Psychosocial Validation of 3D Food Printing

A Major Qualifying Project

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Abstract

3D food printing (3DFP) produces food products using a cutting-edge manufacturing technique. The US Army Combat Capabilities Development Command (CCDC) Soldier Center has taken an interest in 3DFP to allow troops greater personalization in their diet in order to reduce food waste and increase calorie intake. However, research including taste-tests of 3D food products with human subjects has been limited. This study used 3DFP to design a 3-layer bar and assessed the psychosocial properties of the bars, including participants' satiety, hedonic ratings, and perception of the bar as food, while simultaneously making iterative improvements to the bar and investigating attitudes towards new food technologies in future servicemen and women using survey methodology. Four different iterations of the bar were tested amongst nine participants. The average neophobia in the ROTC sample was 52.80 out of 91 ($N = 45$, $SD = 8.83$). Demographic differences were not explored given that most individuals identified as white, male, and were between 18 and 22 years of age. Further research comparing 3DFP to traditionally produced foods is required to validate 3D printed food as real food, and successfully implement 3DFP in the real world.

Keywords: 3D food printing, eating behavior, new food technology

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Psychosocial Validation of 3D Food Printing

Three-dimensional food printing (3DFP) allows for the production of food products using extrusion-based printing. Unlike traditionally sourced and produced food, 3DFP moves customization further up the supply chain to the point of consumption. This allows food products to be tailored to the individual needs and preferences of the consumer (Zhang et al., 2021). However, the lack of knowledge on societal acceptance of 3D food makes it difficult to know if it is a viable option for the future of food production. With such a new technology, research on 3D printed food that includes both taste tests and human subjects has been extremely limited. Many studies were only able to survey general opinions (Brunner et al., 2018; Gayler & Kalnikaitē, 2018), whereas others focused exclusively on the mechanical side of printing without a human subject component (Keerthana et al., 2020). It is necessary to validate 3D food products in human subjects to ensure this technology has the potential to solve various issues in the food industry.

One such issue currently faced by the United States Armed Forces is fieldstripping, where warfighters in the field will discard uneaten food products to avoid carrying the extra weight. The US Armed Forces includes six military branches: Army, Air Force, Navy, Coast Guard, Marine Corps, and Space Force (Owens, 2020). “Warfighter” will be used throughout the paper to be inclusive of all branches of the military, rather than using “soldier”, which refers specifically to members of the Army. Fieldstripping is not only fiscally inefficient, but also means warfighters are lacking in necessary nutrients and do not consume enough calories, which can lead to other health issues in the future. One possible application of 3DFP is utilizing the technology to improve warfighter nutrition (Benson, 2016), but 3DFP acceptance is necessary for real-world implementation.

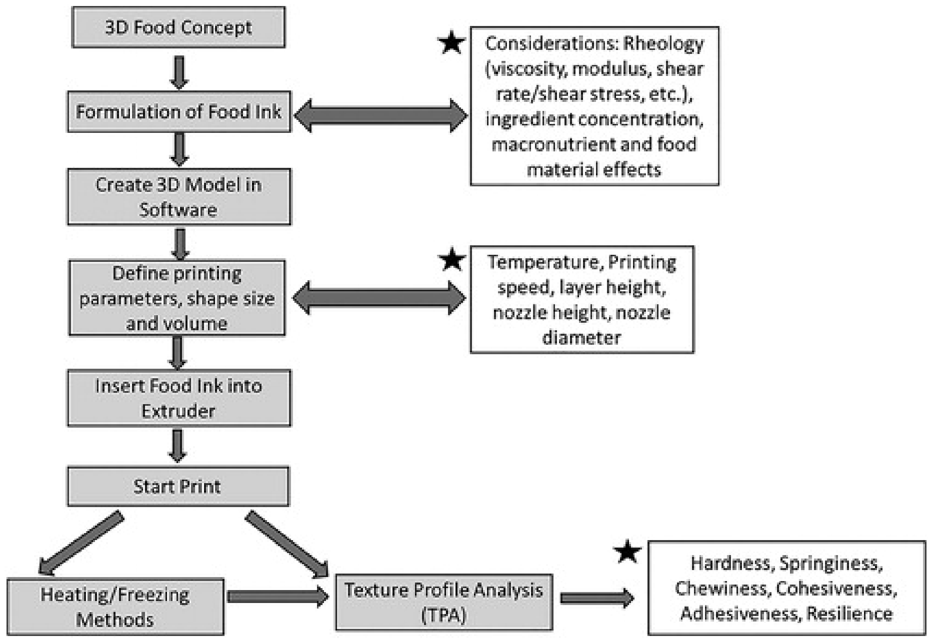
The goal of this project was to fill this gap in knowledge by designing a 3D printed three layer nutritional bar, conducting sensory tests on participants while simultaneously making iterative improvements to the bar, and investigating neophobia towards new food technologies in a particular population of interest.

