0.3% w/w
Carrots	WC = 90%	WC = 90% with XG = 0.3% w/w	WC = 90% with each of XG and KC = 0.3% w/w	WC = 90% with XG = 0.3%, KC = 0.5% w/w	WC = 90% with XG = 0.3%, KC = 0.7% w/w
Bok Choy	WC ≈ 96%	WC ≈ 96% with XG = 1% w/w	WC ≈ 96% with XG = 0.7%, LBG = 0.5% w/w	WC ≈ 96% with XG = 1%, LBG = 1% w/w	WC ≈ 96% with XG = 1%, LBG = 2% w/w

[0082] Example 3: 3D Printing of Food Inks

[0083] FOODINI (Natural machines, Spain), an extrusion based commercial 3D food printer was used to print 3D samples of different vegetable inks. For the experiments in this study, a nozzle size of 1.5 mm was used. To assess the printability of the food inks, a hexagonal prism of 8 layers was printed on a dish. When the printed samples were able to maintain the structure for at least 15 minutes, they were classified as printable. The print speed, extrusion rate and other parameters were finalized in pre-tests. The samples were kept for 30 minutes to observe for shape and structure fidelity and were photographed using an android smartphone. Photographs of the structures were taken right after printing and visually assessed on a scale from 1 (very bad) to 5 (very good).

The term “fidelity” herein refers to the accuracy of the printed 3D structure based on the inputs provided to a software that modulates/operates how the plant-based food ink may be dispensed to afford a printed 3D structure.

[0084] A 3D painting was put together from 3D designs printed with carrot, garden pea
5 and corn inks on the Wiiboox Sweetin chocolate printer, another extrusion-based printer, using 0.84 mm nozzle size.

[0085] Example 4: Syneresis of the food inks

[0086] Syneresis was analyzed using a method modified from filter-paper blotting that is typically used for syneresis analysis of hydrogel. Syneresis experiments were
10 performed by placing 1 g of food ink at the centre of a piece of Whatman grade 4 filter paper. The purees were flattened to cover a circle of 1 cm radius. The filter papers were left undisturbed for 30 minutes for fluid to seep and then photographed. Area covered by the fluid was measured in cm and analysed using an in-house Python program that automatically detected the edge and the water ring. A 1×1 cm² red square was
15 photographed together with the filter paper to be used as a reference for image analysis. Each sample was done in triplicates.

[0087] Example 5: Rheological Characterization

[0088] Rheological properties of the food inks were studied using an oscillatory rheometer (Discovery Hybrid Rheometer DHR-2, TA Instruments, Delaware, USA).
20 Parallel plates of stainless steel of 20 mm diameter were used with a truncation gap of 500 or 1000 μm. Excess sample was squeezed out and removed to prevent the edge effect. Viscosity shear thinning experiments were performed on food inks by applying a stepwise shear rate ramp from 0.001 to 1000 s⁻¹. Oscillation amplitude sweep experiments were carried out by applying stresses varying from 0.1 to 2000 Pa with a
25 constant frequency of 1 Hz to study the viscoelastic properties (e.g. yield stress) of the inks. All the experiments were performed at 25 ± 0.1°C in triplicates. Recovery experiments were done to mimic the three steps the inks underwent in the syringe – before extrusion, during extrusion, and after extrusion through the nozzle. Flow ramp tests were carried out at 25° ± 0.1°C where initial shear rate of 0.1 to 1 s⁻¹ was applied
30 for 60 s followed by high shear rate of 0.1 to 200 s⁻¹ for 2 s and again from 200 to final 0.1 s⁻¹.

[0089] Example 6: Textural Properties Characterization

[0090] Texture Pro CT V1.3 Build 15 (Brookfield Engineering Labs, Inc) was used for double-cycle compression tests to obtain force-time curves. For this test, a hexagonal prism sample of 6 layers was printed using the FOODINI and stably fixed at the centre of the platform. The test parameters were as follows: block probe with trigger load of 5 g, pre-test speed at 2.0 mm/s, test and post-test speed at 2.0 mm/s and the compressive strain was at 45%. Each test was repeated at least three times per sample. Hardness, chewiness, adhesiveness, gumminess, springiness and stringiness were reported by normalizing against the highest value in the compared group.

[0091] Example 7: Scanning Electron Microscopy

[0092] The microstructure of the food inks was studied by scanning electron microscopy (JEOL JSM-5600LV). Samples were freeze-dried and then sputter-coated with gold (10 mA for 90 s) in vacuum condition. The images were processed at 500 × and 1500 × magnifications with excitation voltage of 10kV.

[0093] Example 8: International Dysphagia Diet Standardisation Initiative (IDDSI) tests

[0094] IDDSI categories texturally modified food into 8 levels (0-7) and sets out a combination of tests to determine which level a texturally modified food falls into ("IDDSI Framework testing methods 2.0/ 2019", 2019). Fork pressure test was employed where the printed samples were pressed by thumb until it blanched using a fork (pressure of about 17 kPa), equivalent to the tongue pressure used while swallowing. The spoon tilt test was performed on all the ink formulations for testing the adhesiveness and cohesiveness.

