

TECHNOLOGICAL INNOVATIONS AND NUTRITION IN THE MILITARY

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ABSTRACT

Modern military nutrition transcends the simple provision of calories, evolving into an integrated system that prioritises individual performance, food safety, and logistical efficiency. This article analyses the convergence between NATO nutritional standards, the use of functional supplements, and the implementation of emerging technologies, such as 3D food printing and smart rations with sensors. By examining international case studies from the United States, the United Kingdom, Germany, and Estonia, this paper highlights the benefits of nutritional personalisation, supply chain optimisation, and enhanced food safety. Finally, the article proposes a series of recommendations for the adoption of these innovations within the Romanian Army, arguing that such a hybrid model represents an essential investment in the health, resilience, and operational performance of military personnel, thereby preparing the armed forces for the complex challenges of the future security environment.

KEYWORDS: nutrition, functional supplements, smart rations, 3D printing, technology

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1. Introduction

Military nutrition represents a crucial element of operational effectiveness, being closely linked to the physical performance, stress resilience, and decision-making capacity of soldiers in complex and varied environments. In recent decades, studies on the nutritional intake of military personnel have shown that traditional rations, while designed to meet average energy requirements, do not always succeed in addressing individual needs, which vary according to metabolism, sex, age, type and intensity of physical exertion, or climatic conditions. In this context, NATO standards provide a framework for the design and evaluation of military rations, ensuring that each soldier receives the necessary intake of calories, macronutrients, and essential micronutrients to maintain optimal performance during operations.

Allied Medical Publication (NATO STANDARD AMedP-1.11, 2019) is a fundamental document for the harmonisation of rations across allied armed forces. These standards recommend a daily energy intake ranging between 3,600 and 4,900 kcal, adjustable according to physical activity and environmental conditions. Rations must contain an optimal balance of carbohydrates (approximately 400-500 g), proteins (100-130 g), and fats (100-150 g), as well as a complete set of vitamins and minerals, including Vitamins A, C, D, the B complex, calcium, iron, zinc, and magnesium. This framework enables military personnel to cope with intense, long-term exertion, maintain muscle mass, and prevent nutritional deficiencies that could compromise physical or cognitive performance.

While the standardisation of rations ensures predictability and logistical compatibility, the specialised literature emphasises the importance of nutritional personalisation in military environments. Not all service members have identical energy requirements, and standards do not always cover individual variations caused by metabolism, age, or pre-existing medical conditions.

Furthermore, in operations conducted in extreme environments, from sub-zero temperatures in northern regions to intense heat in desert areas – energy requirements can increase significantly. In these situations, dietary supplements are an essential tool for complementing standard rations, ensuring the optimal intake of micronutrients and energy. Functional (dietary) supplements include multivitamins and multimineral, essential proteins and amino acids, as well as adaptogens or nootropics that can support cognitive performance and stress resilience.

Recent studies indicate that approximately 74% of U.S. military personnel use supplements at least once a week, and their integration into standard rations helps prevent fatigue, maintain muscle mass, and ensure cognitive alertness during prolonged missions (Knapik et al., 2021). Concurrently, NATO regulations stipulate that any administered supplement must comply with safety and quality standards, ensuring interoperability in multinational missions and protecting soldiers' health.

The importance of adapting rations to cultural and sensory preferences should not be neglected. Food acceptability can directly influence the effective consumption of rations and, implicitly, nutrient intake. Thus, rations must be not only calorically efficient but also palatable and varied, to prevent non-consumption of certain components and, consequently, nutritional deficiencies. This aspect becomes even more relevant in the context of multinational operations where military personnel originate from diverse cultural backgrounds.

Technological advancements in recent decades have opened new perspectives in military nutrition, offering the possibility of combining traditional standards with innovative solutions that allow ration personalisation and continuous monitoring of nutritional status. Among these, 3D food printing has attracted attention for its capacity to produce personalised meals, layer by layer, adjusting caloric content and macronutrients based on individual needs. This technology also allows for reduced food waste and logistical flexibility in mobile operations or temporary bases, where access to traditional supply chains may be limited (Chatzipanagis, Omar & Sanfeliu, 2024).