3D Food Printing Overview

3DFP is a process that allows a three-dimensional food product to be constructed layer-by-layer based on a predetermined computer-generated design. First, food inks are added to an extruder. To achieve printability, the food ink must be able to flow through a nozzle and set on the printing surface after it has been deposited. It is vital to choose ingredients with suitable particle sizes for the nozzle, as the composition of print material impacts the level of effectiveness of printing, as well as the rheological properties of the final printed product. The print settings for each food ink need to be optimized for a successful print. The printing parameters of interest include temperature, printing speed, layer height, nozzle height, flow rate, and nozzle diameter. After determining the ideal print parameters and food ink composition, the food ink is pushed out of the extruder through a nozzle by an external source of power, which is typically an air pressure unit. Finally, the food ink is printed into the desired shape layer-by-layer. Depending on the food ink composition, the product may require post-processing methods such as baking or freezing (Zhang et al., 2021). This process is outlined in Figure 1 below.

Figure 1

3DFP Process (Zhang et al., 2021).



Compared to traditional food manufacturing techniques, the advantage of 3DFP is its customization abilities. Unlike typical mass-scale food production, 3DFP is able to adapt to individual dietary requirements, allergies, or taste preferences (Zhang et al., 2021). Two different 3D food printers are discussed below.

Natural Machines Foodini

The Foodini, developed by Natural Machines, is a 3D food printer designed to be a kitchen appliance for consumers. The printer has a touch-screen, Internet-capable Android tablet that is used to operate it. First, the user chooses the recipe they want to make. The Foodini comes with recipes that the user can select. If one of these pre-set recipes is chosen, the user is instructed on what ingredients or formulations they need to put in the capsules. The Foodini has five capsules made of stainless steel with nozzles that can be replaced. The Foodini has the ability to heat the capsule through a heating temperature setting, before or during printing. After the capsules are correctly loaded, the food paste is extruded through the nozzle by an external source of power into the preset shape, layer by layer. The Foodini also provides users with the option to design their own recipes and ingredients. New ingredients have to be calibrated to determine their optimal printing parameters. Prints will not be consistent if the formulation is not properly calibrated. The advantage of the Foodini is its simplicity of use; it does not require any technical expertise to operate.

The Hyrel

Unlike the Foodini, the Hyrel Engine Standard Resolution (SR) is a 3D printer that involves a steep learning curve for those without 3D printing experience. Rather than being able to simply design a product, the Hyrel SR uses a .GCODE file. The .GCODE commands the printer to complete certain commands at certain coordinates. There are settings on the printer itself that can be adjusted, but the majority of the product design is completed in the .GCODE. Although the Hyrel SR can be used to print food using plastic syringes with varying nozzle sizes, it was not originally designed for food production. Because of this, it is more difficult to operate, but has a wider range of abilities than the Foodini.

Overall, both the Hyrel SR and the Foodini are viable options for 3DFP as they both possess the customizing abilities mentioned above. However, further research on how people respond to food produced through 3DFP is required.

3DFP and the Psychology of Eating

Main Challenges in 3DFP Implementation

Although 3DFP has the potential to make a real difference in the food industry, it is faced with many challenges. One of the main obstacles 3PFP faces that this paper will focus on is consumer acceptance (Jiang et al., 2018). Consumers view new food technologies with suspicion for a number of reasons. For example, the direct contact between the food ingredients and 3D printer parts during printing has made some individuals concerned about potential health risks such as microbiological contamination due to ineffective cleaning protocols. This form of contamination can lead to severe illnesses caused by bacteria, mold, and yeast. It is important that consumers understand that 3DFP involves strict cleaning procedures to ensure safety. Others have concerns about the composition of the formulation being unnatural. Fortunately, informing consumers about how 3DFP works has been shown to reduce neophobia (Brunner et al., 2018). This obstacle will be discussed in further detail below.

3D Printed Food Neophobia

Although the acceptability of 3DFP is a major challenge, very little research has examined it. One study conducted by Gayler & Kalnikaitē (2018) aimed to assess how people either familiar or unfamiliar with 3D food printing felt about new food technology. Half of the participants belonged to a mailing list for a 3D printed food company, and the other half were computer science students. Participants completed measures of neophobia towards novel foods, their perceived risk of 3DFP, and whether they had any direct experience with 3DFP. They also generated ideas of potential applications for this technology. Of the 30 participants in the study, 12 had eaten 3D printed food before. The researchers found that prior familiarity with 3D printed food resulted in more positive scores on the first questionnaire. Participants were able to come up with a wide range of creative ways to apply 3D food printing (Gayler & Kalnikaitē, 2018).

Further research on neophobia towards novel foods showed the importance of understanding 3D food printing on decreasing neophobia. In another survey-based study by Brunner et al. (2018), researchers wanted to know if teaching participants about 3D food printing would allow them to overcome their food neophobia. Two questionnaires and an informational packet were mailed out to Swiss citizens. The first questionnaire assessed their overall knowledge and perception of 3D food printing. The majority of the participants had very low initial knowledge. After completing the initial assessment, participants read some information about how 3D food printing works and four different ways it can be applied. Finally, they answered the second questionnaire that assessed how and if their attitudes changed. The researchers were somewhat successful; they overcame 3D food neophobia, but not 3D food printing technology neophobia. Explaining to participants that the printing process does not change food composition allowed them to move past their aversion to the potential of eating 3D food. However, participants were still unable to view a 3D food printer as kitchen equipment; it was still a strange technology that did not have a connection to food (Brunner et al., 2018). The success in overcoming food neophobia after the reading reiterates that it is vital to inform participants about 3D food printing in order to increase their willingness to eat 3D food.