[0095] Example 9: Data Analysis

[0096] Data was plotted on GraphPad Prism software and radar charts for textural profile analysis were plotted on Microsoft Excel. Mean values and SD shown in the paper were analysed using GraphPad Prism via one-way ANOVA- Kruskal Wallis tests. Significance was reported as p value ≤ 0.05 .

[0097] Example 10A: Results - Rheological Properties of Food Inks

[0098] Food inks prepared from frozen garden pea, fresh carrot and fresh bok choy were characterized to evaluate their shear thinning property, yield stress and recovery behaviour. Each vegetable had five ink formulations shown in Table 1 above. Three ink formulations were made from peas with increasing water %, i.e. ink 1 (WC = 80%), ink

2 (WC = 85%) and ink 3 (WC = 90%). Pea ink 4 contained 0.1% (w/w) XG and KC each, and pea ink 5 had 0.3% (w/w) XG and KC each. For carrots, the control puree, i.e. ink 1, had 90% WC, and the rest of the carrot inks had the same WC % but varying amounts of HCs. Carrot ink 2 had only 0.3% (w/w) XG, ink 3 had 0.3% (w/w) XG and KC each, ink 4 contained 0.3% and 0.5% (w/w) XG and KC respectively, and ink 5 had the highest concentration of HCs with 0.3% (w/w) XG and 0.7% (w/w) KC. Bok choy ink 1 was the control puree with WC $\approx$ 96%, ink 2 had 1% (w/w) XG, ink 3 had 0.7% (w/w) XG and 0.5 % (w/w) LBG, ink 4 contained 1% (w/w) XG and LBG each, and ink 5 contained 1% and 2% (w/w) XG and LBG, respectively.

10 **[0099]** WC and HCs are controlled to render different rheological properties of the food inks. HCs have been used because of their ability to modify the rheological properties of the food. Successful 3DFP may be affected by ability of the inks to flow easily under a high shear stress during printing and to maintain the structural integrity after printing. All the food ink formulations displayed desired shear thinning pseudoplastic behaviour.

15 The viscosity of all the food inks decreased with increasing shear rates between 0.001 to 1000 s⁻¹ (FIG. 1A).

[00100] Garden pea inks, ink 2 and ink 3 with respective WCs of 85% and 90% displayed slightly lower viscosities than the control ink 1 with a WC of 80% at the same shear rate. Pea ink 4 and ink 5 had higher viscosities due to the addition of XG and KC.

20 The highest viscosity was obtained for ink 5 (XG, KC = 0.3% w/w, WC = 80%) whereas the lowest viscosity was observed for ink 3 (WC = 90%).

[00101] The WC of all the carrot ink formulations was 90%, the initial viscosities at a low shear rate were comparable, and all the inks showed shear thinning behaviour. An interesting effect was observed in carrot ink 2 whereby the viscosity of ink decreased slightly with added XG compared to the control carrot ink 1 (FIG. 1A). The phenomenon of decreased viscosity with added XG may be due to the effect of XG on other ingredients. The rest of the carrot ink formulations with two HCs had higher viscosities than carrot ink 1 and ink 2.

25

[00102] All bok choy inks had WC $\approx$ 96% and displayed shear thinning properties. The control puree (ink 1) was not printable because it behaved like a non-viscous fluid (FIG. 2A). At a low shear rate, bok choy ink 1 and ink 2 displayed higher starting viscosities which may be attributed to the phase separation. As the shear rate approached the

30

crossover point (yielding of the inks, FIG. 2C), the bok choy ink with a combination of two HCs, i.e. ink 5 (XG=1%, LBG=2%) had higher viscosity compared to bok choy inks 1 and 2.

[00103] Oscillatory amplitude sweep tests were performed to determine the yield stress of the food inks (FIG. 1B). Mechanical strength of the inks depends on the storage modulus (G'), a parameter that indicates the elastic response of the material and determines the ability to form self-supporting structure after printing. And the viscous response is represented by the loss modulus (G''). Upon the application of a low sinusoidal oscillatory stress that mimics the inks at the resting stage before extrusion, a linear viscoelastic range (LVER) was observed where G' remained constant and preserved the internal structure of the inks (FIG. 2C). With increasing shear stress, the microstructure of the inks collapsed, leading to a liquid-like flow, i.e. the yielding of the inks resulting in G'' becoming greater than the G' , and the inks exhibited properties of a viscous flow. Yield stress, the minimal stress required to break the microstructure of the inks and to make them flow during extrusion, was determined by taking the stress value at the cross-point of G' and G'' (FIG. 1B).

