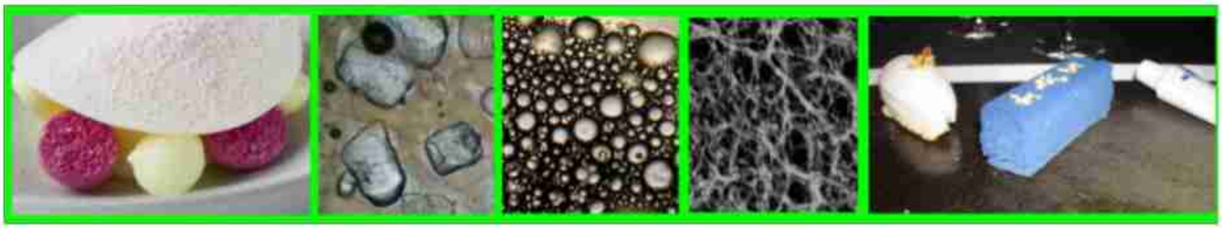

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Developing a Customised Note by Note Prototype Recipe Which Can be 3D Printed

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Abstract

Note by Note (NbN) cooking and 3D food printing individually and in combination allow for the creation of customized foods. A NbN recipe was developed and printed using a Procusini 3.0, 3D food printer. The recipe was adapted from a commercial powdered pastry dough recipe, to create two versions of a prototype food, containing in each case a different plant-based protein, *i.e.*, soya (*Glycine max* L.) or hemp (*Cannabis sativa*). The printed foods were identical in shape and had a crisp consistency following cooking. They had different colours and contained different proteins in the amounts of 10.3 % of soya or 5.7 % of hemp before cooking, which increased to 17.5 % and 9.7 % respectively following evaporation of water during cooking. The main challenge was optimizing the consistency of each recipe mixture before adding it to the syringe prior to printing. The development of the prototype foods which were created in this study shows that recipes of pure compounds and/or mixtures of compounds could be prepared by innovative chefs who want to surprise their diners. Food product developers can create customised foods for consumers, who wish to eat for example more plant-based proteins, those with allergies or intolerances to certain proteins and/or sports athletes.

Keywords
note by note cooking; 3d food printing; texture, consistency, customised foods.

Introduction

NbN cooking can be used to create bespoke foods (Burke *et al.,* 2020). This type of cooking involves preparing dishes using pure compounds, or more practically a mixture of compounds obtained by fractioning plant or animal tissues, instead of using these tissues themselves (This, 2013).
Three-dimensional (3D) printing is an emerging

technology with the potential to revolutionize people's eating habits (Liu *et al.*, 2020). The target is to fabricate food pieces with customized color, shape, flavor, texture and even nutrition (Sun *et al.*, 2018). Customization of food using the 3D printing technique is a convenient way to cook food with maximum utilization of materials, and consequently, this technique has received considerable attention from the public in recent years (Y. Liu *et al.*, 2019) and also from researchers.
Ingredients such as polysaccharides which are used in NbN cooking are also suitable for 3D food printing (Ross *et al.*, 2021), and therefore customized foods can be produced by 3D printing NbN recipes. Printability of the ingredients and the quality of the 3D printed food products are dependent on several product and printing parameters such as temperature, fill density, ingredient ratios and their interactions (Varghese *et al.,* 2020).
For the technology to succeed, studies need to address the composition of printable foods and the stability of printed matrices delivering acceptable sensory properties (Chow *et al.*, 2021). Printing materials and recipes should be optimized to improve the quality and efficiency of 3D printing (L. Liu *et al.*, 2019). Various scientists have shown that rheological properties such as the storage modulus, yield stress, consistency index and flow behavior index can predict the printability of a material, while 3D printer parameters such as nozzle velocity and layer height have an impact on the final quality of the printed structure (Pérez *et al.*, 2019).
For example yield stress evaluates the material’s ability to retain its dimensional shape, while shear storage (*G’*) and loss modulus (*G*”) show the viscoelastic properties of the material, and thus its capacity for extrusion (Le Bail *et al.*, 2020). As noted by Pulatsu *et al.* (2020), it is important to understand the effects of key components of food materials on the printing, which enables a wider range of structures, and provides tailored nutrition and personalization when just using a single nozzle in extrusion-based 3D printing; understanding the effects of food processing on 3D printed food items is critical to broadening its applications.
During the 10th International Workshop on Molecular and Physical Gastronomy (AgroParisTech Inrae International Centre for Molecular and Physical Gastronomy, 2021), a prototype NbN recipe that can be 3D printed was discussed by one of the authors (Róisín Burke), and it was shown that it can be adapted by innovative chefs to suit customer dining experiences.
Many studies have been conducted on different aspects of 3D printing, *e.g.*, sensory and nutritional properties. However there have been no known studies to date on the combined approach of 3D printing a customized NbN food. In this study, it was found that while optimizing the consistency of a NbN mixture can be a challenge, the other sensory properties are easier to design, for example the inclusion of specific colorants, taste and odorant compounds.
The shape of the 3D printed food can be designed as required by using shapes, or scanning in photographs or images (Procusini Company, 2022). Food product developers can also customize the printed NbN foods to suit consumer needs such as nutritional, *e.g.*, vegan and/or lactose-intolerant or dietary needs of sports athletes. As in this study, added protein ingredients can be exchanged for another protein, and concentrations of proteins can be increased or decreased as required. Results and discussion of the versatility of using the double approach of 3D printing a NbN recipe is presented later in this text.