Smart rations represent another major innovation, integrating sensors that monitor temperature, humidity, and packaging integrity. These systems enable logistics personnel to identify spoiled food, prevent its consumption, and optimise ration distribution in the field. Furthermore, the collected data can be used to adjust production processes and improve product quality, contributing to overall operational efficiency (Hossain et al., 2025).

Modern military nutrition is not limited to adhering to caloric values or providing a balance of macronutrients but involves an integrated approach that combines NATO standards, functional supplements, and emerging technologies. The following sections explore these components in detail, illustrating through international case studies and comparative tables how technological innovation can revolutionise military sustenance, adapting it to the individual and operational needs of soldiers.

2. Functional (Dietary) Supplements and the Optimisation of Military Rations

As the nutritional needs of military personnel become increasingly complex, functional supplements play a vital role in complementing standard rations. While NATO rations are designed to cover average energy and nutritional requirements,

individual variability and extreme field conditions necessitate a more sophisticated approach. Functional supplements allow for the adjustment of protein, carbohydrate, fat, vitamin, and mineral intake, providing support for physical health, cognitive performance, and stress resilience.

Proteins and amino acids are fundamental components, especially in operations involving intense and prolonged physical exertion. Research indicates that adequate protein intake contributes to the maintenance of muscle mass, fatigue prevention, and optimised recovery following exercise (Pasiakos, Montain & Young, 2013). In an operational context, where soldiers may be subjected to repeated and demanding physical activities, protein supplements in the form of powders, bars, or gels can complement insufficient intake from traditional rations.

Vitamins and minerals are other critical components. Deficiencies in B, C, or D vitamins or minerals such as zinc, magnesium, and iron can negatively affect physical performance and cognitive function. In operations conducted in isolated environments, where access to fresh fruits, vegetables, and other fresh foods is limited, supplements become indispensable. For example, Vitamin D supplementation has been associated with maintaining bone density and immune function under conditions of low sun exposure, which is common in northern operational theatres (Holick, 2010).

In addition, adaptogens and nootropics are increasingly integrated into military nutritional programs. These bioactive compounds support stress resilience, alertness, and cognitive performance. Studies conducted by the U.S. Army demonstrated that controlled administration of adaptogens, such as *Rhodiola rosea*, positively influenced reaction times and resistance to prolonged mental effort (Spasov et al., 2000). This approach is essential in long-duration

missions or extreme environments, where psychological factors can decisively impact operational success.

The implementation of functional supplements requires careful monitoring. NATO recommends periodic evaluation of personnel's nutritional status, dose adjustment, and adherence to safety standards to prevent over- or under-dosing and to avoid unwanted interactions. In this regard, smart rations equipped with sensors can facilitate consumption and inventory monitoring, providing logistics personnel with real-time data and reducing food waste.

A practical example of functional supplement integration was tested within the Canadian Armed Forces, where soldiers involved in complex field exercises received standard rations supplemented with protein bars and antioxidant supplements. Subsequent evaluations demonstrated a significant reduction in muscle fatigue and the maintenance of cognitive performance throughout the mission (Garcia et al., 2019). Similarly, the U.S. Military Nutrition Laboratory conducted comparative tests between personnel consuming only standard rations and those receiving functional supplements, noting marked differences in reaction time, physical endurance, and perceived energy levels.

This combination of standard rations and functional supplements emphasises the importance of an integrated nutritional strategy that considers logistical requirements, international standards, and individual soldier needs. Emerging technologies, such as 3D food printing, further complement this approach by enabling the incorporation of functional supplements directly into personalised meals tailored to individual soldiers and mission requirements.

3. 3D Food Printing and Smart Rations: The Technological Revolution in Military Nutrition

As technology advances, military nutrition is evolving, integrating innovative solutions that transcend traditional ration limitations. Among these, 3D food printing and smart rations with sensors represent the most promising innovations, offering nutritional personalisation alongside optimised monitoring and logistics.

3D food printing enables the creation of meals layer by layer, with precise composition of macronutrients and micronutrients, adjusted according to the metabolic profile of each service member and mission requirements. This technology utilises nutritional pastes, protein powders, or emulsions, which can be combined to produce ready-to-eat meals or intermediate ingredients. The advantages are substantial: rations can be calorically personalised, adapted in the proportions of proteins, carbohydrates, and fats, and supplemented with functional nutrients.