Though useful, these findings about overcoming food neophobia come from surveys without a taste-test component. A study conducted by Mantihal at al. (2019) was able to use real 3D printed food for participants to taste-test. Thirty panelists with some experience in food tasting completed two taste-tests. The first used 3D printed chocolate samples printed in honeycomb patterns with 25%, 50%, and 100% infill percentages. An infill percentage is how much the interior of a shape is filled in; 0% infill would be hollow, so 100% infill is entirely filled in. The panelists had to rank the three samples in order of preference based on appearance and hardness. In the second taste-test, the panelists were given a 3D printed chocolate bar and a traditionally produced chocolate bar, and were asked to choose their favorite between the two. The only significant difference found was a preference for the appearance of the 25% and 50% infill patterns. The researchers also had a survey component, where they surveyed participants on the design of the samples and novel technology in general. Survey participants did not taste the samples, and were only shown pictures. The majority had heard of 3D food printing before, but had never seen it applied in real life and were impressed by the outcome. 3D food was positively perceived, despite the lack of knowledge about the process (Mantihal et al., 2019).

3DFP may have numerous advantages, but the lack of information on societal acceptance of 3D food makes it hard to know if it is a viable option for the future. Fortunately, surveys on how 3D food is perceived have generally found positive attitudes towards the technology (Brunner et al., 2018; Gayler & Kalnikaitē, 2018; Mantihal et al., 2019). However, people tend to think of 3D printed food as a novelty or entertainment, rather than a source of sustenance. Words that have little to do with food like "futuristic", "innovative", and "visionary" were often used to describe it. Overall, past research has found that people are very interested in 3D food printing, but do not have a strong understanding of what it is (Mantihal et al., 2019). Since it is viewed positively but not necessarily as food, people are especially impressed when they enjoy the taste. Providing more information about the technology will be beneficial to improving its perception as well.

Reducing Food Neophobia

Due to the limited studies on 3D food printing, further research on decreasing food neophobia in general was necessary. In a study by Okamoto et al. (2009), researchers found that knowing what a food is before eating it increases the enjoyment of the food. They investigated this by giving participants one of four aqueous solutions. The solutions were flavored with either lemon, coffee jelly, consomme soup, and caramel candy. Half of the participants received a solution that was labeled with its flavor, and the other half received a solution labeled with a random 3-digit number. Participants were asked to judge the intensity and familiarity of the solution, as well as report how much they liked it. Results showed that participants who knew what the solution flavor was enjoyed it significantly more, especially when the flavor on the label seemed to match the taste of the solution (Okamoto et al., 2009). However, the label should not be overly descriptive. If the given description did not match what the participant tasted, the lack of congruency decreased the enjoyment of the food (Okamoto et al., 2009).

Satiety

Previous studies have shown that people do not feel full after eating something if they do not initially perceive it as something that will make them feel full. Rolls et al. (1998) examined this more closely by focusing on how the volume of food served affects satiety. Twenty men were recruited to come to the lab for four non-consecutive days to eat three meals. A milk preload was served to the participants on three of the four days. The three milk preloads served were identical in energy content, but varied in volume (300 mL, 450 mL, & 600 mL). For the rest of the day, the participants were given a wide variety of meals to choose from and the amount they consumed at each meal was measured. Participants also had to report how full they felt throughout the day. Results showed that the largest volume preload (600 mL) made participants feel the most full, despite all the preloads having the same amount of energy (Rolls et al., 1998). It is expected that people would feel more full after seemingly consuming more.

Military Application for 3DFP

History of Meals Ready to Eat (MREs)

The United States Army currently depends on Meals-Ready-to-Eat (MREs) as a main source of food for its warfighters. MREs are field rations that use a water-activated exothermic reaction to heat up the food, and were originally created to provide nutritious meals to soldiers. They became standard issue in 1986, but the idea of food rations can be seen as far back as the Revolutionary War. In this time, rations were beef, peas, or rice. During the Civil War, the U.S

Army gave out canned food that was less perishable. By World War I, rations transitioned to salted or dried foods due to the weight of the cans. In World War II, it became clear that providing basic nutrition was not enough for those in the field. They gave a variety of options tailored to warfighters in different environments. By the time official MREs were being regularly produced, there were already 12 different meals on the menu. In 2021, there were 24 options with a vegetarian option as well (Grunewald, 2016).