[00104] As depicted, the yield stress of pea inks decreased with increasing WC %. The addition of HCs to the pea ink 5, (0.3% w/w XG, KC) significantly increased the yield stress compared to ink 3 without HC. Pea ink 1's yield stress was higher than that of ink 2 and ink 3, which meant that pea ink 1 could better maintain the shape of the printed structure (FIG. 2A).

[00105] For carrots, the yield stress value of ink 2 decreased compared to ink 1, which also corroborated the decreased viscosity observed in FIG. 1A. With a combination of two HCs, the yield stress of carrot ink 3 increased significantly compared to ink 2 containing XG only.

[00106] For bok choy inks, a similar trend was observed with the addition of XG. XG alone decreased the yield stress, and the addition of two HCs increased the yield stress. This phenomenon could be explained by the fact that XG alone could not form a gel, whereas XG and LBG together form soft elastic gels. Bok choy ink 4's yield stress was significantly higher than that of the ink 2 containing XG alone. Bok choy ink 5 with the highest concentration of HCs (3% w/w) had the highest stress value. Yield stress must

be considered to achieve sufficient mechanical stability for printed structures while not adversely affecting the extrusion process.

[00107] Another desired property of food ink is the reversibility of the viscosity. Experiments were carried out with three ink formulations – ink 1 of garden peas, ink 2 of carrots and ink 4 of bok choy (FIG. 2A). These inks were subjected to three stress levels that mimic the three stages of extrusion-based printing – inks stored in the syringe with no pressure, extrusion through nozzle upon applied shear stress, and restructuring of the inks after deposition when the extrusion pressure is removed. The viscosity of these three inks exhibited a high reversibility. After the shear stress was removed after printing, the viscosity restored to almost the same level as the initial stage, indicating that the food inks were able to maintain the structural integrity after printing (FIG. 1C).

[00108] Example 10B: Results – 3D Printed Structures

[00109] The printability of food formulations was evaluated based on the syneresis, shape fidelity and structural integrity. The prints were scored from 1 to 5 (1 = very bad, 5 = very good) based on a modified print scoring system. For the pea inks, ink 1 and ink 4 gave the highest print score (see Table 2 below).

[00110] Table 2 - Printability of food inks assessed by shape fidelity and shape stability.

Print score	Ink 1	Ink 2	Ink 3	Ink 4	Ink 5
Garden peas	5	3	2	5	4
Carrots	3	5	5	2	2
Bok choy	1	2	3	4	4

[00111] As seen in FIG. 2A, pea ink formulations 2 and 3 exhibited syneresis with visible accumulation of fluid at the base of the printed structure. This syneresis was eliminated by keeping the WC low at 80% (ink 1) or by adding XG and KC at concentrations of 0.1% and 0.3% (w/w) in inks 4 and 5, respectively. Pea inks 1, 4 and 5 showed good print scores but inks 2 and 3 are still deemed 3D printable (FIG. 2D). Though food HCs are deemed safe, a general perception among elderly patients is that HCs may introduce a furry/non-natural taste, which may hinder the consumption and acceptance of 3D printed food. Hence, inks with the least amount of HCs were chosen

as the formulations of the food type amongst the ones with the same print scores (see Table 2 above). Pea ink 1 was able to form stable self-supporting structures without requiring any additives. Thus, the best garden pea ink was ink formulation 1 with no HCs. Pea represents the starchiest vegetable in the three defined categories. Starch by itself is used as a thickener hence explaining the good printing outcome in pea ink 1 without any HC addition. The starch content of peas ranges from 44.11% to 46.70% in different cultivars of wrinkled peas. Starch granules have the capability of swelling up on heating and rupturing near boiling point causing marked thickening.

[00112] Carrots have a relatively higher WC % and a median starch content as compared to garden peas. Starch content in carrots has been known to vary, ranging from 8-15 mg/g dry weight, whereas decrease of starch content in carrot from 152 ± 18 mg/g dry weight to 11 ± 7 mg/g dry weight may occur in cold storage conditions. This variability may be attributed to the difference in the cultivars examined, extraction methods as well as the storage conditions. Carrots with WC = 90% were chosen for experiment with the addition of XG and KC at different concentrations. Carrot ink 1 extruded but there was severe syneresis (FIG. 3A and 3B). Also, the shape fidelity and surface quality were poorer than expected. Ink 2 with 0.3% (w/w) XG had a remarkable improvement in printing quality and reduced syneresis. Similar observations were reported for ink 3 (XG, KC = 0.3% w/w). In carrot inks 4 and 5, XG concentration was kept at 0.3% while KC concentration was increased to 0.5% w/w and 0.7% w/w, respectively. The increased KC resulted in overly thickened inks that were difficult to extrude (FIG. 2A), albeit still printable. Again, both inks 2 and 3 had excellent print results with a smooth surface and clearly defined shape without drooping at the layer edges. Since carrots required only one HC (XG) to be printed, ink 2 may be considered the most desirable ink formulation. Experiments with the addition of XG, which had a weak gelling action, prevented syneresis and led to stable 3D prints. There was no need for additional high temperature activation step while using XG. XG also provided a creamier texture to ink 2 (XG = 0.3% w/w) by virtue of increased water interaction. Upon using two HCs—XG and KC (ink 3), good prints of carrot inks could also be achieved with excellent print score, but the need for extra HC was obviated by XG addition alone.