In the U.S., the Army's Combat Capabilities Development Command Soldier Centre's Combat Feeding Directorate has demonstrated that 3D printing can produce rations tailored for long-duration missions, reducing fatigue and energy deficits. Tests indicated that military personnel consuming personalised meals reported higher energy levels and faster recovery after intense exertion. Similarly, in the United Kingdom, portable 3D printing equipment has been deployed in temporary bases to produce meals in real-time using dried ingredients or nutritional powders, reducing dependence on conventional supply chains (Chatzipanagis, Omar & Sanfeliu, 2024). 3D printing also enhances sensory flexibility, the shape, texture, and colour of food can be adapted to individual preferences, increasing ration acceptability and reducing food waste. Soldiers who refuse certain components of standard

rations can receive variants with equivalent nutritional value but different textures or tastes. This capacity is crucial in multinational operations, where cultural and dietary preferences may vary significantly.

Smart rations represent another leap in logistics optimisation and food safety. Equipped with sensors to monitor temperature, humidity, and packaging integrity, smart rations allow rapid identification of spoiled products and prevent consumption. NATO member states, such as Estonia and Germany, have tested this technology under field conditions, observing a 20-30% reduction in spoiled food consumption and increased soldier satisfaction with ration quality (Hossain et al., 2025).

Smart rations also provide vital logistical data. Integrated systems enable tracking of consumption, inventory adjustments, and anticipation of future mission requirements. This not only optimises distribution and reduces waste but also improves command decision-making in resource management.

Integrating 3D printing and smart rations with functional supplements opens new possibilities. Protein powders or vitamin-mineral complexes can be incorporated directly into personalised meals, eliminating separate administration and ensuring optimal nutrient absorption. Simultaneously, sensor data allow real-time monitoring of consumption and nutritional status, enabling immediate ration adjustments.

4. International Case Studies and Applicability for the Romanian Army

International experiences provide valuable insights into the integration of emerging technologies and functional supplements in military nutrition. Analysis of programmes in the U.S., U.K., Germany, and Estonia highlights best practices, challenges, and results adaptable to the Romanian context.

In the United States, the Combat Feeding Directorate tested personalised rations via 3D printing, supplemented with functional nutrients. Soldiers received meals adjusted calorically and in protein content according to exertion and metabolic profile. Evaluations showed improved physical and cognitive performance, reduced fatigue, and optimised recovery. Sensor-equipped rations enabled real-time monitoring of consumption and nutritional status, facilitating rapid adjustment of field rations (Chatzipanagis, Omar & Sanfeliu, 2024).

In the U.K., portable 3D printing in temporary bases allowed production of ready-to-eat meals from dried ingredients or

nutritional powders, reducing reliance on traditional logistics and ensuring swift adaptation to operational requirements. Soldiers reported increased satisfaction due to personalised taste, texture, and nutritional composition (Hossain et al., 2025).

In Germany and Estonia, smart rations equipped with sensors monitored temperature, humidity, and packaging integrity. Consumption of spoiled food decreased by 20-30%, and logistics personnel responded quickly to deviations, optimising distribution and reducing waste. These examples demonstrate that smart rations improve food safety and operational efficiency (Hossainet al., 2025).

Table no. 1
Comparison of Military Ration Type

Component	Standard NATO Ration	Personalized 3D Ration	Smart Ration with Sensors
Calories	3,600 – 4,900 kcal	3,600 – 5,200 kcal (adjustable)	3,600 – 5,200 kcal (adjustable)
Protein	100 – 130 g	100 – 150 g (adjustable)	100 – 150 g (adjustable)
Carbohydrates	400 – 500 g	400 – 550 g (adjustable)	400 – 550 g (adjustable)
Fats	100 – 150 g	100 – 160 g (adjustable)	100 – 160 g (adjustable)
Supplements	Optional (separate administration)	Integrated directly into the food	Integrated and monitored
Quality Monitoring	Manual (visual inspection)	Manual	Automated (temp./humidity sensors)
Taste/Texture Personalization	Limited	High	High