MREs Perception & Effects of Long Term Consumption

Since MREs were first developed, the meal options have expanded (Carvalho et al., 2019). However, MREs have not been fully accepted by warfighters. The Brazilian Army also uses MREs to feed their warfighters, and funded a study that compared the taste and nutrition of MREs to freshly prepared meals (FPMs). The main benefit to using MREs is the lack of a need for temperature control; they do not require refrigeration for storage or heating for consumption. However, no matter how much meal options expand, it is not possible to make any FPM into an MRE. The heavy processing to make the MRE also removes nutritional and rheological properties from the food. This leads to a monotonous diet that warfighters quickly grow tired of. This effect was seen in a study by Carvalho et al. (2019) comparing FPM to MREs. Ninety-two male Brazilian warfighters were recruited to participate. The study went on for 21 days to test the acceptability of MREs over a longer period of time, along with the sensory analysis. Researchers developed seven meals in both a MRE and FPM version. The meals were selected from the weekly menu at the base based on which ones warfighters preferred most prior to the study. The chemical composition of all the meals was analyzed to determine the nutritional breakdown and moisture content in the food. Meals were served to the warfighters in the usual dining hall at lunch and dinner. The warfighters used a 9-point hedonic scale to evaluate each meal. Their plates were weighed before and after eating to measure the volume they consumed. The acceptance and sensory analyses from the first MRE day and the twenty-first MRE day were analyzed and compared. Results from the chemical composition analysis showed that the MRE meals were higher in sodium and fat, and had excess liquid ingredients. They did not have the same nutritional benefit as the FPMs. On the acceptance measure, MRE meals were equally or more accepted than FPMs. However, there was a steady decline in acceptance over the 21-day period. They found that 39.9% of the MRE meals were being discarded (Carvalho et al., 2019); this type of food waste is something the military hopes to prevent with 3D food printing technology.

Further research investigated the effects eating MREs over a long period of time has on the body, as well as how consumers respond to it over that time. Two extended studies investigated the underconsumption of MREs over time and potential solutions. The first study was conducted in 1985 with U.S Army troops during a 34 day field training exercise at the Pohakuloa Training Area on the island of Hawaii (Hirsch et al., 1985). In 1993, the study continued at the Massachusetts Institute of Technology (MIT), where paid student volunteers were fed MREs as their only source of food over a 44-day period. The students were fed their meals in a small dining room. They were provided with hot and cold water to prepare their MREs, as well as a microwave oven. Both groups were fed the identical MRE rations. Data was collected on the energy intake and body weight change over the duration of MREs consumption. A 9-point hedonic scale was used for participants to rate the MRE (Hirsch and Kramer, 1993).

Results showed that the students in the lab's energy intake was greater than those in the field by around 1000 kcal. The warfighters in the field also lost an average of 10.4 pounds, versus the students in the lab that only lost around 1.5 pounds. The warfighters lost on average seven times more weight than those students in the laboratory. The students in the lab rated the MRE an average of 6.05, while the warfighters found the MRE more acceptable with an average hedonic rating of 7.

The study was repeated in 1986 with newer versions of the MREs with larger portions and slight changes to the menu. One was an improved MRE, and the other two were versions of the rations from the original. Overall, there was less noticeable weight loss for the troop groups that were studied over 11 days. The troops rated the food on a hedonic scale again, but this time they rated the different food categories for the different MREs (Marriott, 1995). Overall, the improved MRE received the highest scores compared to the MRE Version Four and Version Seven. Version Four was the MRE tested in the first study, which received the lowest scores overall. Even with the improvements made to the MREs, much work has to be done in order to ensure that warfighters are getting the necessary calorie intake and nutrition from meals.

Problem Statement

The US Army Combat Capabilities Development Command Soldier Center (CCDC) had expressed interest in taking advantage of 3DFP customizing abilities for its troops to reduce waste, increase calorie intake, and improve nutritional value. The first goal of this project was to design a 3D printed 3-layer bar. In the second part of this study, the 3D printed bars were pilot taste-tested in the lab with human subjects to assess the psychosocial properties of the bars including participants' satiety, hedonic ratings, and perception of the bar as food. The data from each taste-test was analyzed to feed back into the first phase and support iterative improvement of the bar. However, many people may not necessarily be comfortable eating food produced using such new technology. Therefore, attitudes towards novel food technologies in future warfighters were assessed using an online survey.

Method

Objective 1: Developing Bar Formulation

Procedure

The first objective was to design a nutritional bar and develop a printable formulation. The Army sponsor requested a three-layer bar, with the specification that the first layer included oats and nuts. Recipes and ingredients recommended on the Foodini user website were reviewed to design the formulation (Natural Machines). Before going directly to 3D printing the bar, different recipes were taste-tested in the kitchen by the researchers to optimize the flavor profiles. Once a satisfactory recipe that best fit the parameters was chosen, adjustments were made to ensure all the ingredients were shelf-stable. Shelf stability was important to the Army to ensure that the ingredients could be kept for long periods of time in varying weather conditions out in the field before they are printed. Michelle Richardson, a senior food technologist at the CCDC Soldier Center, was consulted about different issues with the bar.

