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“It takes the identity out of the food”: Soldiers’ perceptions of 3D-printed food

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A R T I C L E I N F O

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A B S T R A C T

Ensuring acceptance of novel food technologies is nearly as vital as advancing the technology itself. Three-dimensional (3D) printing is an example of advanced manufacturing being applied towards tailored food production. 3D food printing (3DFP) provides benefits of personalized nutrition, deployable food production, customized aesthetic expression, and optimized performance. These attributes may not be readily apparent—especially those positioned to use 3DFP in the future. Military applications and government-funded efforts currently supporting this technology, make it important to understand perceptions of large potential user populations like U.S. Army Soldiers. At the DEVCOM Soldier Center, we conducted a set of focus groups and sensory panels with 17 voluntary, military respondents. Two group panels were conducted to better understand preconceived notions and attitudes of Soldiers about 3DFP technology, 3DFP food attributes, 3DFP food labels and naming conventions, and 3DFP products they would want to see developed. Initially, Soldiers showed skepticism and reluctance towards use of the technology. However, after 3DFP technology was explained and 3D-printed prototypes were provided, Soldiers’ acceptance increased considerably. Novel 3DFP prototypes with some visual familiarity tended to score higher than prototypes that were unfamiliar. Individual differences of affect between panelists were most apparent for flavor and texture attributes. Keywords related to appearance and texture were discussed most with regards to 3DFP.

1. Introduction

Understanding perceived benefits of emerging cooking technologies is critical to a new technology’s success (Kuhne et al., 2010; Siegrist, 2008; Siegrist and Hartmann, 2020). Three-dimensional food printing (3DFP), or food additive manufacturing (FAM), exemplifies innovative technology (Blutinger et al., 2022; Derossi et al., 2024; Lipson and Kerman, 2013; Periard et al., 2007), with continuous advancements in both commercial food sectors (BluRhapsody, n.d.; F-EAT Inc., n.d.; Nourished, n.d.; Revo Foods, n.d.; Redefine Meat, n.d.; Steakholder Foods, n.d.) and research communities (Blutinger et al., 2022; Hertafeld et al., 2019; High Tech Campus Eindhoven, 2024; Matas-Gil et al., 2025). Additive manufacturing technology provides a unique opportunity for food design not offered in current food manufacturing technologies. It does this through customizable aesthetics (Blutinger et al., 2023; Mizrahi et al., 2016), tailorable textures (Derossi, 2021) and personalized nutrition (Klomp, 2023; Sun et al., 2015).

These attributes make 3DFP appealing for applications requiring precise nutritional delivery and human performance optimization, such as in a military setting. Operational rations have long been the standard for sustaining Soldiers in the field (Darsch and Brandler, 1995). “Operational rations” include a spectrum of individually packaged meal suited for different operational expectations and conditions. Some of these operational rations include Meals, Ready-to-Eat (MRE), Unitized Group Rations (UGR) for groups, First Strike Rations (FSR) for high-mobility operations, Close Combat Assault Ration (CCAR), and Meal Cold Weather (MCW) rations tailored for cold environments. Designed to be calorically dense, light weight, and nutritionally balanced with extended shelf lives (U.S. Army RDECOM, 2012), these ration platforms remain vital for military field-feeding logistics. But they are not individualized to each Soldier’s nutritionally needs. Often, Soldiers will “strip” and stylize the ration components to meet their own personal preferences and unique needs. The practice of field stripping is common and attests to the general need for adaptive guidance found in a variety of military and on-line guides (The ITS Crew, 2009).

Despite advancements in food technology, warfighters frequently experience nutritional deficiencies. For instance, a seven-day mission without resupply requires a Soldier to carry 21 bags of MREs, weighing

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over 30 pounds. With additional equipment such as weapons, ammunition, and communication devices, Soldiers might choose to carry less food to lighten their load, which could affect nutritional intake. Producing food closer to the point-of-need (PON) and tailored to individual needs may better support Soldiers.

Several research and government-funded efforts are exploring PON nutrition solutions for military field feeding. For example, Wageningen University & Research (WUR) has partnered with the Dutch Organization for Applied Scientific Research (TNO) to develop containerized food assembly and cooking processes that include precision 3DFP products being tested by the Dutch military (Eppinga, 2024). Additive manufacturing not only enables personalized nutrition but also decentralizes food production, enhancing its potential in a military theater (Ben-Ner and Siemsen, 2017). In parallel, the Defense Advanced Research Projects Agency (DARPA) is funding "Cornucopia," a project to produce food from naturally available environmental resources (Defense Advanced Research Projects Agency, 2023). Multiple companies are contributing to the concept's development and success (Air Protein, n.d.; Savor, n.d.; Solar Foods, n.d.).

With these advancements and funded efforts, understanding Soldiers' perceptions of food additive manufacturing becomes essential. Recent studies have examined consumer acceptance of 3D-printed food products (Caulier et al., 2020; Lanz et al., 2024; Rodríguez-Parada et al., 2025; Shigi and Seo, 2024) and plant-based meats (Hoek et al., 2011; Williams, 2024), which share technological novelty and align with 3DFP in terms of production methods (Redefine Meat, n.d.; Wen et al., 2023). However, no studies have focused on U.S. military personnel's perceptions of 3D-printed food. We need to look at how food acceptance is influenced by factors such as education, income, biological sex, and other demographics (Hoek et al., 2011; Michel et al., 2021; Wright, 2022). Furthermore, we should underscore the importance of addressing biases and stigmas through education and group discussion.

Few prior studies have examined consumer perceptions of 3D-printed foods. Several studies have examined how sensory attributes like shape, taste, and texture affect consumer acceptance (Scheele et al., 2022; Silva-Paz et al., 2025). Others have investigated how psychological factors and consumer attitudes, such as Novel Food Technology Neophobia (NFTN), can influence their willingness to adopt 3D food printing (Bareen et al., 2025; Seo et al., 2024; Shigi and Seo, 2024). Perceived unnaturalness, lack of familiarity, and the technology's novelty factor remain barriers for acceptance (Ross et al., 2022). As such, educating consumers and emphasizing the personalized benefits of this technology are essential to improve broader acceptance.

This study explores perceptions around 3DFP by engaging with U.S. Army Combat Medics. We used focus groups to gauge initial perceptions and their knowledge about the technology, followed by sensory panels where Soldiers sampled a two-ingredient 3D-printed food item crafted in advance. Participants rated affect in their degree of liking of various attributes of the 3D-printed sample through questionnaires (see Supplementary File 1). Soldiers offered their perspectives on 3DFP and novel cooking technologies in an open forum. This study gathered insights to inform the design of visually appealing, flavorful, and nutritionally optimized 3D-printed foods for military and other applications.

