

Development of a High-Protein Brownie for Military and Emergency Ration Systems

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AIM: The main objective of this study was to develop a nutritionally optimized, protein-enriched brownie suitable for freeze-drying and inclusion in individual field rations for the Czech Armed Forces.

SPECIFIC OBJECTIVES:

- ✓ Formulate and optimize brownies based on legumes (beans) and whey protein concentrate with varying protein content (0–30%).
- ✓ Evaluate the physical, nutritional, and sensory characteristics of the freeze-dried product.
- ✓ Test the stability of selected formulations under storage conditions simulating logistic environments (5° C, 25° C, and 40° C).
- Compare the newly developed prototypes with commercial dessert products in terms of nutrition, shelf life, and consumer acceptance.

Texture analysis summary

Texture profile analysis was conducted using a TA.XTplus texture analyzer. Pre-lyophilization samples were evaluated for six parameters: **hardness**, **springiness**, **cohesiveness**, **gumminess**, **chewiness**, and **resilience**. The measured values are given in gram force.

The highest hardness was observed in the bean-based brownie with 30% protein (FB30), while the softest sample was the nut-based control without added protein (OB0). Overall, increased protein content correlated with greater hardness, gumminess, and chewiness. Bean-based variants generally exhibited higher values in all textural dimensions than nut-based ones. Among all tested samples, the FB10 (bean-based brownie with 10% protein) stood out as the most balanced in terms of texture and sensory acceptability. It combined moderate firmness with good cohesiveness and chewiness, making it the most suitable candidate for field consumption from a textural standpoint.

■ OB0 ■ OB10 ■ OB20 ■ OB30 ■ FB10 ■ FB20 ■ FB0



INTRODUCTION: In military field conditions, food is not only a source of energy but also a crucial factor in sustaining morale, physical performance, and psychological resilience. Despite these needs, existing dessert components in combat rations often suffer from low nutritional value – with excessive levels of simple sugars and minimal content of high-quality protein or fiber. There is growing interest in improving these components by incorporating more functional and nutritionally valuable ingredients.

This study focuses on the development of a high-protein brownie formulation designed for freezedrying and subsequent inclusion in Czech Armed Forces rations. However, its potential application extends beyond the military, as such a product could be effectively used by other units of the integrated rescue system, including police, firefighters, and emergency responders. The product is based on legumes (specifically beans), cocoa, and protein-enriched ingredients, aiming to enhance the nutritional profile, shelf stability, and sensory acceptability of the dessert. Particular attention is paid to post-processing characteristics, stability under varied storage conditions (5 $^{\circ}$ C, 25 $^{\circ}$ C, and 40 $^{\circ}$ C), and consumer acceptance. This novel brownie has the potential to replace or complement conventional sugary bakery products currently used in field rations.



After freeze-drying and three months of storage, only hardness was measured using a knife blade probe due to the increased firmness of the samples. The results confirmed that protein enrichment and storage temperature significantly influenced hardness:

•Storage at 25 °C often resulted in the highest firmness, likely due to sugar recrystallization.

•At 40 °C, a softening effect was noted in some samples, possibly caused by degradation or partial moisture migration. •FB30 stored at 5 °C showed the highest hardness of all (≈9000 g), exceeding even typical values for chocolate-coated wafers.These findings demonstrate that texture is strongly affected by both protein content and storage conditions, which should be considered when optimizing the product for long-term field deployment.



Fig. 1: Brownies samples in PE/PA packaging and prepared brownies samples for senzory analysis

METHODS:The study focused on the development of high-protein brownie prototypes designed for freeze-drying and potential deployment in field rations. Two formulations were created: one based on legumes (specifically canned red kidney beans) and the other on walnuts. Both versions were enriched with whey protein concentrate (WPC 80), adjusted to protein levels of 0%, 10%, 20%, and 30% in the dry matter. The basic recipe included cocoa powder, semi-coarse wheat flour, eggs, butter, sugar, and baking powder. All ingredients were mixed to form a homogeneous batter and baked at 170 °C for 20 minutes.