The Hyrel SR was used to print the bar. Formulations for the first and second layers were prepared ahead of time and filled plastic syringes with 1.5mm nozzles. For the third layer, hard chocolate was placed into the same type of syringe and slowly heated to melting in the toaster oven. Once the capsules were ready, each layer had to be calibrated to find the optimal print conditions for the formulations to print evenly. The base layer was printed first, then post-processed in the toaster oven. After it finished baking, the base was placed back on the Hyrel so that the second layer could be printed on top. Finally, the third layer is printed on top of the second.

Objective 2: Conducting Pilot Taste-tests

Participants

Nine participants were recruited from the WPI student population. All participants provided informed consent, and all procedures were approved by the WPI IRB. Individuals with food allergies were excluded from the study to ensure their safety. Participants identified as male (n = 2), female (n = 6), and non-binary (n = 1). Participants identified as White (n = 6), Hispanic/Latinx (n = 2), Asian/Pacific Islander (n = 1), and other /multiracial (n = 1). All participants were 21-22 years of age.

Procedure

Participants were asked to come into the laboratory to participate in a taste-test of a 3D printed food product. Prior to their arrival, the 3D bar was weighed. Participants were instructed to refrain from eating for at least one hour prior to their session to ensure they were not too full to eat more food. A script was used throughout the entirety of every session to ensure that all participants received the same information and instructions. At the beginning of the study, participants read a consent form. Upon consenting to the study, participants moved forward with the task. Participants were given the bar and a paper survey to complete during their taste-test. Participants were asked to follow the specific instructions on the form as they completed the rating task. Participants were first told not to touch or taste the bar, and only rate the appearance. Next, they were asked to smell the bar, but not taste it. These instructions were included so that participants would give their honest opinion on the appearance and scent of the bar, without being biased by the taste or texture. After inspecting and smelling the bar, participants were told they could now taste it to complete the remainder of the form. They were given ten minutes by themselves to taste the bar. Previous research has shown that eating around others impacts eating behavior, so participants were left alone to ensure their taste tests were not biased by others (Ruddock et al., 2019). After the taste test, the bar and paper survey were collected and participants were asked to complete an electronic survey with the Food Technology Neophobia Scale from Cox & Evans (2008) and demographic questions on the computer in the lab. Participants were debriefed at the end of the survey. Participants were not compensated.

Measures

Product Rating Form. First, participants were asked to rate the appearance, smell, overall texture, and overall flavor of the bar on a scale of 1-6, with 1 being "Extremely unappealing" and 6 being "Extremely appealing". Next, participants ranked specific flavors and textures, including saltiness, sweetness, bitterness, sourness, chewiness, dryness, and crunchiness. These items were scored on a scale of -3 to 3, with -3 being not enough of the quality (i.e. "not nearly sweet enough", 0 being "just right", and 3 being too much of the quality (i.e. "way too sweet"). This fed into the improvements for the next iteration of the bar. Next, participants were asked to rate the bar overall on a scale of 1-6, with 1 being "Extremely unappealing" and 6 being "Extremely appealing". To conclude the product rating task, participants were asked some miscellaneous yes/no questions: would the bar be satisfying as a snack? A meal? Would they purchase it if it were available in a store? These questions gauged if the bar was perceived as satiating and if participants generally liked it or not. Participants were also asked if they had ever tried 3D printed food before. Past research has shown that people enjoy 3D printed food more if they had previously tried it (Gayler & Kalnikaitē, 2018). Finally, space was provided for participants to share any additional thoughts.

Food Technology Neophobia Scale. Participant attitudes towards novel food technologies were assessed using the Food Technology Neophobia Scale from Cox & Evans

(2008). This scale measures attitudes by asking participants to indicate their agreement on a seven-point scale to 13 different statements about novel food technologies. The total score on the scale indicates how strong a person's neophobia is to new food technologies; higher scores indicate higher neophobia. Statements 1-9 expressed negative attitudes, such as "New food technologies may have long term negative environmental effects." Statements 10-13 were reverse-coded, because they expressed positive attitudes such as "New products produced using new food technologies can help people have a balanced diet." Cox & Evans (2008) found high internal validity on this scale ($\alpha = 0.84$).

Objective 3: Making Iterative Improvements to the Bar

Throughout the pilot testing phase, various alterations were made to the bar based on feedback from the initial tests. The Product Rating Form from Objective 2 was designed to pinpoint issues with the bar. For example, participants were asked to rate the crunchiness of the bar from "Way too soft" to "Way too crunchy". If participants responded that the bar was "Way too soft", bake time and temperature could be increased to make the texture of the base more brittle. All taste test forms were analyzed in this method to identify where changes should be made.

Objective 4: Assessing Attitudes Towards Novel Food Technologies

Participants

Forty-seven participants were recruited through an email sent from WPI-affiliated Lieutenant Colonels to a distribution list of Army and Air Force Reserve Officers' Training Corps (ROTC) students from Worcester Polytechnic Institute, College of the Holy Cross, Assumption College, Clark University, Worcester State University, Fitchburg State University and University of Massachusetts Lowell. All participants gave informed consent. Two participants provided consent but did not complete any items, leaving 45 participants with data for analyses. The majority of participants were aged 18 to 22, with three older participants who were 42, 50, and 57 years old, respectively. Participants identified as male (n = 40), female (n = 4), and non-binary (n = 1). Participants identified as White (n = 39), Asian/Pacific Islander (n = 4), Hispanic/Latinx (n = 1), and other /multiracial (n = 1).