2. Materials and methods

2.1. Participants

This study involved two separate panels ($n = 17$) comprised of 9 participants in Group A and 8 participants in Group B; groups were split to more easily facilitate verbal discussion. Each panel session lasted 1.5 h and was divided into two parts: a focus group for the first half and a sensory panel for the second. The respondents included one female and 16 males, ranging in age from 19 to 31 years (mean age = 23 years, SD = 3.3, median age = 22). All participants were U.S. Army Combat Medics who voluntarily agreed to participate after being informed that the study would explore the topic of "3D-printed food."

2.2. Focus group

The first part of the panel discussion was structured as a focus group to explore Soldiers' initial perspectives and preconceived notions about 3D printing. The second portion focused on the Soldiers' perception of 3D-printed food's associations, concerns, attributes, and perceptions of positive and negative aspects of the technology. Following the discussions, the potential benefits of 3DFP were outlined to the panelists to establish a shared understanding of the technology.

To guide the discussion, the following questions were presented:

- Who here knows what "3D printing" is? [*show of hands*]
- What do you know about it? [*directed at those who raised their hand*]
- What about "3D-printed food"? [*show of hands*]
- What associations do you have with 3DFP?
- What concerns, important attributes, positives, or negatives come to mind?
- [*Explain the benefits of 3DFP to respondents*]
- If you had a 3DFP with unlimited ingredients, what would you want it to create?
- Do you like the phrase "3D food printing"? If not, how would you improve it?

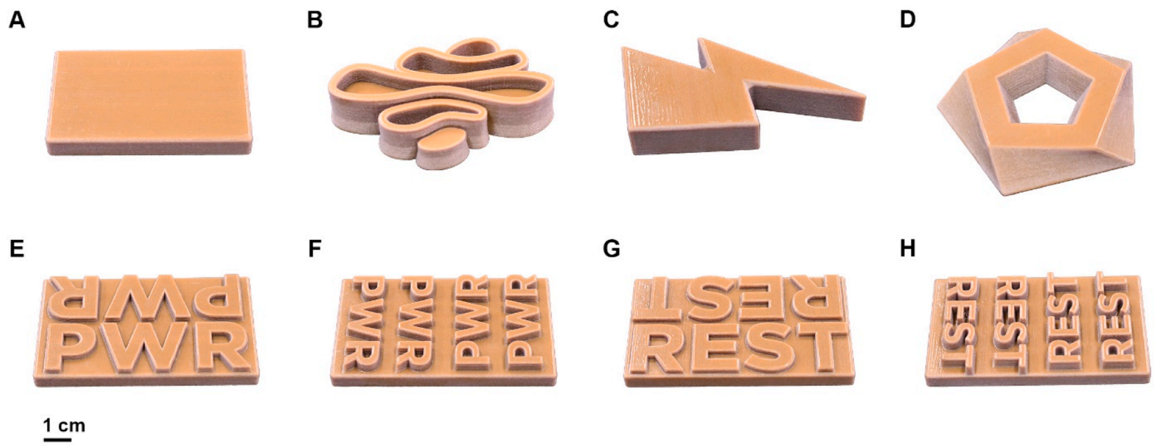
After this guided discussion, eight uniquely designed 3D-printed food bars were presented simultaneously (Fig. 1) to demonstrate the range of physical possibilities in 3D-printed food design. These tangible models were plastic prototypes that were not edible and purely for handling and observational purposes. Respondents were asked to sketch their own 3D-printed foods, specifying ingredients and taking on the role of a chef or food designer. These designs were shared with the group, allowing for discussion and feedback to further improve understanding of technical feasibility.

2.3. Inedible bar designs

During the focus group, participants were presented with eight unique bar designs for observation. The first group of respondents experienced this before being asked to sketch bar designs of their own. Conversely, the second group sketched bar designs prior to handling prototyped bars. This was done to assess the affect it would have on printed bar ideation. Designs were selected to highlight different geometric features (e.g., twisted walls, organic shapes, pocketed sections, and raised lettering). Each design maintained the same volume (2 in^3) to match a smaller "First Strike Bar," (35 g) which was used as the control (Fig. 1A) (NSRDEC Public Affairs, 2007). Soldiers were asked to rate the appearance of these bars in their individual questionnaires. Additional bar geometries were designed to elicit varied responses and included:

- An organic, pocketed blob (Fig. 1B), representing an unfamiliar, amorphous geometry with soft, rounded edges
- A lightning bolt (Fig. 1C), representing a familiar and more symbolic shape associated with energy and power
- A pentagonal twisted ring (Fig. 1D), incorporating a familiar polygonal base with a novel, twist to add some geometric complexity
- A rectangular bar with "PWR" embossed on it (Fig. 1E and 1F), to test the effect of intentional messaging on bar preference
- A rectangular bar with "REST" embossed on it (Fig. 1G and 1H), to contrast the previous bar with semantic messaging related to recovery

All prototype designs were additively manufactured using a glossy polymer on a Stratasys J850 (Stratasys, Rehovot, Israel). The "mustard yellow" hexadecimal color of #b48142 was selected because it most closely matched the light brown color of a typical nutrition bar.



. **1.** Inedible bar designs that were 3D-printed on a Stratasys J850. Each model has the same volumetric size and color (#b48142), but a different geometry and surface area. A (**A**) rectangle, (**B**) organic blob, (**C**) lightning bolt, (**D**) pentagonal twisted ring, (**E** and **F**) “PWR” bar, and (**G** and **H**) “REST” bar was used. The scale bar corresponds to 1 cm.

2.4. Participant evaluations

The sensory panel was a combination of free-response questions and questions on a Labeled Affective Magnitude (LAM) scale (Schutz and Cardello, 2001). The 11-point LAM scale was selected over the traditional 9-point hedonic scale because it better reflects the psychological magnitude of liking and disliking between anchor points. We also felt that the LAM scale’s verbal and numeric anchors would be more intuitive for participants, enhancing the usability for this study. The questions evaluated Soldiers’ degree of liking for various food designs, their thoughts of messaging on a food item, flavor associations with functional nutrition bars, and their organoleptic preferences for a custom 3D-printed nutrition bar that they were asked to sample. Respondents completed a written questionnaire (Fig. 2), which is included in Supplementary File 1.

The questionnaire prompted each participant to rate their liking of the appearance of six differently shaped food products (Fig. 1A–D, 1E, and 1G); identify and explain their favorite bar geometry; draw a representation of the text they would like to see on a food item; and describe the flavor they would associate with a “POWER” bar and a “REST/RECOVERY” bar in a battlefield context. Once printed food sample were disseminated to respondents, they were then asked to rate the appearance, texture, flavor, and aroma of the edible samples. After respondents tasted the samples and completed their questionnaires, we ended the session with a verbal debrief. We gave the Soldiers an opportunity to share last thoughts or impressions on the printed samples.