[00113] Bok choy represents green leafy vegetable with the highest amount of water percentage ($WC \approx 96\%$) and lowest starch content among the vegetables chosen for the study. Two different HCs were necessary, single HC could not provide the structural integrity nor prevent syneresis post printing. As seen in FIG. 2A, ink 1 with no HCs was essentially a liquid that spread after extrusion. Hence, this ink was not used for either textural profile analysis (TPA) or IDDSI tests. Ink 2 with one HC ($XG = 1\%$ w/w) was able to print but had syneresis and ill-defined layers, which was not considered good for 3D printing, albeit still printable to have a structure. By combining two HCs, namely XG and LBG (ink 4), syneresis was prevented, and a well-defined shape could be achieved with 1% and 2% (w/w) of XG and LBG, respectively. Between bok choy ink 4 and ink 5, ink 4 was deemed as the most desirable formulation because of the lower HC concentration.

[00114] To improve the quality of living for dysphagic patients, an enjoyable, nutritious and safe meal is of the utmost importance. Visual presentation of dysphagic diets is critical as aesthetically pleasing foods lead to an increased intake. In this regard, 3D printing can provide much superior presentation (FIG. 2B) compared to the widely used silicone moulds. In the photos of FIG. 2B, a 3D Chinese painting that depicted a fisherman on his boat leaving his home in the mountains was printed. The boat, hut and pagoda were printed out of the carrot inks, mountains were printed using pea inks, and the fisherman's hat was printed using corn inks on the Wiiboox Sweetin printer. Foodini food printer is unable to print customized design. The use of a different extrusion printer validates further the printability of the food inks.

[00115] Example 10C: Syneresis (Water Spreading) of Food Inks

[00116] Syneresis refers to the undesired leakage of water from foods that gives a non-appealing visual presentation (FIG. 3B). The spreading of the water affects the overall integrity of the printed food structure and leads to non-stable prints that collapse easily. In this study, an approach was employed to quantitatively determine the amount of water leaking from the 3D printed food by measuring the area wetted by water on a piece of Whatman filter paper (FIG. 3C).

[00117] Garden pea ink 2 ($WC = 85\%$) and ink 3 ($WC = 90\%$) had higher syneresis compared to the control ink 1 ($WC = 80\%$). The addition of XG and KC in pea inks 4

and 5 decreased the syneresis. Pea ink 5 had significantly less water seepage compared to ink 2 and ink 3.

[00118] Carrot ink 2 with XG alone showed smaller wetted area compared to the rest of the inks. XG works as a thickener and weak gelling agent that was adequate to prevent the syneresis on its own in the case of carrot ink 2 (FIG. 3B). Carrot ink 2 showed significantly reduced syneresis compared to the control ink 1. For the rest carrot inks (ink 3, ink 4 and ink 5), the combination of two HCs increased the water seepage as compared to ink 2, possibly because KC hindered the water swelling capacity of XG.

[00119] Bok choy inks exhibited a pattern of less fluid seepage with increasing HC concentrations (FIG. 3A). For bok choy inks, the combination of two HCs (ink 3, ink 4 and ink 5) showed reduced syneresis because of synergistic gelling action of XG and LBG as they are known to form soft elastic gels. Bok choy ink 5 had significantly less syneresis compared to the control ink 1.

[00120] Example 10D: Microstructure of Food Inks

[00121] Scanning electron micrographs of different food ink formulations highlighted the differences between purees with and without HCs (FIG. 4A to 4C). Garden pea ink 1 with no HCs showed agglomerates in the SEM image. Pea ink 5, which contained XG and KC, showed a mesh structure typically observed in hydrogels. Both pea ink 1 and ink 5 displayed good printing quality (FIG. 2A), suggesting that the clump structures, which was likely due to the starch content, were sufficient to maintain the structural integrity of 3D printed foods. For carrot ink 1 (control puree with no HC additive), fibers were observed along with a few pores without much interconnections in between the layers. The addition of 0.3% (w/w) XG alone to carrot ink 2, caused the fibers to interconnect and form weak gel-like structures, which enhanced the mechanical stability of the inks to maintain the structural integrity. For bok choy ink 1 (the control puree with no HC), the pores observed in the microstructure were significantly larger compared to carrot inks. The pore density in bok choy ink 4 was maintained with the addition of the XG and LBG. However, the pores decreased in size, and much more interconnections of fibers and sheets were observed. This was caused by the formation of pronounced gel-like matrix which imparted mechanical stability to the ink for 3D printing.

