

Development of Two High Fiber - High Protein Snacks for Warfighters

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INTRODUCTION

- Military personnel have a high nutritional demand to support muscle performance, sustained energy and satiety during prolonged physical activity.
- High-fiber and high-protein foods promote stable energy release and are essential for numerous physiological activities, particularly gut health and muscle health, respectively.
- The Warfighter Nutrition Guide recommends a daily intake of 25-30g of dietary fiber and 0.8-1.6 g/kg body weight of protein for soldiers.
- We have developed two high fiber-high protein snacks- watermelon rind-based puff snacks (WRP)^{4,5} and soft soy pretzel bites (SSP)⁶ to cater to the military's nutritional requirements.
- Watermelon rind, a waste product, is high in bioactives such as polyphenols, L-citrulline, and fiber⁷, whereas, soybeans are rich in proteins, dietary fiber, and isoflavones.⁶
- Citrulline and soy isoflavones have anti-inflammatory activities and aid in athletic performance and recovery.^{6,7}

OBJECTIVES

- Evaluate the sensory acceptability of two high fiber-high protein snacks among soldiers under on-field conditions.
- Identify key sensory drivers (e.g., flavor, texture, mouthfeel) influencing liking.
- Apply sensory insights to guide product optimization towards on-field military application.

METHODS

Product Development

Watermelon Rind Puff Snacks



Figure 1. Preparation of watermelon rind-based puff snacks for sensory evaluation, including extrusion processing, seasoning with barbecue and cheddar cheese flavors, and final packaging.

Soft Soy Pretzel Bites

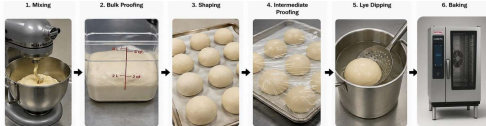


Figure 2. Preparation of Soft Soy Pretzel Bites from soy flour, soy milk powder, high gluten wheat flour, vital wheat gluten and yeast

Sensory Evaluation

- Sensory evaluation was conducted with active-duty U.S. Army soldiers during Dirt Days, an event organized by Civil-Military Innovation Institute (CMII) in West Virginia in February 2026.
- Soldiers (N=17) could select either or both of the snacks.
- They interacted naturally with the product in an authentic field environment to assess acceptability, quality, and usability.
- A structured questionnaire was used to collect feedback on both products:
- Overall liking on a 10-point hedonic scale
- Preferred serving size
- Perceived noise level and sensor-triggered detection
- Qualitative feedback on flavor and mouthfeel
- Comparison with commonly consumed field snacks
- Data were collected in real time and analyzed using descriptive statistics.

RESULTS

High Fiber-High Protein snacks

- Serving size of the WRP was 28g (>30 puffs), providing 5-8% of fiber's AI and 15-20% of protein's RDA for soldiers.
- Serving size of the SSP was 8 bites of 20g each offering 20-25% AI of dietary fiber and 25-30% RDA of protein for soldiers.



Figure 3. WRP (a) and SSP (b) provided to the soldiers

Table 1. Nutritional Information of WRP and SSP*

Nutrient	Watermelon Rind Puffs (28 g)	Soy Pretzels (8 pretzel bites, ~160 g)
Energy (kcal)	90	337.6
Total Fat (g)	0	6.4
Total Carbohydrates (g)	6	41.6
Dietary Fiber (g)	2	8
Total Sugars (g)	<1	6.4
Protein (g)	17	32
Isoflavones (mg)	—	25
L-Citrulline (mg)	34.4	—

* Values calculated based on data provided by ingredient manufacturers

Sensory Evaluation

- 6 soldiers chose WRP, 9 chose SSP bites and 2 tested both the snacks.

Overall Liking

- SSP bites were slightly liked more (mean 7.45 ± 1.29) than the WRP (mean 5.12 ± 1.96).