2.5. Edible bar design

For the sensory portion of the study, a twisted pentagonal ring design (Fig. 1D) was 3D-printed using a cocoa dough recipe and finished with a layer of Nutella (Ferrero SpA, Alba, Italy). The design was intended to look novel and visually complex, yet still palatable for consumption. The pentagonal shape was also selected to pay homage to the Army headquarters (The Pentagon) in Virginia. The goal was to intrigue the respondents and spark curiosity while remaining appetizing. The ring design featured a uniform cross-sectional thickness to ensure even cooking throughout the structure.

2.6. Software

SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) was

Fig. 2. One panel of respondents filling out the questionnaire (see Supplementary File 1).

used for 3D modeling both edible and plastic bar designs. Simplify 3D (Simplify 3D, Cincinnati, Ohio, USA) was used to slice 3D models into G-code, the standard programming language for 3D printers (see Supplementary Scripts 1 and 2). An infill density of 50 % was used for the final print since it yielded a quicker print time and a more true-to-design final geometry (see Supplementary Scripts 3 and 4). Finally, Blender (Blender, Amsterdam, Netherlands) was used to apply color to polymer bar designs for printing on the Stratasys J850.

2.7. Printing and cooking

Edible food bars were printed using a Hyrel Engine SR (Hyrel 3D, Norcross, Georgia, USA) (Hyrel 3D, n.d.). This system was equipped with multiple extruder heads (P/N: SDS-060XT) for parallelized dual-extrusion, allowing for improved print efficiency. Each set of prints was air-fried for 9 min at 325°F, with a Philips 3000 Series Airfryer (Philips, Amsterdam, Netherlands) preheated for 3 min prior to use. Initial benchmarking determined these temperature and time settings to be optimal; an inner temperature of 200°F was recorded immediately after cooking. Each print was ~15 g in its raw form and ~12 g in its cooked form.

Once samples cooled after cooking, they were packed into multilayer retort pouches (Star Poly Nag Inc., Brooklyn, New York, USA), a three-layer laminate commonly used in military rations, and stored at 0 °C. To ensure food safety prior to consumption, six samples were randomly selected for microbial testing. These samples were incubated at 35 °C for 10 days then tested for the presence of *Escherichia coli* coliforms, aerobic plate count (APC), yeast and mold, and *Staphylococcus*.

2.8. Ingredient preparation

A 1.2 kg batch of dough was prepared using an N50 mixer (Hobart Corporation, Troy, Ohio, USA) equipped with a B flat beater (RVS). Ingredients used for the final printed material are listed in Table 1. Preparation of the final mixture involved the mixing of ingredients in separate bowls prior to combination. In the first bowl, flour (Sysco, Houston, Texas, USA), cocoa powder (WinCrest Bulk Foods, Inc., Munnsville, New York, USA), and pregelatinized starch (Ingredion, Westchester, Illinois, USA) were sieved through a 590 µm sieve and mixed with a whisk. In a separate bowl, sugar, egg white powder (Eggylicious), and salt (McCormick, Hunt Valley, Maryland, USA) were mixed and combined into the flour mixture using a whisk. Shortening (Crisco, Orrville, Ohio, USA) and vanilla extract (Virginia Dare Extract Co., Carteret, New Jersey, USA) were added to the mixer and blended at speed 2 for 30 s. Water was gradually added to the mixture, and the final mixture was then kneaded by hand to ensure uniformity.

2.9. Text analysis

Both focus groups were recorded using two smartphones, strategically placed around the room to more accurately identify speakers based on their placement in the room. The group discussions were primarily moderated by Blutinger, with some follow-up questions posed by Okamoto towards the end of each session. Recordings were transcribed manually by the research team. Transcripts from the sessions were then analyzed to determine the prevalence of different sensory attributes (see Supplementary Files 2 and 3). Natural language processing (NLP) was combined with word frequency analysis and thematic categorization. A custom MATLAB (MathWorks, Natick, Massachusetts, USA) script was crafted using a bag-of-words model with stop word removal. The script identified descriptive words related to four sensory attributes—appearance, texture, flavor, and aroma (Table 2). The frequency of these filtered words was tabulated to determine the relative emphasis on each sensory attribute in discussions about 3DFP.

Table 1
Ingredient list for printable dough.

Ingredient	Mass (g)	% by Mass
Shortening	301.92	25.16
Water	254.88	21.24
All Purpose Flour	240.00	20.00
Extra Fine Sugar	141.60	11.80
Dutch Cocoa Powder	108.60	9.05
Pregelatinized Starch (Novation 4300)	108.36	9.03
Egg White Powder	22.08	1.84
Vanilla Extract	18.00	1.5
Salt (Med. style sea salt)	4.56	0.38
Total Amount	1200.00	100.00

2.10. Sentiment analysis

Comments directed towards 3DFP from respondents were manually classified as being negative (−1), neutral (0), or positive (+1). Only user sentiments that pertained to 3DFP were factored into the user sentiment score. The average sentiment across respondents that commented, during seven distinct regions of time in the discussion, was taken (Table 3). These regions of time were marked by a moderator-triggered event (e.g., a question, handing out 3D-printed objects, or sampling printed food items).

A normalized aggregated sentiment ($\overline{S}_i$) for a given event i can be tabulated by first calculating the average sentiment ($\bar{s}_j$) of each user j,

$$\bar{s}_j = \frac{1}{m}\sum_{k=1}^{m} c_k \tag{1}$$

where c_k represents the sentiment score of a comment (−1, 0, or 1), with m total comments from a respondent j during event i. The group sentiment can then be tabulated using the following equation,

$$\overline{S}_i = \frac{1}{n}\sum_{j=1}^{n} \bar{s}_j \rightarrow \overline{S}_i = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{1}{m_j}\sum_{k=1}^{m_j} c_{jk}\right) \tag{2}$$

where n is the number of respondents during a given event and $\bar{s}_j$ is the average sentiment for a given respondent j after event i.

2.11. Statistical analysis

Quantitative questionnaire responses were analyzed using descriptive statistics. For each question rated on the 11-point Labeled Affective Magnitude (LAM) scale, mean values and standard errors (standard deviation divided by the square root of the number of responses) were calculated across both Soldier groups. To aid interpretation, LAM scores

Table 2
Associative words that were used to refer to certain sensory categories for text analysis.