Materials and Methods

Pasta Powder:
According to the Procusini Company (2022), the contents of the pasta powder package, which

was delivered with the 3D printer, is composed of glutinous rice flour, durum wheat semolina, wheat flour, whole egg powder, salt and yeast. The amounts of each ingredient were not specified on the package, and details of varieties and species from which the ingredients were sourced were not available.

Note by Note ingredients:
Cornflour (Gem pack foods™), caster sugar (Siúcra™), soya protein isolate (Bulk powders™) or hemp protein powder (Bulk powdersTM), salt (sodium chloride, Saxa™), extra virgin olive oil (Basso™), water (tap).

Recipes:
1. Pasta: 7 g of oil and 40 g of water were weighed into a jug and the whole contents (45 g) of the packet of pasta dough powder was added. The dough was mixed using a hand mixer at a low speed (< 3,000 rpm) for 3 min when a dough was formed. Then the dough was filled into a disposable piping bag and let rest at room temperature for 45 min, so the water can penetrate the starch granules by capillary action (This, 2007).
2. Note by Note Mixture: cornflour, 66 g; caster sugar, 2 g; soya protein isolate powder or hemp protein powder, 28 g; salt, 1 g; extra virgin olive oil, 14 g; water (tap), 120 g.
Mix together, and put into the syringe in the 3D printer. Print out according to the method below and cook for 15 min at 150 °C.

Preparation of mixes for extrusion:
Pasta or Note by Note : The cartridge was filled with the piping bag up to the 60 mL mark, taking care to avoid air bubbles. The dosing tip was screwed onto the cartridge. “Pasta” was selected from the food items in the user interface and the cartridge was inserted into the printer.

Printer parameters:
A Procusini 3.0 model was used, which operates with layer-by-layer technology for production of foods. The volume of the dosing syringe is 60 mL. The installation space was X: 250 mm Y: 150 mm Z: 100 mm. The positioning accuracy was 0.1 mm, the diameter of the nozzle 1.2 mm, the production speed 5 – 50 mm/s and movement speed 5 – 200 mm/s. The usable production area is 150 x 250 mm (375 cm²) with maximum space X: 600 mm (plate moves to the left and right), Y: 600 mm, Z: 650 mm. Connectivity is interface browser-based with Google Chrome compatibility and wireless LAN 802.11.

3D Printing process:
The 3D printing machine was used according to the instructions outlined below.
1. The “Produce object” button was selected.
2. The food item was selected by clicking the relevant button. In this case “Pasta” was selected.
3. The prepared 60 mL cartridge was inserted containing the mixture.
4. The device was calibrated as follows:
The production plate was placed onto the device table and positioned so that it locked into place. A piece of kitchen paper was placed on the production plate. Confirmation of ”calibrate now“ was done by pressing ”yes“. The push button was gently pushed down by using the arrow symbols. The large arrows indicate large steps, small arrows indicate small steps. The push button was lowered in small steps until the dosing tip hovered directly above the kitchen paper while the latter could still be moved slightly back and forth (approx. 1mm). The calibration was confirmed with the “DONE” button on the user interface of the browser. The push button automatically returned to its starting position afterwards.
5. The object for production was selected. In this case, the lobster.
6. The production was started by clicking on the start button. After 7 min, the lobster was printed onto the silicone mat and was then cooked for 15 min at 150 °C.