Procedure

Participants were asked to complete the Food Technology Neophobia Scale (Cox & Evans, 2008), followed by demographic questions about age, gender identification, race/ethnicity, and level of education. This survey was completed electronically. Participants were debriefed at the end of the survey. Participants were not compensated.

Measures

Participant attitudes towards novel food technologies were assessed using the Food Technology Neophobia Scale from Cox & Evans (2008). This scale measures attitudes by asking participants to indicate their agreement on a seven-point scale to 13 different statements about novel food technologies. The total score on the scale indicates how strong a person's neophobia is to new food technologies; higher scores indicate higher neophobia. Statements 1-9 expressed negative attitudes, such as "New food technologies may have long term negative environmental effects." Statements 10-13 were reverse-coded, because they expressed positive attitudes such as "New products produced using new food technologies can help people have a balanced diet." Cox & Evans (2008) found high internal validity on this scale (α = 0.84).

Results

Final Bar Results

Michelle Richardson, a senior food technologist at the CCDC Soldier Center, contributed to the development of the final prototype of the bar. She advised changing the dimensions of the bar by making it 3cm shorter to improve its structural stability. She also advised that we swap butter for coconut oil to improve shelf stability, which was important to the Army. The final prototype of the bar was 4cm wide, 7cm long, and ¾ cm thick, and took about 14 minutes to print. It weighed 31 grams. A nutritional label (Figure 2) for the final iteration (Iteration 4) of the bar was created in collaboration with Richardson.

Figure 2

Nutrition Label for Iteration 4 of the Bar

Nutrition Facts	
servings per container	
Serving size	**(31g)**
Amount per serving	
Calories	**110**
	% Daily Value*
Total Fat 5g	**6%**
Saturated Fat 2g	**10%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 10mg	**0%**
Total Carbohydrate 14g	**5%**
Dietary Fiber 2g	**7%**
Total Sugars 9g	
Includes 6g Added Sugars	**12%**
Protein 2g	
Vitamin D 0mcg	0%
Calcium 20mg	2%
Iron 0mg	0%
Potassium 93mg	2%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

The nutritional labels for each individual layer can be found in Appendix A.

Layer One

The base layer of the bar was primarily composed of oats and nuts, specifically almonds. From the first formulation to the final formulation, many changes were made. The base layer was post-processed through baking to increase the range of texture manipulation. The baking times and temperatures were dependent on the size and the mass of the bar. Throughout developing the bar, butter was swapped for coconut oil and crushed almonds for almond flour, and coconut flakes were removed to improve the printability, taste, and shelf stability. In one iteration, cocoa powder was tested in place of ground up chocolate chips to prevent clogging in the 1.5 mm nozzle. However, the resulting taste was very bitter so chocolate chips were chosen for the final formulation. To avoid future clogging in the Foodini, the capsule was heated beforehand to melt the small chocolate pieces.

Layer Two

The second layer was a fruit layer designed to complement the freeze-dried apples and cinnamon in the first layer. Unlike the first layer, the second layer was not post-processed to provide a different texture. Fruit leather was the initial plan for the second layer, but this process was ultimately too time-consuming. A variety of jams were tested as well; the jam with a dried strawberry base with lemon juice and white sugar was also inefficient. Jam made from frozen strawberries was faster to produce, but frequently clogged the 1.5mm nozzle due to the strawberry seeds. Even when the jam successfully printed, it was determined that the strawberry flavor did not complement the flavors in the base. Applesauce proved to be the most successful fruit-based ingredient to add to the second layer, which was both efficient and provided a fresh fruit flavor. The main components of the second layer are cinnamon, applesauce, honey, and almond butter. A full list of ingredients can be seen in Table [] below.

Layer Three

The third layer, a dark chocolate pattern, was added to make the bar more visually appealing and provide a mildly sweet flavor. Dark chocolate was used over milk chocolate or white chocolate to cut the sweetness of the second layer. The last layer is also not post-processed. The chocolate sets after sitting for approximately ten minutes.

Pilot Testing Results

Descriptive statistics for the responses to the Product Rating Form can be seen in Table 1 below.

Table 1

Responses to Product Rating Form Descriptive Statistics

	N	Mean	*SD*	Range
Appearance	9	4.22	0.97	3.0 - 6.0
Smell	9	5.11	0.78	4.0 - 6.0
Texture	9	4.44	1.01	2.0 - 5.0
Flavor	9	4.56	0.73	4.0 - 6.0
Saltiness	9	-0.56	0.73	-2.0 - 0.0
Sweetness	9	-0.22	0.67	-1.0 - 1.0
Bitterness	9	0.11	0.67	0.0 - 1.0
Sourness	9	0.11	0.33	0.0 - 1.0
Chewiness	9	0.78	0.83	0.0 - 2.0
Dryness	9	0.00	1.00	-1.0 - 2.0
Crunchiness	9	-1.11	1.05	-3.0 - 0.0
Overall Rating	9	4.78	0.97	3.0 - 6.0

Note. The scale for Appearance, Smell, Texture, Flavor, and Overall Rating is 1-6. The scale for the remainder of the items is -3 to 3.