Category	Filtered words
Appearance	appearance, appetizing, artificial-looking, beige, bright, bright-colored, cartoonish, color, dense, design, dull, glossy, homogenous, industrial-looking, layer, layered, layers, marbled, matte, natural, patterned, polygonal, processed, rigid, shape, soft-looking, unappealing, vibrant, visual
Texture	brittle, chalky, chewy, cold, crispy, dense, dry, flaky, grainy, gummy, hard, homogenous, ice, mealy, paste-like, rubbery, sludgy, smooth, soft, softer, spongy, sticky, taffy-like, texture, textures, watery
Flavor	artificial, balanced, bitter, bland, burnt, chemical-like, chemicals, earthy, flavor, flavorful, fresh, fruity, metallic, monotony, monotonous, natural, nutty, overpowering, processed, rich, salty, savory, sour, spicy, sweet, tangy, taste, umami
Aroma	aroma, aromatic, artificial, burnt, chemical-like, dairy-like, earthy, faint aroma, fresh, fragrance, fruity, herbal, meaty, metallic, mild, neutral, odor, odorless, pungent, rotten, scent, smell, stale, strong, sweet, yeasty

Table 3
Moderator-facilitated events that occurred during the discussion.

Event	Description
E1	Who knows what 3D food printing is?
E2	What positive or negative attributes do you associate with 3D food printing?
E3	The benefits of 3DFP were explained to participants.
E4	Do you like the term "3D printed food"? If not, how would you change it?
E5	Participants were presented with tangible 3D-printed bar designs.
E6	Participants brainstormed and sketched images of printed food items.
E7	Participants sampled a 3D-printed food bar.

were linearly converted to a −100 to +100 scale, where ranges corresponded to hedonic descriptors (e.g., "Like Moderately," "Dislike Very Much"). This allowed for clearer comparisons between bar designs and sensory attributes—for example, a score of 50 for one item and 20 for another would indicate that the former was liked more than twice as much based on the proportional spacing of the LAM scale.

3.1. Focus group

3.1.1. Attitudes towards 3D food printing

Respondents initially displayed a mix of curiosity and skepticism toward 3D food printing technology. Most of the participants were familiar with "3D printing" prior to the discussion, with 78 % of respondents in Group A and all 8 respondents in Group B indicating prior knowledge (88 % among all surveyed Soldiers). Even fewer participants were aware of "3D food printing"—only 3 of the 7 in Group A and 4 of the 8 in Group B had heard of it (41 % among all surveyed Soldiers). Those familiar with the concept likened it to traditional 3D printing, describing it as machines layering materials, like plastic, to build shapes.

A word frequency analysis was conducted on transcripts from the focus group and sensory panel to assess the frequency of sensory attributes. As shown in Fig. 3, appearance-related terms were the most commonly mentioned during the discussion, followed by texture, taste, and smell. Attributes related to appearance also increased slightly after inedible bar designs were presented to the Soldiers. Common descriptors of appearance included *color, industrial-looking, dull*, and *bright*; while descriptions of mouthfeel included *grainy, sludgy*, and *chewy*. Discussions of taste were with regards to flavor and ingredient quality. Smell was briefly mentioned towards the end of the panel (Fig. 3B) in relation to participants' degree of liking of the 3D-printed food samples.

While appearance was important, many concerns centered on texture, quality, and flavor monotony of 3D-printed food. Participants questioned whether food generated via 3DFP could replicate sensory attributes of traditional food. There was apprehension about the food being bland or unappealing, with associations to *"nutrient paste"* or *"sludgy"* forms that lacked flavor variety. Comments included, *"I feel it could be kind of like a more processed thing, mealy, grainy type of substance, or possible sludgy,"* and *"If it's not going to be a texture that I can tolerate, then I'm not going to eat it."* Another Soldier compared it to SPAM: *"I'm not sure if it's going to be, like, pasty meat, like SPAM almost. I don't like SPAM,"* a comment that would classify as a texture-related concern.

Taste of printed food products was of importance to Soldiers. They emphasized the need for a variety of flavors to reduce the monotony that may result from repeated consumption of MREs. One respondent stated that if he had to eat the same MRE Menu item for a month straight that he would not be content: *"I'll feel monotony and probably not want to eat it as much."* While a certain degree of novelty was favored with food items, participants also stressed the importance of retaining natural textures and familiar appearances for greater acceptance.

An emergent theme was the concept of "food identity." One Soldier noted that 3D food printing *"takes the identify out of food,"* elaborating that *"When you're eating chicken, you see that it's chicken. But if it's just a brick, it almost makes the feeding process monotonous,"* calling attention to the aesthetic of the printed food product. Another Soldier chimed in, likening it to pet food, commenting that it (pet food) *"doesn't look like its ingredients."* He went further to associate it with hamburgers: *"You can still tell it's made from meat because you can see the ripples in it from the original ground beef that it was [made from], but if it's processed enough… it does kind of become a 'calorie block.'"*

The association between "printed" and "processed" food also came up as a concern. One Soldier worried about the use of *"synthetic stuff"* in 3DFP and questioned the sourcing of ingredients. He said, *"I wouldn't expect it to be very organic,"* and that this concern stemmed from an association he had with 3D-printed plastics and lab-grown meats. Another respondent echoed his concern, suggesting that chemicals might be necessary to preserve shape and nutrient stability: *"More organic is what people are looking for."*

Others drew comparisons to existing processed foods, stating things like: *"It's going to be like MREs, it's just going to be a lot of processed stuff,"* and referencing McDonald's chicken nuggets: *"They kind of process their chicken. Like, it's delicious, but what's really going into it?"* Finally, adding a touch of humor, one Soldier referenced a kids' daytime cartoon show: *"I keep thinking of the scene where Plankton makes the 'Krabby Patty' [in SpongeBob SquarePants]."* In the show, this character's goal is to replicate a secret hamburger recipe, but the result ends up looking strange and unappetizing—almost like an artificial or over-processed version of the real thing, which might reflect some of the group's concerns with regards to 3D-printed food.

3.1.2. Nomenclature of 3D food printing

The terminology used to describe new food technologies can impact consumer acceptance (Malerich and Bryant, 2022). To explore this, we asked Soldiers whether they preferred the term "3D food printing" to

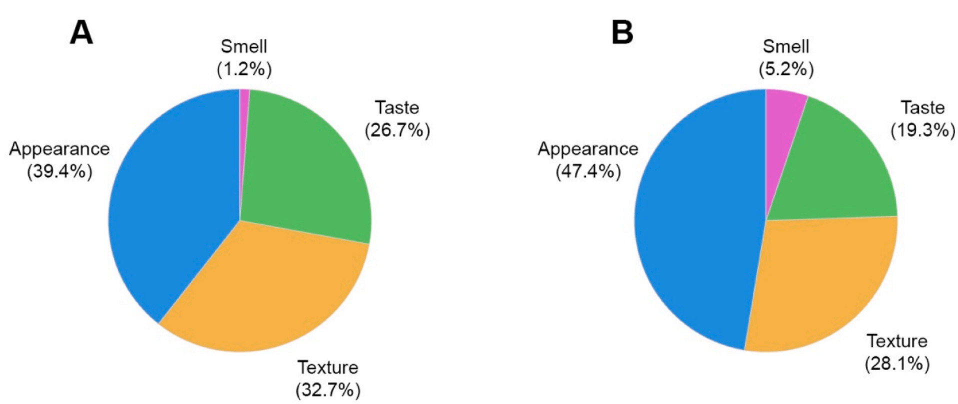


Fig. 3. Pie chart showing the relative emphasis on each sensory attribute (appearance, texture, taste, and smell) based on the focus group discussions before (A) and after (B) the inedible bars were presented to the Soldiers. Data was aggregated from focus group transcriptions, where relevant words and phrases were pre-classified into sensory categories. Each mention of a relevant term contributed to its total count, serving as a measure of perceived importance.

alternative names for food made via additive manufacturing.