Results and discussion

The NbN recipe was based on the pasta dough powder mix supplied by the Procusini Company, *i.e.*, dry ingredients which were formed into a paste with the addition of oil and water. According to Procusini (2018) "in general, the 'doughs' should not be elastic, the egg part stabilises the figure in the water very quickly". Some researchers have found that the materials for 3D printing should present a pseudo-plastic shear-thinning behavior, with enough viscosity to flow through the nozzle but enough elasticity to regain its structure upon printing (Pereira *et al.*, 2021). The NbN recipes consisted of ingredients composed of pure compounds or mixtures of pure compounds (called practical NbN). It is not uncommon for food manufacturers to use compounds such as water, sodium chloride, sucrose, gelatine, etc. (This, 2014). These compounds are commonly used in NbN cooking. While starch and protein are the major biopolymers of feeds used for the extrusion of cereal-based foods, salt and sugar are also commonly included as minor constituents in the formulation (Pitts *et al.*, 2014). The prototype NbN recipe included cornflour, oil, sugar, salt, water and was customised with different plant protein-rich ingredients, *i.e.,* either soya or hemp, which resulted in two different mixes. The consistency of both was optimised after a number of trials. These involved repeating the printing procedure with adaptions of the recipe to try to improve the flow from the nozzle during printing. Each trial involved adding more water until the mixture was printed without any breaks occurring. The consistency of all of the final mixes was similar, *i.e.*, for the pasta, soya and hemp-based recipes. They held their shape well without breaking when printed.

Figure 1 shows the appearance of the NbN soya mixture which was used for 3D printing. It resembled thick putty, and its consistency has been developed so that it can be printed readily : it should not stick to one's fingers (This, 2007).

During the printing process, several printing parameters (*i.e.*, printing and motor speed, nozzle tip diameter, nozzle height, extrusion rate, temperature) can induce changes in the printed structures (Pérez *et al.*, 2019). In this study the printing parameters were pre-set by the printer manufacturer (see the Materials and methods section) to deliver a 3.4 g detailed lobster shape, made from pasta dough, in 7 min. Figure 2 (left) shows the printed pasta lobster before cooking and Figure 2 (right) after cooking.

Figure 1.The appearance of the uncooked NbN mixture containing soya protein.

Soy proteins, rich in essential and non-essential amino acid residues, have physicochemical and functional properties which have the potential to make it a promising food material in 3D printing food. However, very limited information of food proteins in 3D printability is available (Chen *et al.*, 2019). Soya protein isolate (SPI, formerly

Figure 2.(left) Pasta uncooked and (right) cooked.

known as Soya protein isolate 90) which contained 26 g of protein per 30 g serving was used to customize the recipe as it is a complete protein (Nishinari *et al.*, 2014) and has a high concentration of branched chain amino acid (BCAA) residues. It is rich in arginine and glutamine (Wang and Xiong, 2019).

Hempseeds are an emerging protein-rich plant material and are becoming an important alternative protein source in the food and nutraceutical industry (Wang and Xiong, 2019). A study by Russo and Reggiani (2015) noted that the dioecious varieties of hempseeds are to be preferred as they show lower contents of antinutritional compounds with respect to the monoecious varieties. Data from a study by Tang *et al.* (2006) suggests that hemp protein isolates (HPI) from the species *Cannabis sativa* L. have poor functional properties when compared with soy protein isolates. The poor functional properties of HPI have been attributed to the formation of disulfide bonds between individual proteins and subsequent aggregation at neutral or acidic pH, due to its high free sulfhydryl content from sulfur-containing amino acids. In spite of its nutritional value, the specific functions and applications in food systems of the native hempseed proteins are impeded by poor solubility. At pH 7.0, only about 38 % of proteins was solubilized in 0.01 M phosphate buffer. However, above pH 8.0, the protein solubility increased up to more than 90 %. Therefore, structure-modifying techniques must be vigorously explored through scientific research to convert hemp proteins into a more soluble and diversely functional protein (Wang and Xiong, 2019).