[00122] Example 10E: Textural Properties

[00123] The texture profile analysis (TPA) was done for the printed food samples, and the results were depicted in the FIG. 5. The values have been normalized against the highest value in the group. Currently, even though IDDSI mentions certain parameters for dysphagia diets in terms of textural properties like hardness, adhesiveness, springiness, etc., there is no clear guideline on the TPA range of dysphagic diet containing vegetables. In other words, there is no co-relationship between hardness and cohesiveness as the two textural properties are associated with different stages of food processing in the mouth. Mainly qualitative assessments, such as fork pressure test, spoon tilt test, syringe flow test, are recommended by IDDSI for selecting proper dysphagic diets. For the pea inks, the hardness value of ink containing the highest concentration of HCs (XG, KC = 0.3% w/w), i.e. ink 5, was highest, and the least hardness was observed in ink 3 (WC = 90%). Pea ink 1, which was able to be printed in nice 3D shapes, had the highest adhesiveness and gumminess. High adhesiveness may be responsible for pea ink 1's excellent print score. Semi-solid foods are represented by gumminess with low hardness and high cohesiveness values, ideal for dysphagic diets. Ink 1 had the highest gumminess value. For carrots, ink 3 with the least concentration of XG and KC had the highest hardness. Ink 2 with XG alone was the gummiest among all carrot inks, again indicating its suitability as dysphagic food. Bok choy ink 5 had the highest values for hardness, adhesiveness, gumminess, springiness and chewiness which correlated nicely with the highest concentration of HCs (XG = 1%, LBG = 2% w/w). XG and LBG can form soft elastic gels and work in a synergistic manner. Rest of the bok choy inks showed similar pattern. Ink 4, which was deemed as best formulation in terms of print score, had sufficiently high values of hardness, gumminess, adhesiveness.

[00124] IDDSI classifies foods into 8 levels (0-7): levels 0-3 for thickened drinks and levels 4-7 for pureed, minced and moist, soft-bite-size and easy-to-chew foods. Food can be classified by a number of IDDSI tests. Since purees can flow and the 3D prints also resemble soft foods ready for chewing, further characterization of the food inks was done using both IDDSI fork pressure and spoon tilt tests. Representative results are shown in FIG. 6A and 6B, and the full testing results are shown in FIG. 6C and 6D. The spoon tilt test was used to determine the stickiness of foods (adhesiveness) and the ability to hold together (cohesiveness). On the basis of both spoon tilt tests and fork

pressure tests, it may be concluded that the food inks are transitional foods (IDDSI, 2019) as they started with a soft and solid 3D printed structure but disintegrated or flattened upon the application of pressure. The printed food may also melt and transform on water/saliva contact. However, to be labeled as dysphagic diet, these 3D-printed food need to be certified by relevant regulatory bodies.

[00125] Example 11: Discussion

[00126] Presently, moulds are being used to shape the pureed foods, which requires a heavy investment on manpower, more intensive manual handling during plating, more storage and heavier utilization of plastics. The present 3DFP method provides an alternative better solution to some or all of these issues. In one example, 10% w/w XG was used to prepare food ink from freeze-dried spinach powder for 3D printing. Broccoli, spinach and carrot powders have also been 3D printed, but the amount of HCs used was in the range of 10%, which is very high and leads to taste alteration. Aroma and taste perception decreases with increase in HCs concentration. Addition of XG has been shown to reduce the perceived intensity of sweetness, sourness and bitterness of sucrose, citric acid and caffeine solutions. For firm gels with high HC concentrations, the perceived flavour perception is lower and a longer time is needed to establish the taste as compared to softer gels. Compared to the existing methods of preparing vegetable-based food inks from freeze-dried powders (except for mashed/pureed potatoes), the present method based on vegetable purees can involve a low overall usage of HCs of not more than 2% w/w. Utilizing no or very low amounts of HCs may be beneficial to the patients to alter their perception about the taste of 3D printed foods, making the food more palatable.

[00127] Garden peas (WC = 80%), the starchiest amongst the three representative vegetables are printed without the need of HCs as stabilizers or thickeners and show minimal water leakage. Carrots owing to a higher water content (90%) require one HC, 0.3% w/w XG, for good print outcome, whereas bok choy, with almost negligible starch content and highest water content ($\approx 96\%$) needs 2 HCs, XG and LBG for printing stable shapes. This method of processing and modulating the textural properties can be applied to other vegetables having similar starch and WC %. Potatoes, corn, sweet potatoes can be processed like garden peas without the need of HC addition. Beets and turnips with median starch content can be treated in a similar manner as carrots (using only a single

HC), whereas green leafy vegetables like spinach, kale with low starch and high water content can be processed for printing by adding a combination of two HCs. However, the desirable formulation for any food ink may be configured accordingly based on the specific food type, HC, and type of printer used, because each food may have a different physical and chemical of interaction with the HCs.