Some Soldiers appreciated the terminology, "3D food printing," for its transparency, stating, *"it doesn't hide anything… it is what it is."* Others liked it because it stirred intrigue: *"They could get curious, they could get creative, and then it involves food, which I know basically everybody needs… so the name is simpler that way."* One respondent felt it could help people associate the technology with the broader 3D printing community, making its meaning easier to understand. Another Soldier felt that while the term diverged from the concept of "organic" and "home-cooked" food, it provided transparency: *"3D printing is, like, the opposite [of home-cooked food] … But at least you know what it is."*

For many respondents, "printing" did not have an immediate food association: *"I think of work, industrial, like, paper and stuff like that… I don't want to think of paper when I think of food."* When asked for alternative names, one Soldier suggested *synthetic food 3D printing*, which was quickly dismissed by others for use of the word "synthetic." Other suggestions included *3D food processing, crafted foods*, and *3D food synthesis*. Further discussion, led the consensus that "processing" had a more negative connotation than "printing": *"Now that you said 'processing,' I'm like meh, it sounds like a step backwards [from 'printing']."* While there was an initial reluctance to use the current nomenclature, the discussion ultimately led the Soldiers to recognize the challenge of naming such a technology for widespread adoption.

3.1.3. 3D-printed bar design preferences

To assess Soldiers' understanding of 3DFP and their food preferences, they were prompted to design their own 3D-printed foods. While sketches from the respondents varied, a few themes emerged. Participants from Group B, who were not shown example 3D-printed food shapes (Fig. 1) prior to design conceptualization, tended to draw familiar foods such as shrimp, steak, chicken, rice, pizza, and fish. Whereas the first group, that handled plastic bar designs prior to brainstorming, designed food products that were more geometrically complex, incorporating polygonal shapes and embedded messaging on the food product.

When evaluating 3D-printed bars, there was a slight preference for more familiar food designs (Fig. 4). When rating the appearance of food bars, Soldiers liked the lightning bolt (Fig. 1C) and the pentagonal twisted ring (Fig. 1D) more than twice as much as the control bar (Fig. 1A), which was modeled after a First Strike Bar. The organic, pocketed blob (Fig. 1B) received mixed reactions; with two people liking it extremely and two disliking it very much, it was the design with the widest range of responses. Although the average response was neutral, one person compared it to something from a *"fancy restaurant somewhere."*

The lightning bolt was the second most preferred bar design in terms of appearance. The Soldiers appreciated its functional symbolism: *"the lightning bolt [functionally] describes the product's purpose: energy."* Another respondent commented, *"the shape is fun and whimsical."* The most popular, however, was the pentagonal twisted ring (Fig. 4A), which was liked marginally higher than the lightning bolt. Respondents described this bar geometry as *"something unique and mysterious," "abstract," "some[thing that could hold] filling in the center," "unique yet practical,"* and *"the most stable shape that isn't a bar."*

When evaluating the impact of messaging on a nutrition bar, respondents preferred bars with text—such as "PWR" (Fig. 1E) and "REST" (Fig. 1G)—twice as much as a bar without messaging. Other suggested words were the day of the week to be used as a "daily nutrition bar," colloquial slang (e.g., "WOMP," "CRASH OUT"), pop cultural references (e.g., "40 ROUNDS!" "SEND IT"), and as a label for dietary preference (e.g., "VEGAN," "HALLAL," "KOSHER"). These suggestions reflected a preference for messaging that either served a functional purpose or incorporated humor to enhance the food product's appeal.

3.1.4. Changes in soldier sentiments over time

As group discussions progressed, Soldier sentiments toward 3DFP technology generally trended from skepticism to cautious optimism. Initially, concerns from respondents were centered around associations of perceived ingredient artificiality, unappealing textures, poor aesthetics, questionable palatability, and overall practicality of the

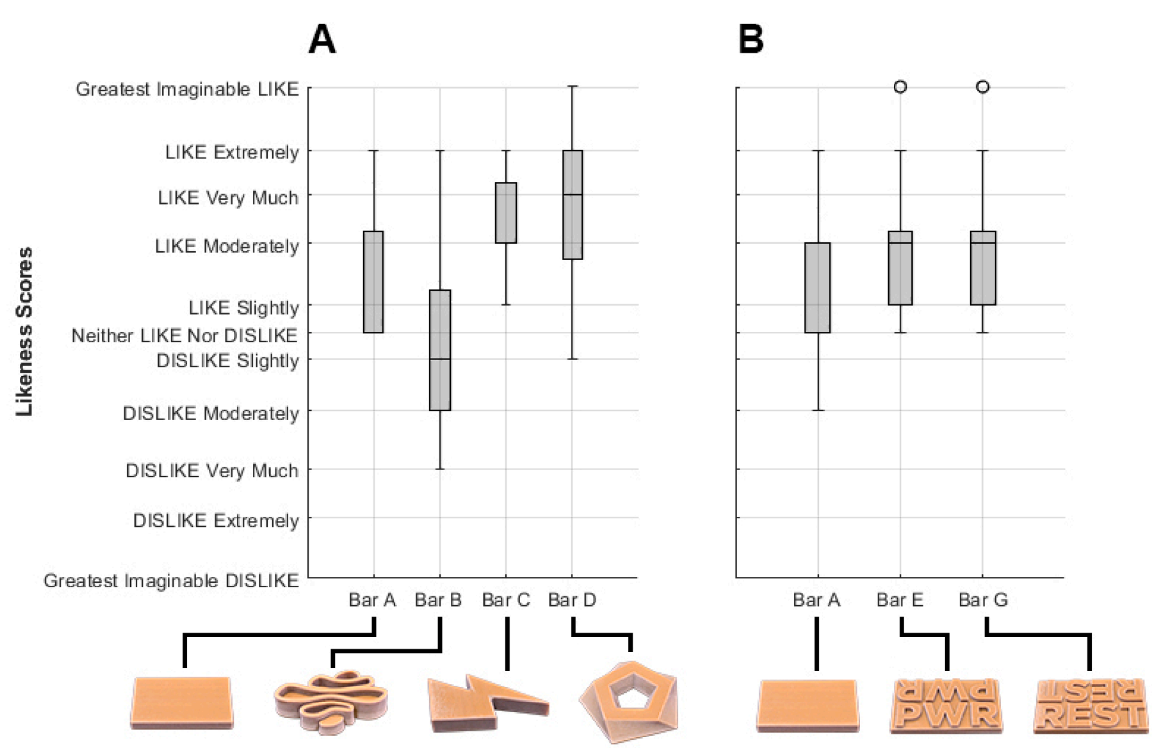


Fig. 4. Soldier degree of liking scores for bar appearance are presented using box-and-whisker plots ($n = 17$). Respondents rated (**A**) their liking towards different bar geometries and (**B**) their preference for bars with embedded messaging.

technology. Many participants expressed unfamiliarity with the concept of 3DFP, and only a few had heard of it prior to this experience.