None of the participants had ever tried 3D food before ($N = 9$). Of the participants, 55.56% would purchase the bar if it were available in stores ($N = 5$), 77.78% would find it satisfying as a snack ($N = 7$), and 33.33% would find it satisfying as a meal ($N = 3$).

Total neophobia towards novel food technologies was found to be 46.89 out of 90, with a range of 34-60 and a standard deviation of 9.19 ($N = 9$).

Iterative Improvements Results

Four iterations of the bar were tested with nine participants. The bars all used the same formulation with different post-processing, which in this case was baking. The strategy for making iterative improvements to the bar is shown below in Table 2.

Table 2

Iterative Improvement Strategy

Iteration	Times tested	Average rating (1-6)	Main issues in iteration	Solution for next iteration
Iteration 1	1	3.0	Unpleasantly soft texture	Bake time increased: 18 min to 19 min Bake temperature increased: 300F to 325F. Layer 2 infill decreased: 100% to 70%
Iteration 2	1	4.0	Burnt outside, undercooked inside	Bake time increased: 19 min to 23 min Bake temperature decreased: 325F to 300F
Iteration 3	3	5.3	Not crispy enough	Bake time increased: 23

				min to 25 min.
Iteration 4	4	5.0	Too crunchy	N/A

Novel Food Technologies Survey Results

The average neophobia in the sample was 52.80 out of 91, with a range of 38-74 and a standard deviation of 8.83 ($N = 45$). Demographic differences were not explored given that most individuals identified as white, male, and were between 18 and 22 years of age.

Discussion

A 3-layer bar was successfully designed and printed by the Hyrel, and was taste-tested by human subjects. Improvements were made to the bar between taste-tests. Neophobia towards new food technologies was found to be medium in a sample of future servicemen and women. Four iterations of the bar were taste-tested by nine participants. The first iteration was ranked the worst of the four. However, it is important to note that the bar the first participant tasted had been printed the night before. This likely caused the second layer to soften the first, and alter the texture unintentionally. Following the first taste-test, it was ensured that all bars were printed no more than two hours before tasting. Participants that tried Iteration 3 enjoyed the bar more, giving it an average overall rating of 5.3 out of 6, but still expressed they wanted a crispier texture. However, after making the base crispier, the average rating went down to a 5 out of 6. Given that this was a pilot test, this is likely due to personal preference for chewier versus crunchier granola bars. Due to this explanation, there were no more iterations of the bar after the fourth iteration because it was determined that the only remaining criticism was based on personal preferences.

There was medium total neophobia towards new food technologies in the ROTC members sampled, meaning that there is some opposition to foods produced using methods like

3DFP. Addressing neophobia in warfighters may be necessary to successfully implement 3DFP in the Army. For 3DFP to adequately address the issues the Army is facing such as fieldstripping and warfighter weight loss, the warfighters must be willing to consume the 3D food they are given.

Limitations

There were several limitations and potential sources of error throughout this study. When preparing the formulations for the different recipes, ingredients were measured using measuring spoons/cups rather than an electronic balance. This was done to increase the efficiency of prints, but likely caused some minor variability between different prints. For example, some prints were slightly sweeter than others because the amount of sugar measured was not precise to the gram. Inconsistency in food-processing the apples/oats/chocolate chips due to issues with the food processor also led to variability in particle sizes between prints. Later in the project, food-processing time for these ingredients was standardized to ensure the particle sizes were consistent. Once taste-tests began, the formulations were prepared in much larger portions. This was a potential source of error because the drier ingredients tended to clump up in these bigger portions. If these clumps were not properly mixed into the formulation, there would be an inconsistent ratio of apples and flour between prints. This is something that the Army may have to contend with, given that they would be producing these bars on an even larger scale. Other issues were with efficiency; when the formulation ran out, more had to be produced. This would interrupt the flow of the printer, and take up a lot of time. The nozzles of the capsules would often clog with pieces of apple, nut, or chocolate, which would also stop print flow.

As previously mentioned, the first bar was printed the night before the taste-test. This caused the second layer to soften the first. For the remainder of the taste-tests, efforts were made to print the bar no more than two hours before tasting. However, bars were still printed anywhere in that two hour range, meaning that there could still have been variability in texture. The taste-tests also may have affected participant eating behavior due to the unnatural lab setting.

The ROTC sample that took the Food Technology Neophobia Scale (Cox & Evans, 2008) was not diverse enough to test for any differences, given that the majority of the sample identified as white, male, and were aged between 18 and 22 years old. This also prevents the results of this survey from being generalizable to other populations. The Food Technology Neophobia Scale has not been validated on actual eating behavior; it only assesses attitudes (Cox & Evans, 2008), so it is possible participants would have behaved differently if actually given food to taste.