After cooling, the brownies were cut into uniform cubes and subjected to freeze-drying (lyophilization) using a Lyotrade AMARU freeze dryer under standard conditions. The lyophilized samples were then vacuum-sealed in multiplayer aluminium packages and stored at three temperatures: 5 °C (refrigerated), 25 °C (room temperature), and 40 °C (accelerated ageing) for up to 3 months.

Throughout the study, various analyses were conducted to evaluate the effect of protein enrichment and storage conditions. These included determination of nutritional composition (protein, fat, carbohydrates, energy), measurement of water activity (aw) using a Steroglass WaterLab, instrumental texture profile analysis (TPA) using a Stable Microsystems TA.XT plus100 texture analyzer, and color evaluation using a HunterLab ColorFlex. Sensory evaluation was carried out by trained panelists using ranking tests, hedonic scales (9-point), and descriptive analysis, focusing on taste, aroma, texture, and overall acceptability.



Fig. 5: Sensory profile comparison

Senzory analysis results

Fig. 4: Hardness, gumminess and chewiness values

The sensory analysis of the freeze-dried protein brownies included three evaluation rounds (immediate, 3-month, and 6-month storage), each assessing visual appearance, texture, flavor, and overall acceptability using hedonic and ranking methods. Samples were stored at 5 °C, 25 °C, and 40 °C to simulate varying logistical conditions. **Overall Acceptability and Storage Effects:**

The most favorable results were consistently observed in **FB10 (bean-based brownie with 10% protein)** across all storage conditions and time points. This variant achieved the highest hedonic scores, particularly in taste (\geq 8.3/9) and overall rating (up to 8.0), indicating a strong consumer preference for its flavor and aroma stability. In contrast, **OB30 (nut-based brownie with 30% protein)** received the lowest scores due to off-flavors and decreased texture quality.

Temperature and Protein Influence:

Storage temperature had a clear impact on sensory quality. Samples stored at 5 °C retained the best sensory attributes, especially in flavor and appearance. At 25 °C, mild degradation was noted, while 40 °C storage led to significant deterioration, particularly for nut-based samples with higher protein content. A clear trend was observed where higher protein content reduced sweetness, increased bitterness and chewiness, and negatively influenced sensory ratings.

Texture and Consistency:

Nut-based brownies without protein (OB0) were consistently rated best for texture. Protein addition generally made the texture firmer and less airy, especially under warm storage. Bean-based samples were harder, yet retained better flavor and aroma.

Off-Flavors and Hedonic Decline:

Ranking tests showed that **OB30 and OB20 had the strongest perception of off-flavors**, while **FB10 and FB20** were least affected. Protein enrichment in nut-based recipes increased the incidence of undesirable tastes, particularly after extended storage.

RESULTS:

Y This study demonstrated that protein-enriched bean-based brownies can serve as a nutritionally valuable, sensorially acceptable, and shelf-stable dessert component suitable for inclusion in

military field rations.

- Y The 10% protein variant (FB10) emerged as the optimal formulation, showing superior sensory properties, microbiological stability, and technological feasibility for freeze-drying and storage
 under various temperature conditions.
- Y The developed product outperformed commercial dessert bars in protein content and textural balance, offering a promising alternative for long-term deployment rations designed for soldiers, police officers, or rescue services.

CONCLUSIONS:

- Y This study demonstrated that protein-enriched bean-based brownies can serve as a nutritionally acceptable, and shelf-stable dessert component suitable for inclusion in military field rations.
- Y The 10% protein variant (FB10) emerged as the optimal formulation, showing superior sensory properties, microbiological stability, and technological feasibility for freeze-drying and storage under various temperature conditions.
- Y The developed product outperformed commercial dessert bars in protein content and textural balance, offering a promising alternative for long-term deployment rations designed for soldiers, police officers, or rescue services.

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