Fig. 5, which shows average group sentiment, illustrates the mental shift that respondents had after key moderator interventions in the discussion. Initial hesitancies from respondents trended towards a more positive perception of 3DFP throughout the discussion. Some of the respondents liked the messaging, visual playfulness, and functionality of some of the bar designs, which became more apparent when they could physically handle the objects.

Both groups experienced a positive sentiment shift after the benefits of the technology were verbalized. Positive comments from respondents continued when they could physically handle 3D-printed bars, brainstorm printable foods for themselves, and sample a printed food item during the sensory panel. Group B's initial hesitancy was lessened during hands-on engagement with the samples. Conversely, Group A was more receptive to the technology, especially with regards to the customizable snacks and the nutrient-focused angle. This difference in average group sentiment may reflect more divergent group dynamics or different levels of food technology neophobia. Regardless, in both groups, the shift in positive sentiment was clearly tied to physical interaction and sensory sampling. The embodied experience had a marked affect on their technology acceptance, especially with food, where visual, tactile, and gustatory cues strongly affect perception.

3.2. Sensory evaluation

Printed cocoa dough formulation was generally well-liked by the participants (Fig. 6C). Appearance was the highest-rated attribute, followed by aroma, texture and flavor (see Supplementary File 4). Fig. 6 shows the final printed sample along with the corresponding liking scores; flavor and texture showed the highest variance in terms of preference. Post-sampling feedback from respondents highlighted mixed reviews on a few key sensory attributes: *"it was kinda chalky," "it gave protein-bar vibes," "it kind of looked like it came out of a Hostess bag," "it's so hard, yet it's chewy,"* and *"if we got this, I wouldn't be angry."*

Respondents seemed pleasantly surprised by the tasting experience. One Soldier detailed his sensory experience: *"It kind of threw me off because when I initially touched it, it was really hard on the outside, but when I bit into it, I was like 'Wow! This is like, almost like a cookie,' I was expecting a crunchiness."* He ultimately appreciated the unexpected texture contrast, which others echoed. Another Soldier noted that he liked *"how it was softer on the inside and kind of firmer on the outside."* Preconceived notions about how the bar would taste affected others' thoughts as well: *"I think it tasted a lot better than I thought it would… The texture was really good! It was kind of crispy, a lot better than I figured it would be."*

Preferences for flavor and texture sparked the most debate, and these attributes also showed the greatest variability among the sensory traits. One respondent noticed the 50 % infill of the printed structure, which he critiqued: *"There was definitely air-pockets inside of the crisp. Like, I popped it open, and I saw that some areas were just missing filling from the actual paste."* Another Soldier elaborated, *"if you can make [the infill] like the fluffiness of like a cake… then it would taste a lot better."*

Comments on the visible layer lines—a common artifact of 3D printing—were mixed. One participant wasn't bothered because it was a *"treat instead of like an actual food item that you'd eat for nutrition."* He added that if it were just a *"food product, I may not go that deep into it,"* indicating that his preference for the visual layer lines is a function of the type of food item being sampled. Lastly, in terms of flavor, berry and chocolate were the most desired flavors by the Soldiers for energy and recovery bars.

4. Discussion

As a collective understanding was developed, Soldier perspectives on 3DFP technology evolved positively (Fig. 5). With this being the first exposure to 3D-printed foods—let alone the concept of 3DFP—for many of the respondents, mixed responses were expected and could be explained by neophobic tendencies (Cox and Evans, 2008; Giordano et al., 2018). Food neophobia, or the fear of trying new or unfamiliar foods, combined with a lack of prior knowledge may have contributed to the respondents' negative associations with the word "printing" (Cardello et al., 2007). This term was paralleled to processed artificial