Future Directions

Future steps for this project should include testing the third and fourth iterations of the bar in a larger sample size to look for reliable trends in rating, rather than ratings based on personal preferences. It would also be interesting to compare this bar that was produced by 3DFP to a bar of the same formulation that was traditionally produced. This could help give insight as to whether or not the method of production impacts the way the bar is perceived. Comparing the bars is essential to ensure that the 3DFP bar is rated at least as well as the traditional bar, and is ideally rated even better. This would validate the 3DFP bar as real food. The ratings of the bar(s) should also be compared across different demographics, as well as to neophobia scores on the New Food Technology Neophobia scale (Cox & Evans, 2008). This scale should be distributed to a larger, more diverse sample than the one in this study to investigate if neophobia towards new food technologies differs across different demographic groups.

Next steps should include designing a 3D food printer that is capable of printing and post-processing on a single machine to improve the utility of 3DFP. This would make the implementation of 3DFP easier, as well as improving the efficiency of the entire 3DFP process. With the current technology, raw material is printed into the desired shape in the 3D printer, then gets transported to a secondary location for post-processing (cooking, freezing, etc.). A machine that could do both would be a significant technological advancement in the food industry.

Although 3DFP technology has a lot of potential, there are still limits on what food textures and ingredients are printable. The United States Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) is investigating potential applications for 3DFP, such as monitoring warfighter health to print meals customized to their nutritional needs. This new technology is projected to be ready as early as 2025. For example, if a warfighter needed more Vitamin C, the 3D food printer would print a food product with the necessary amount. If a warfighter needed to be up for many consecutive hours, their meal could include extra caffeine or nutrients that help fight fatigue. According to Mary Sceerra, food technologist from NSRDEC, 3DFP could reduce costs through its customization abilities by printing what someone wants to eat at that moment. (Benson, 2016). Lauren Oleksyk, another food technologist with NSRDEC, agrees that 3DFP has strong potential military applications due to its long shelf stability (Benson, 2016).

The future of 3DFP looks optimistic, but further research on validating 3D printed food against traditionally produced foods is required to successfully implement 3DFP in the real world. This validation is necessary to ensure 3D printed food achieves the same benefits as normal food, while still incorporating all the benefits of 3DFP.

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Appendix A

Nutrition Labels for Layers 1-3

Figure A1

WPI 3D Layer 1 Formula

Number of Servings: 2 (44.24 g per serving)
Weight: 88.49 g

Nutrition Facts

servings per container

Serving size	**(44g)**
Amount per serving	
Calories	**140**
	% Daily Value*
Total Fat 7g	**9%**
Saturated Fat 3g	**15%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 10mg	**0%**
Total Carbohydrate 19g	**7%**
Dietary Fiber 2g	**7%**
Total Sugars 12g	
Includes 8g Added Sugars	**16%**
Protein 3g	
Vitamin D 0mcg	0%
Calcium 18mg	2%
Iron 1mg	6%
Potassium 119mg	2%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Ingredients:

Water, baking chips, semisweet chocolate, honey, clover, apple, freeze dried, diced, Almond Meal, Rolled Oats, sunflower seed butter, natural, oil, coconut, expeller pressed, organic, IMITATION VANILLA FLAVOR (WATER, PROPYLENE GLYCOL, CARAMEL COLOR, AND ARTIFICIAL FLAVOR), Ground Cinnamon.

Allergens:

Contains Milk, Soy, Tree Nuts.

Figure A2

WPI 3D Layer 2 Formula

Number of Servings: 1 (8.4 g per serving)
Weight: 8.4 g

Nutrition Facts

servings per container
Serving size (8g)

Amount per serving
Calories 30

	% Daily Value*
Total Fat 1.5g	2%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 5mg	0%
Total Carbohydrate 4g	1%
Dietary Fiber 0g	0%
Total Sugars 3g	
Includes 2g Added Sugars	4%
Protein 1g	
Vitamin D 0mcg	0%
Calcium 10mg	0%
Iron 0mg	0%
Potassium 29mg	0%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Ingredients:

Clover Honey, almond butter, applesauce, cinnamon, Almond Meal, rice cake, apple cinnamon, apple, freeze dried.

Allergens:

Contains Tree Nuts.

Figure A3

WPI 3D Layer 3 Formula

Number of Servings: 1 (1.1 g per serving)
Weight: 1.1 g

Nutrition Facts

servings per container
Serving size **(1.1g)**

Amount per serving
Calories **5**

	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 0mg	**0%**
Total Carbohydrate 1g	**0%**
Dietary Fiber 0g	**0%**
Total Sugars 0g	
Includes 0g Added Sugars	**0%**
Protein 0g	
Vitamin D 0mcg	0%
Calcium 1mg	0%
Iron 0mg	0%
Potassium 6mg	0%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Ingredients:

baking chips, dark chocolate, 53% cacao, morsels.

Allergens:

Contains Milk.