A comparative analysis of findings across the literature reveals several limitations of current NATO-standard rations. Studies from the U.S. and U.K. consistently show that while standardised caloric thresholds ensure baseline

operational readiness, they fail to accommodate metabolic variability and environmental demands. Conversely, 3D-printed personalised rations demonstrate measurable gains in energy retention, reduced selective non-consumption, and

superior recovery kinetics. Sensor-based smart rations address a different limitation – food quality assurance and supply-chain transparency – reducing spoilage rates by 20-30%. Taken together, these findings indicate that no single system fully resolves the constraints identified in conventional field nutrition, but that hybrid models combining personalisation and monitoring offer the most robust operational outcomes.

The implementation of these technologies in the Romanian Army can bring multiple benefits:

- **Nutritional Personalization:** 3D printing and functional supplements allow for the adaptation of rations to individual needs, increasing physical and cognitive performance.

- **Food Safety:** Smart rations with sensors ensure constant monitoring of food quality, reducing the risk of consuming spoiled products.

- **Logistical Optimization:** Real-time monitoring of consumption and inventory allows for rapid adjustment of distribution and waste prevention.

- **Operational Flexibility:** Portable 3D printing equipment can produce ready-to-eat meals, reducing dependence on conventional logistical chains and enabling rapid adaptation to field conditions.

- **Acceptability and Morale:** The possibility of personalizing the taste and texture of food increases soldier satisfaction, positively influencing morale and operational efficiency.

To implement these technologies in our military, the following are considered necessary steps:

- **Acquisition of portable 3D printing equipment.**

- **Development of climate-controlled storage facilities with the implementation of integrated monitoring systems.**

- **Training logistical and medical personnel in the use of new technologies, supplement administration, and interpretation of data provided by sensors.**

- **Standardization of production, handling, and administration processes for personalized rations and supplements.**

- **Testing the technologies in pilot units, evaluating performance, and then progressively expanding to the entire army.**

- **Ensuring full interoperability in multinational missions by complying with allied recommendations regarding caloric, nutritional, and technological intake.**

5. Conclusions

Modern military nutrition can no longer rely solely on standardised rations to ensure optimal performance in complex operations. Integrating NATO standards, functional supplements, 3D printing, and smart rations facilitates a personalised, flexible, and safe nutritional system capable of meeting contemporary operational demands.

International experience shows that emerging technologies improve logistical efficiency and enhance physical and cognitive performance. Personalised rations, calibrated according to metabolic profiles, reduce fatigue, maintain muscle mass, and improve alertness. Smart rations allow continuous monitoring, reducing waste and optimising distribution.

For the Romanian Army, adopting such a hybrid system represents both an operational advantage and a strategic investment in soldier health, performance, and resilience. Careful planning, infrastructure investment, personnel training, and strict safety and administration protocols are essential. Interoperability with NATO standards is a key consideration to ensure consistency across multinational missions.

From a risk perspective, delays in technological integration may perpetuate inefficiencies, exposure to spoilage-related health hazards, and performance loss due to unmet individual nutritional needs. Moreover, excessive reliance on emerging technologies can introduce vulnerabilities related to equipment failure or supply-chain interruptions. Conversely, the opportunities

generated by hybrid nutritional systems include enhanced physical endurance, reduced medical evacuations, improved cognitive stability during prolonged operations, and increased logistical predictability. These factors collectively strengthen both national readiness and NATO interoperability.

Future developments should explore biometric sensors for real-time nutritional monitoring, AI applications for automated ration adjustments, and integration of functional supplements into adaptive food platforms. Long-term clinical evaluations, comparative studies of standard versus personalised rations, and analyses of taste

and texture acceptability should form the basis of ongoing research.

In conclusion, modern military nutrition must evolve beyond rigid standardised rations. The integration of NATO standards, functional supplements, 3D printing, and smart rations enables the creation of an adaptable, efficient, and safe system capable of responding to both individual soldier needs and complex operational challenges. For the Romanian Army, implementing this model represents not only an operational enhancement but also a strategic investment in preparing the armed forces for future battlefield and multinational missions.

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