[00128] Example 12A: Further Examples and Comparison Using Other Amounts of Hydrocolloids with Garden Peas, Carrot and Bok Choy

[00129] Formulation of vegetable inks and water content measurement in this example have been described in examples 1 and 2 above.

[00130] Different amounts of hydrocolloids, namely Xanthan Gum, Kappa Carrageenan (KC) and Locust bean gum (LBG) were added to the puree at different concentrations (refer below). The puree and the gums were mixed thoroughly by a hand blender and the beaker containing the inks was sealed with clingwrap to avoid loss of moisture. The beakers were then kept in a water bath for 30 minutes at a temperature of 72°C and 90°C for KC-containing inks and LBG-containing inks, respectively. The inks were then cooled to room temperature before printing or stored in refrigerator for future use. The inks in this example differ from Table 1 above in that carrot ink 4 (which include 0.5% XG), carrot ink 5 (which include 0.7% XG), and bok choy ink 3 (which includes 0.7% XG and 0.7% LBG) from this example, are additionally tested.

[00131] Following formulations were used to 3D print test models for garden peas:

[00132] a) Pea puree with water content = 80% (Ink 1/control)

[00133] b) Pea puree with water content = 85% (Ink 2)

[00134] c) Pea puree with water content = 90% (Ink 3)

[00135] d) Pea puree with water content = 80% and 0.1% XG and 0.1% KC w/w (Ink 4)

[00136] e) Pea puree with water content = 80% and 0.3% XG and 0.3% KC w/w (Ink 5)

[00137] Following formulations were used to 3D print test models for carrots,

[00138] a) Carrot puree with water content = 90% (Ink 1/control)

[00139] b) Carrot puree with water content = 90% and 0.3% XG w/w (Ink 2)

[00140] c) Carrot puree with water content = 90% and 0.3% XG and 0.3% KC (Ink 3)

[00141] d) Carrot puree with water content = 90% and 0.5% XG and 0.5% KC (Ink 4)

[00142] e) Carrot puree with water content = 90% and 0.7% XG and 0.7% KC (Ink 5)

[00143] Following formulations were used to 3D print test models for Bok Choy at $WC \geq 96\%$,

[00144] a) Bok Choy puree with 0.7% XG and 0.5% LBG w/w (Ink 1)

5 [00145] b) Bok Choy puree with 1% XG and 1% LBG w/w (Ink 2)

[00146] c) Bok Choy puree with 0.7% XG and 0.7% LBG w/w (Ink 3)

[00147] For 3D printing of vegetable inks, FOODINI (Natural machines), an extrusion based commercial 3D food printer was used to print 3D samples of different vegetable inks. The printer has 5 capsules that can hold 100mL of ingredients and 3 nozzle sizes,
10 0.8mm, 1.5mm and 4mm. For our experiments, 1.5 mm nozzle was used. The print speed, extrusion rate and other parameters were adequately set in pre-tests for getting optimal prints. The samples were kept for 30 minutes to observe for shape and structure fidelity and were photographed using an android smartphone.

[00148] For syneresis characterization, water leakage experiments were performed by
15 taking 1 gram of puree and putting it in the centre of Whatman grade 4 filter paper. Distance covered by the water was measured in cm.

[00149] For rheological properties measurement, the rheological experiments were done by using rotational rheometer-Discovery HR-2, DHR (TA instruments, USA). 20 mm geometry was used with a gap of 1000 μ m. Flow ramp tests were performed on food
20 inks at a shear rate of 0.01 s⁻¹ to 1 s⁻¹. Oscillation amplitude experiments were carried out at a frequency of 1Hz to determine the yield stress of the inks. Triplicates were done for each sample and average data was represented.

[00150] Data were plotted in graph pad prism software and analysis was done using t tests. Significant results were reported as p value less than 0.05.

25 [00151] **Example 12B: Discussion of Garden Peas in Example 12A**

[00152] The requirements of 3D printing for food inks are extrusion through the printer nozzle and structure formation after deposition, with the deposited layers fusing and adhering to the previously printed layers. The formed structure has suitable strength to retain the printed shape. Five different formulations were prepared, three of which had
30 varying water content percentage without the addition of any thickening agent or hydrocolloids and the other two food inks had two hydrocolloids combinations (FIG. 7A). The control puree with water content at 80% could print nice stable structures

without collapsing or water leaking from the sides. On searching for the water content in peas this formulation came close to the moisture percentage found in frozen garden peas. On increasing the WC % by 5% and 10%, model shapes could be printed but the layers in the prints were structurally not good and on printing, syneresis may be
5 observed, wherein water leakage occurs from the sides of the printed models. FIG. 9A represents the spread of water (syneresis) by the food inks on filter paper. With increasing WC %, the distance travelled by water present in the food inks increases and addition of hydrocolloids prevents the extent of spreading.