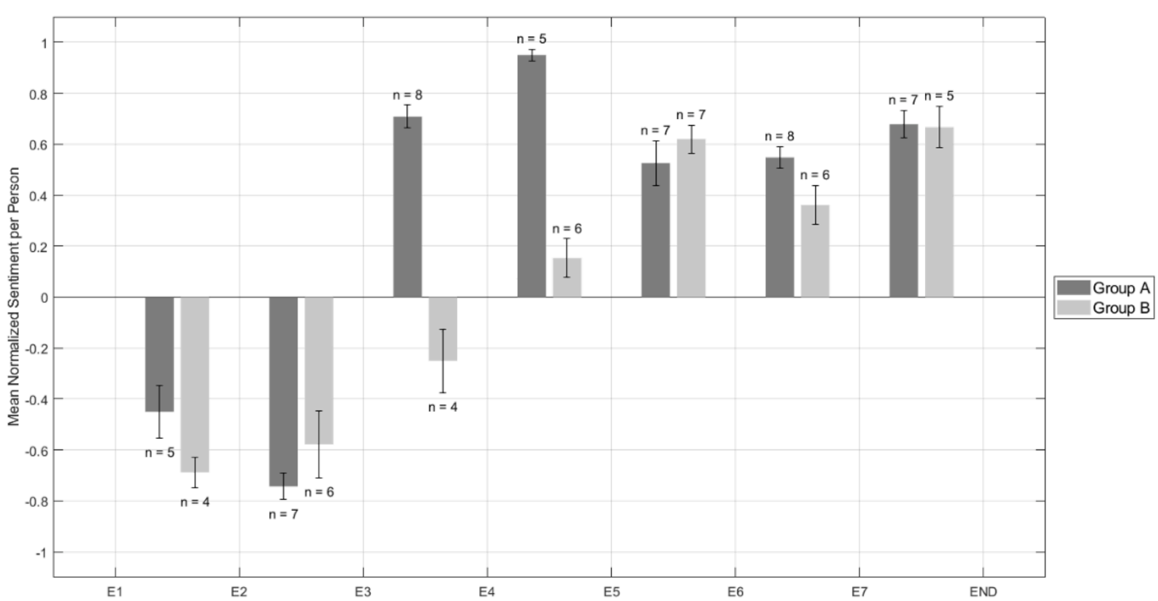


Fig. 5. Aggregated sentiment analysis for Group A and Group B. Each cluster of bars represents a period of discussion following a moderator-facilitated event (e.g., E1, E2, etc.). E1 prompted, "Who knows what 3D food printing is?"; E2 prompted, "What positive or negative attributes do you associate with 3DFP?"; E3 included an explanation of 3DFP benefits and then asked, "What food would you want a 3DFP to make for you?"; E4 prompted, "Do you like the term 3D-printed food? If not, how would you change it?"; E5 involved participants handling and observing 3D-printed bar designs; E6 asked participants to sketch images of printed food items; and E7 asked participants to sample printed food items. Note: The timing of the bar design exercise (E6) and the revealing of 3D-printed bar designs (E5) was reversed between the two groups to see the effect this would have on printed bar ideation; Group A experienced E5 first while Group B experienced E6 first.

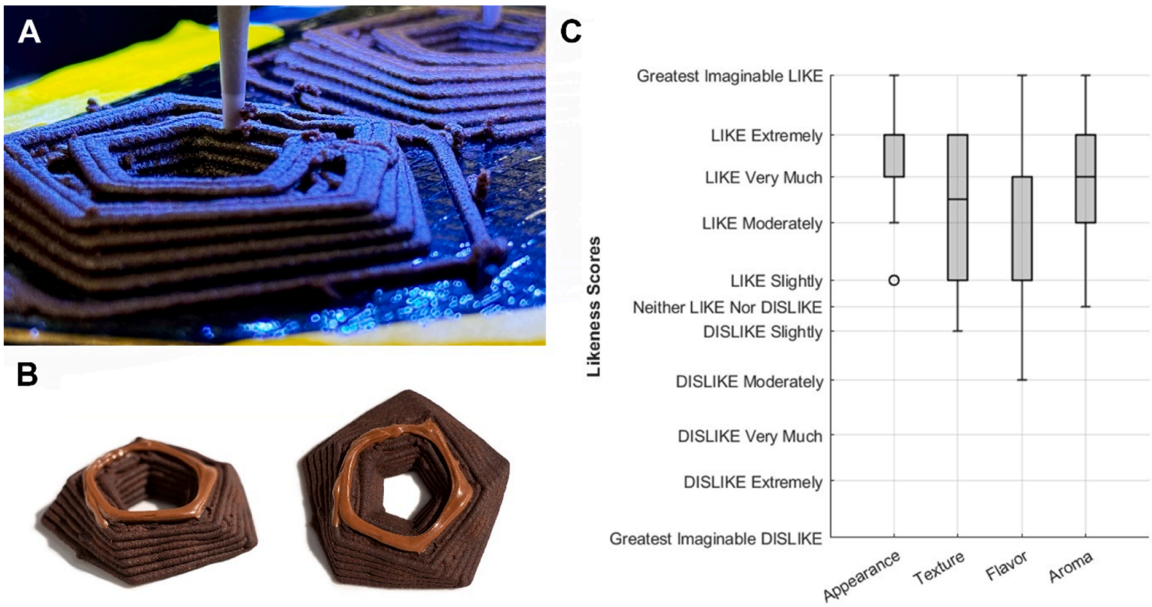


Fig. 6. Twisted pentagonal ring-shaped bites were provided to the Soldiers for evaluation. (**A**) The 3D-printed design consists of a cocoa dough recipe. (**B**) An isometric and top view show a 3D printed Nutella glaze along the top surface for a two-ingredient print. (**C**) The aggregated liking scores for the sensory preferences are displayed in a box-and-whisker plot ($n = 17$); one respondent did not fill out their preferences for appearance and texture.

materials likely due to associations with industrial use-cases with ink on paper (2D printing) and plastics (3D printing). Once respondents were told that chicken nuggets, pasta, and burger patties are technically produced via material extrusion (1D printing), they agreed that it was an effective way to inform people: *"You just need to tell everyone that and then they'll [accept it]."*

There tends to be a natural conservativeness towards the adoption of new food technologies (Cardello, 2003; Wendt and Weinrich, 2023), which we attempted to combat through gradual education, exposure to 3D-printed bar designs, and taste-testing of printed food items. Familiarity—through handling tangible 3D-printed items and brainstorming and sketching 3D-printable foods—appeared to foster greater acceptance among respondents (see Supplementary Fig. S1). Other studies on consumer attitudes towards 3DFP revealed similar findings (Brunner et al., 2018; Lupton and Turner, 2017); knowledge—or lack thereof—is a strong driver of consumer preference towards 3DFP. Not just discussing the technology but physically witnessing the 3D printing process is also an effective technique to further consumer acceptance (Gosine et al., 2020), which could be considered for future explorations.

For the Soldiers in this study, printed food didn't inherently evoke the idea of homecooked or natural meals. In the context of food, for example, the word "natural" has an association with the absence of additives, pollution, and human intervention (Rozin et al., 2012). There is also a higher preference for "natural" when it comes to food versus medicine (Rozin et al., 2004). Oddly enough, this is one of many terms that remains unregulated by the U.S. Department of Agriculture (USDA) or Food and Drug Administration (FDA) (David, 2023; Hansen, 2013) and is often used purely as a marketing tool to suggest a food's healthiness. Just as "natural" is leveraged as a marketing tool to shape consumer perceptions of food, effective branding and messaging will play a crucial role in the adoption of emerging cooking technologies like 3DFP.

Some Soldiers analogized food printing to alternative meats, which has been a victim of targeted disinformation campaigns by select media outlets (Rainey, 2023). This could explain the supposed artificial associations that a few respondents had with the technology. We posit, however, that printed food offers a high degree of transparency in the cooking process, ultimately yielding healthier food options for its consumers. It gives a consumer more control over the food that is being crafted than ordering a meal at a restaurant or fast-casual eatery. Consumers can visualize, design, and quantitatively control the nutrient profiles of their printed foods as if they were witnessing a nutritionist and personal chef craft a tailored meal.

Synthetic associations with 3DFP may also stem from the appearance of printed food items (Lupton and Turner, 2018). Printed layer lines and infill density—artifacts of the additive manufacturing process—may make printed foods appear machine-made, but some features can be leveraged as functional design elements. For example, layer line roughness can enhance food holding capacity, similar to how pasta ridges are designed to retain sauce (Chu and Tarazano, 2019). Certain food shapes and colors also tend to connote specific flavor or sensory responses (Spence and Deroy, 2013; Spence and Gallace, 2011; Spence, 2023). Spence and Deroy (2013) discuss the crossmodal effects angular and rounded food items have on our organoleptic perception of food. Even the priming of visual media prior to consumption or the design of the plate on which a meal is served can affect our perception of sweetness (Liang et al., 2013; Spence and Deroy 2013).