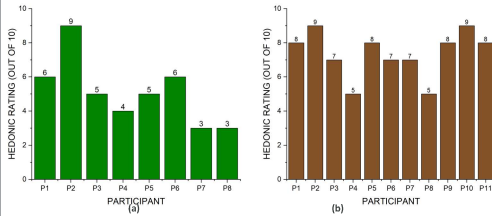


Figure 4. Overall liking scores for (a) puff snacks and (b) pretzel bites on a 10-point hedonic scale.

Recommended Serving Size

- A pack of 10 puffs and 5-7 SSP bites were considered to be an adequate portion size, lesser than what was offered in the study.

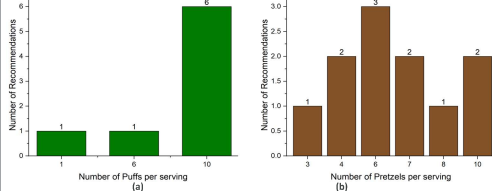


Figure 5. Recommended serving size for (a) puff snacks and (b) pretzel bites.

Acoustics of the Snacks

- Both products complied with the military's sound tolerance levels.

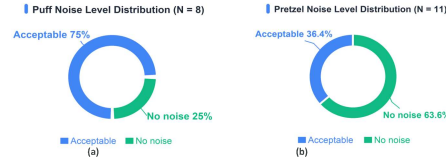


Figure 6a. Self-reported noise level during consumption of (a) puff snacks and (b) pretzel bites.

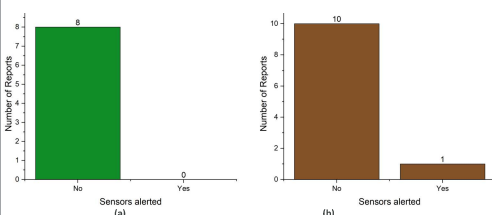


Figure 6b. Frequency of sensor-detected noise during consumption of (a) puff snacks and (b) pretzel bites.

Qualitative Feedback

- Overall, the soldiers deemed both the snacks as 'healthier alternatives' that were light to carry for field events and were satiating.
- However, both products were perceived to be bland for consumption on their own without any supplementaries.

Table 2. Participant-reported strengths and weaknesses of watermelon rind puff snacks.

Positive	Critique
Lightweight and portable	Low flavor intensity
No sensor-detected noise alerts	Dry, cardboard-like mouthfeel
Desirable crunchy texture	Generally perceived as bland

Table 3. Participant-reported strengths and weaknesses of soft soy pretzel bites.

Positive	Critique
Acceptable flavor	Dense texture
Soft texture	Bland flavor
Satiating	Dry texture
Lightweight	Potential gastrointestinal distress

CONCLUSIONS

- The two high fiber-high protein snacks were well appreciated by the soldiers and were described as 'healthy', 'filling', 'good taste'.
- They met the nutritional and physical requirements for tactical deployment.
- The warfighters recommended improving flavor of the watermelon rind puffs with 'spicy' and 'savory' notes and the soft soy pretzel bites with 'savory', 'sweet' and 'salty' notes.
- Iterative formulation development is necessary to enhance palatability.
- Studies on shelf-life extension and army-suitable packaging are warranted.

FUTURE DIRECTIONS

- Develop new flavor profiles and optimize coating uniformity to improve flavor acceptance of WRP
- Incorporate flavorants in SSP formulation to mask beany off flavors of soy.
- Evaluate shelf-life stability of puff snacks, focusing on moisture, texture, and crispness.
- Include natural humectants in SSP to prevent water migration-induced hardness during storage
- Evaluate bioactivity of L-citrulline from WRP and isoflavones from SSP on satiation, inflammation and muscle performance and recovery in soldiers.
- Ascertain gut modulatory effect of dietary fiber content of the two snacks among the soldiers.
- Work with Natick and other appropriate DOD entities to translate these products to warfighters

ACKNOWLEDGEMENTS

We thank CMII for providing access to their facilities to conduct this study and their support on-site and with data collection. We also acknowledge Floura & Co. for supplying the dried watermelon rind flour used in this study. The research presented in this poster is supported in part by the Department of Food Science and Technology.