The colour of hempseed protein products can range from light tan to dark brown, depending on the pH condition used during processing and the

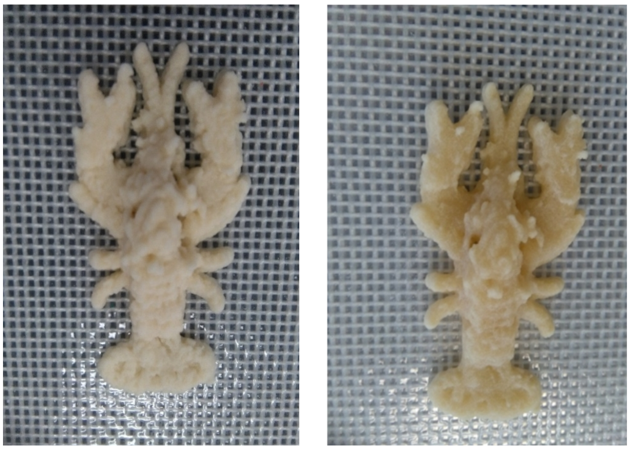

Figure 3. The printed soya-based Note by Note lobster before cooking (left) and after cooking (right).

Figure 4. (left) Uncooked hemp-based Note by Note lobster shape and (right) cooked hemp-based Note by Note lobster shape.

temperature involved in the final product drying (Wang and Xiong, 2019). The presence of chlorophylls and carotenoids imparted a green colour on the hempseed powder used in this study. During cooking the colour of the pasta and soy samples darkened, and in the case of the hemp sample it became a very dark brown colour (Figure 4).
Zahari *et al.* (2020) noted that colour changes in extruded high moisture extruded meat analogues containing soy protein and hemp protein occurred due to several reactions, including the glycation reactions, caramelization, and the degradation of pigments. Acidic conditions can cause the replacement of magnesium for hydrogen and change chlorophylls into pheophytins. The pheophytins are brown in colour, and are normally undesirable in most foods (Lack and Simándi, 2001)
The starch granules from the cornflour inflated during baking and formed starch that gradually bound together as the water evaporated (This, 2007). The texture of all of the baked samples became crisp once they cooled.
The final percentage of water in each uncooked mixture was 51.9 % (soya and hemp) compared to 43 % of the uncooked Procusini pasta recipe. After cooking there was a 21.6 % reduction in the weight of the pasta lobster compared to a 17.9 % reduction for both the hemp and the soy lobsters. The final protein contents for the cooked soya lobster was 17.5 % compared to 10.3 % on a wet weight basis for the soya lobster and 9.7 % for the cooked hemp lobster compared to 5.7 % for the uncooked hemp lobster.
The pasta recipe is designed to be used by professional caterers. Similarly the NbN recipes could also be used and adapted by these professionals. The recipes are prototypes and can be produced in various shapes, colours, flavours (including odours) and textures. For the food product developer, the recipe can be adapted to suit nutritional and/or dietary needs.
According to Pereira *et al.* (2021), 3D printing has the potential to create tailored food products. However, to reach the consumers, a lot more research needs to be conducted to offset the restrictions and limitations, that the technology still presents. These restrictions and limitations include: high associated costs, low number of compatible materials, slowness of printing, perception of food safety and sanitation concerns and consumers' perception. Despite these limitations, they do not seem to hinder the opening of restaurants such as Sushi Singularity,

in Japan, which intends to be a futuristic sushi restaurant that proposes the printing of sushi pieces based on the client's dietary needs (Sushi Singularity, 2022).

Conclusion

The development of the 3D printed NbN prototypes demonstrates that foods can be customized using the 3D printing technology in combination with NbN cooking. Bespoke recipes of pure compounds and/or mixtures of compounds can be served to diners. Food product developers can expand their creativity and innovation to address the dietary and sustainability requirements of a growing number of consumers. The number of preparation trials for 3D printed NbN recipes could possibly be reduced by obtaining an optimal measurement of viscosity of the material to be extruded which would allow for faster optimization of the consistency of the recipe to be printed. Handheld portable viscometers could be a practical solution as they can easily be used in restaurant and development kitchens.

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