Aside from the impact a food item's aesthetics may have on perceived flavor, raised lettering on a bar (Fig. 7) may also serve a functional purpose by enhancing the tactile experience. First, it enhances breakability by creating weak fracture points between the letters or words. Second, if the letters are large enough, they can be felt through the packaging (Fig. 7A), doubling as a form of "food braille." Several Soldiers mentioned using this technique to identify the contents of the bar.

This type of tactile information is not just limited to words; variations in the frequency of ridges, thickness or bumps could be used to indicate certain flavor profiles. Additionally, the orientation of the text on the bar could help the Soldiers identify the type of bar upon opening the package either lengthwise or widthwise. Respondents also noted that the environment (e.g., low light, dirty or clean conditions) and the texture of the bar (e.g., sticky or brittle) might influence the way they open and consume it. For example, with a sticky bar or in a dirty environment, they would likely use the foil packaging to avoid touching the bar directly, whereas a firmer bar in a cleaner setting might lead them to tear off the entire sleeve to consume it quicker.

While the present study has a sample size of 17 individuals due to the limited pool of Soldier Research Volunteers (SRVs) available at the US Army Soldier Systems Center, the selected format of a focus group

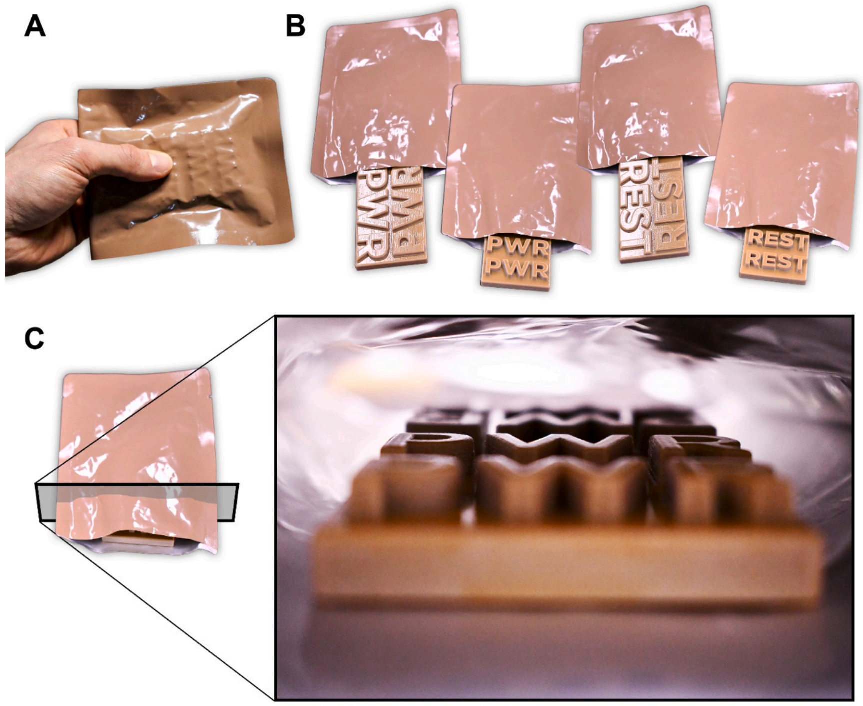


Fig. 7. Power and Recovery bars with embossed messaging. **(A)** 3D-printed “PWR” bar with embossed letters being felt through a package. **(B)** 3D-printed rectangular bars with “REST” and “PWR” embossed onto them in different orientations while being opened from a package. **C**: A cross-sectional view of the raised lettering inside one of the "PWR” bar packages.

followed by a sensory panel provided an in-depth look at the attitudes of U.S. military personnel toward 3DFP technology. Though generalizability of this information to a broader military population might be restrictive due to the sample size, the qualitative findings can serve as a valuable benchmark for future studies to build from. Larger scale studies will need to be performed to validate these trends and assess group differences more robustly. Furthermore, preparation of 3D-printed food items took a considerable amount of time, which is a process that will be streamlined moving forward. A future study exploring the potential psychological impact of 3D printed text on a bar (e.g., “power”) when combined with a performance enhancing ingredient (e.g., caffeine) may uncover synergistic effects that may improve Soldier performance.

Understanding how food neophobia can be mitigated in a Soldier population, and to what extent personalized nutrient bars can be tailored for a Soldier population in a real-world combat scenario is important for military acceptance. Since Soldier sentiment scores improved over time as they were exposed to information about 3DFP technology, it is possible that introducing novel food technology through education during basic training would help prepare Soldiers to more readily accept foods produced by these processes when encountered in the battlefield. Providing opportunities for Soldiers to witness 3D food printers, robotic food arms, and other automated food systems in military dining facilities or during field training exercises may further increase their familiarity and acceptance of these future food technologies. Moreover, these findings and educational learnings may also be transferrable to civilian populations for 3DFP and other novel food technologies.

5. Conclusion

Based on the responses from the young U.S. military population surveyed, there are clear apprehensions about consuming 3D-printed food, and opportunities for consumer perceptions to be improved upon. Initially, most respondents were unaware that the technology existed and expressed concerns about ingredient sourcing, texture palatability, and overall healthiness of printed food. Many also assumed that 3DFP could only create simple, uniform foods. Despite these reservations, however, they exhibited a curiosity and willingness to learn about the technology, ultimately leading to a more positive reception. Exposure—through hands-on interaction with printed items and verbal explanations—helped shift perceptions by showcasing the technology’s potential for personalized nutrition, intricate food designs, and health-conscious ingredient sourcing.

An underlying theme throughout the study was around the *identity* of food. While novel geometries were preferred, designs that were too abstract or that lacked a recognizable reference point elicited negative reactions. Although 3DFP can create truly innovative ingredient combinations and avant-garde meal experiences, its success will depend on how well the added value is perceived and aligned with consumers’ cultural and social expectations. Similarly, a new naming convention for the technology should be considered for different user populations and applications. Ultimately, we don’t just “eat with our eyes”—we eat with our memories.

Ethical statement

This study was conducted with Soldier Research Volunteers (SRVs) at the U.S. Army Combat Capabilities Development Command Soldier Center in Natick, MA. All participants provided written informed consent prior to participation and verb consent to being recorded for note-taking purposes. The study complied with the ethical principles of the Declaration of Helsinki and Department of Defense regulations for research with human subjects. All data was reviewed for operational security (OPSEC) and contained no personally identifiable information (PII).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT to edit grammar and flow. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Jonathan Blutinger: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alan Wright:** Writing – review & editing, Methodology. **Michael Okamoto:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2026.100906.

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