[00153] For extrusion to happen, the inks should display shear thinning properties, i.e.
10 the inks should thin out and flow when shear is applied and once the shear is removed, they should form self-supporting structures without much deformation. For this to happen the inks should have low viscosities under shear, displaying pseudoplastic behaviour. All the food ink formulations displayed shear thinning behaviour on applying shear rate between 0.01 s^{-1} to 1 s^{-1} . Highest viscosity was obtained for XG and
15 KC = 0.3% ink whereas lowest viscosity was observed for 90% WC ink (FIG. 8A).

[00154] Yield stress is the minimum amount of stress applied to start the flow of material, in terms of 3D printing the stress should be adequate to allow for the material to extrude out of the nozzle and not so strong that the food ink cannot reform again. Higher yield stress generally leads to a well-formed print. Pea food ink 1's yield stress
20 measured was significantly higher than ink 2 and ink 3, correlating to the fact that it could be extruded uniformly and the structure retained its shape. With the addition of hydrocolloids at 0.3% w/w, the ink could be extruded but the texture of the model printed was not smooth (FIG. 8B).

[00155] Hydrocolloids (HCs) have been used because of their ability to modify the
25 rheological properties of food i.e. viscosity and texture, this enables the HCs to act as thickening and gelling agents, emulsifiers, stabilizers, etc. Most of the HCs require a hydration step for functionality, which involves heating the solution containing HCs at elevated temperatures (for example, KC = 72°C , LBG = 90°C) for around 30 minutes.

[00156] Herein, it was demonstrated that at a certain water content percentage (80%),
30 there is no requirement of addition of any hydrocolloids for boiled garden peas. The 3D-printed shapes are self-supporting with good layered structuring that are stable for more than 30 minutes with not much syneresis. Since there is no HC, the additional step

of double heating/boiling is not required thereby preventing any moisture or nutrient loss. Moreover, the taste of the 3D printed food is of primary importance for dysphagia patients. If the 3D-printed pureed food tastes like the original starting material, it can be better consumed in their diet and also consumer perception is in favour of non-addition of any HCs. Garden peas vegetable may have optimal 3D prints by different ink formulations. In this case, the one with the least external modifiers can be selected.

[00157] Example 12C: Discussion of Carrots in Example 12A

[00158] Five food inks were formulated with boiled and cooked carrot puree having adjusted water content of 90% (FIG. 10B). Ink 1 (control puree) without any HCs could be printed but within minutes of printing the structure, the print started leaking water along the edges (FIG. 10A). With the addition of Xanthan gum (XG does not need high temperature activation step) which is a thermostable thickener, the water weeping (syneresis) is arrested (FIG. 11) and hence increased structure stability after printing was observed (FIG. 10A). XG also provides a creamier texture to the ink by virtue of increasing water interaction. FIG. 12 shows the syneresis measurement whereby water leakage is controlled to a great extent by addition of XG at 0.3% w/w. In combination with other HCs like KC, there is less water leakage compared to the control but not as efficient as using XG alone (FIG. 12).

[00159] An interesting effect of XG addition is observed on the viscosity of carrot ink (Ink 2) whereby the viscosity decreases compared to the control (FIG. 13B). The rest of the ink formulations had higher viscosities than the control and Ink 2. The highest viscosity observed was for double HC combination of XG and KC (Ink 5). Carrot ink 2 and ink 3 had the most desirable prints in terms of shape and structural integrity (FIG. 10A). With increasing viscosities, it gets difficult to extrude the inks with the same pressure. The yield stress of Ink 2 with XG at 0.3% is significantly lower than the control. The viscoelastic properties of the ink 2 makes it suitably ideal for 3D printing.

[00160] Example 12D: Discussion of Bok Choy in Example 12A

[00161] Bok choy comes under the leafy green vegetables with a high-water content. Three different formulations of inks were tested for printing by adding three HCs- XG, LBG and LG in different w/w percentages (FIG. 14). Ink 3 with LG and LBG had visible syneresis, Ink 1 and Ink 2 prints had no water leakage, however ink 2 had

comparatively better structure and layering. So, the addition of two HCs may be necessary to 3D print Bok choy.

[00162] Example 13: Commercial and Potential Applications

5 [00163] The present food ink composition and method offer a categorized approach to prepare food inks from fresh vegetables and/or fruit for 3D food printing. This is advantageous at least for improving dietary requirements of dysphagia patients.

10 [00164] Dysphagia is a condition that results in an abnormal delay in the passage of food during oropharyngeal or esophageal stages of swallowing with a periodicity varying yearly or with every attempt. One of the approaches may be through nutrition and dietary modification. The texturally modified food shapes made by using silicone moulds are not very appealing to the senses and tends to have problems with reproducibility, costs, time consumption, and safety. The present method, involving 3D food printing, can be employed to increase the food intake of such patients by customizing food designs and personalize nutrition. Enhanced visually appealing foods
15 with modified textural properties safe for consumption for elderlies are very advantageous.

[00165] 3D printed vegetables confer an entirely new dining experience to dysphagia patients, visually and nutritionally. Conversely, existing sources of vegetables involved specifically processed vegetable powder, which requires the addition of a higher content
20 of hydrocolloids for 3D printing and may be perceived as "canned vegetables". 3D printing of fresh raw vegetables may remain a challenge due to mixed results when existing methods/technologies are used. Some vegetables (e.g. corn) appear to be more printable than many others after blending. In the present disclosure, use of different water and fresh vegetables with different starch content were studied for different
25 rheological behaviours after blending, resulting in printability variation. Therefore, the present method configures fresh vegetables to have rheological behaviours for printability based on their water and starch content. The present approach addresses the mixed results when printing specific vegetables using existing technologies.

30 [00166] The present food inks and method establish a unique way of categorizing different vegetables, each having dissimilar water and starch content, to render them 3D printable. The higher the starch content and the lower the water percentage of the vegetables, the less HC needed in the ink formulation. One of the significance of the

present food ink and method is in the use of undehydrated vegetables along with the least amount of HCs to print aesthetically pleasing and palatable food while preserving the nutrition and flavours.

5 **[00167]** The present methodology of processing fresh vegetables can be well utilized in hospitals, nursing homes, day care centers for the ageing population with dysphagia and other swallowing disorders. Said differently, the present food inks and method can be applied for the processing of fresh vegetables for safe and nutritious consumption in hospitals, old age homes for people with swallowing difficulties. All the above reasons justify the use of fresh and non-processed vegetables for the present 3DFP.

10 **[00168]** While the present disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims. The scope of the present disclosure is thus indicated by the appended claims and all changes
15 which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. An edible and 3D printable plant-based ink composition for consumption by dysphagic patients, the edible and 3D printable plant-based ink composition comprising:

a vegetable puree and/or a fruit puree, wherein the vegetable puree and the fruit puree are not freeze-dried and contain one or more hydrocolloids; or

a vegetable puree and/or a fruit puree, wherein the vegetable puree and the fruit puree are not freeze-dried;

wherein each of the one or more hydrocolloids is present in an amount of 10 wt% or less based on the vegetable puree and/or the fruit puree.

2. The edible and 3D printable plant-based ink composition of claim 1, wherein the vegetable puree and/or fruit puree comprise a starchy vegetable, a root vegetable, or a leafy vegetable.

3. The edible and 3D printable plant-based ink composition of claim 1 or 2, wherein the one or more hydrocolloids comprise xanthan gum, kappa carrageenan, or locust bean gum.

4. The edible and 3D printable plant-based ink composition of any one of claims 1 to 3, wherein

the vegetable puree comprises pea; and

the one or more hydrocolloids comprise xanthan gum and/or kappa carrageenan.

5. The edible and 3D printable plant-based ink composition of claim 4, wherein the xanthan gum and the kappa carrageenan are respectively present in an amount of 0.1 to 0.3 wt% based on the vegetable puree.

6. The edible and 3D printable plant-based ink composition of any one of claims 1 to 3, wherein

the vegetable puree comprises carrot; and

the one or more hydrocolloids comprise xanthan gum and/or kappa carrageenan.

7. The edible and 3D printable plant-based ink composition of claim 6, wherein the xanthan gum and the kappa carrageenan are respectively present in an amount of 0.3 to 0.7 wt% based on the vegetable puree.

8. The edible and 3D printable plant-based ink composition of any one of claims 1 to 3, wherein
the vegetable puree comprises bok choy; and
the one or more hydrocolloids comprise xanthan gum and/or locust bean gum.

9. The edible and 3D printable plant-based ink composition of claim 8, wherein the xanthan gum and the locust bean gum are respectively present in an amount of 0.5 to 2 wt% based on the vegetable puree.

10. A method of forming the edible and 3D printable plant-based ink composition of any one of claims 1 to 9, the method comprising:
providing a puree of a vegetable and/or a fruit;
sieving the puree to remove any solid particles which blocks a nozzle of a 3D printer; and
cooling the puree to room temperature for 3D printing.

11. The method of claim 10, wherein providing the puree comprises:
boiling or steaming the vegetable and/or the fruit; and
blending the vegetable and/or the fruit after the boiling or the steaming to form the puree.

12. The method of claim 10 or 11, further comprises mixing the puree with one or more hydrocolloids.

13. The method of claim 12, wherein the one or more hydrocolloids comprise more than one hydrocolloid.

14. The method of claim 13, further comprising dry mixing of the more than one hydrocolloid prior to mixing with the puree.

15. The method of any one of claims 10 to 14, further comprising incubating a mixture comprising the puree and the one or more hydrocolloids at:

a temperature of 70 to 75°C, wherein the one or more hydrocolloids comprise kappa carrageenan; or

a temperature of 90 to 95°C, wherein the one or more hydrocolloids comprise locust bean gum.