



From Food Safety to Operational Readiness: A Risk-Based Framework for Military Ration Systems

Abbas Nourmohammadi ^{1,*}, Mohsen Chamanara ^{2,3}, Mahdieh Doaei ⁴

¹ Aerospace and Subaquatic Medicine Research Center, AJA University of Medical Sciences, Tehran, Iran

² Toxicology Research Center, AJA University of Medical Sciences, Tehran, Iran

³ Student Research Committee, AJA University of Medical Sciences, Tehran, Iran

⁴ Iranian Registry of Clinical Trials (IRCT), Ministry of Health and Medical Education, Tehran, Iran

*Corresponding Author: Aerospace and Subaquatic Medicine Research Center, AJA University of Medical Sciences, Tehran, Iran. Email: dr.nourmohammadi@yahoo.com

Received: 19 May, 2026; Revised: 27 May, 2026; Accepted: 15 June, 2026

Abstract

Context: Operational rations constitute a health-support system rather than a simple inventory item. They must remain safe, nutritionally appropriate, acceptable, and usable across diverse missions and environments. A ration may meet its written specification yet fail operationally if it is not consumed, is degraded during storage, cannot be prepared under field conditions, or cannot be rapidly traced during a safety event. This expert review presents a risk-based framework that links ration governance to measurable readiness outcomes.

Evidence Acquisition: PubMed/MEDLINE was searched from inception through July 31, 2026, supplemented by targeted searches of official military, food-safety, and standards sources. Eligible evidence addressed energy balance and intake, acceptability, nutrient adequacy, enteric disease, packaging, shelf life, hazard control, traceability, and surveillance. A reproducible PubMed search logic is reported in the full text. Twenty-eight sources were retained for narrative synthesis; because the original expert-review search was iterative, a formal PRISMA-style deduplicated screening count was not maintained prospectively.

Results: Evidence supports an implementation gap between food issued and food consumed. Field studies show marked energy deficits despite ration availability, and factors such as preparation time, food temperature, task tempo, menu fatigue, and equipment constraints influence intake. Foodborne outbreaks can cause clustered illness and duty loss, and thermal or packaging failures can degrade quality before obvious spoilage. The proposed five-domain Ration-to-Readiness (R2R) framework comprises mission profiling, product and supplier assurance, logistics integrity, consumption assurance, and health-readiness feedback, with leading indicators, example accountable functions, and illustrative, locally calibrated triggers.

Conclusions: Military ration systems should be evaluated based on verified consumption, safety, and readiness effects rather than procurement compliance alone. The R2R framework is an author-developed, standards- and evidence-informed policy model; however, its proposed benefits and action thresholds require prospective validation across forces, climates, and mission profiles.

Keywords: Military Personnel, Food Safety, Operational Rations, Nutritional Readiness, Risk Management

1. Context

Military feeding operates under constraints rarely encountered in institutional catering, including uncertain resupply, high physical workloads, compressed eating opportunities, temperature extremes, limited water and preparation equipment, and a requirement for long shelf

life. Under these conditions, nutrition, food safety, packaging, logistics, and medical surveillance become interdependent. Energy requirements can rise markedly with load carriage, cold exposure, altitude, and sustained operations, whereas actual intake often declines as workload and fatigue increase (1-5). Consequently, a technically compliant ration can coexist with negative

energy balance, micronutrient shortfalls, gastrointestinal symptoms, or avoidable waste.

The conventional supply-chain question—whether the required number of meals reached the unit—is necessary but insufficient. Readiness depends on whether the meal remained within specification, could be prepared safely, was accepted and consumed, and supported health and performance. Reviews describe ration nutrition and technology; however, governance is commonly divided among procurement, logistics, food services, preventive medicine, clinicians, and commanders (6, 7). This fragmentation can obscure downstream consequences related to intake, illness, and duty loss.

This expert review addresses this systems gap. Its objectives are to: (i) synthesize evidence on the main nutritional, behavioral, microbiological, and logistical failure modes of operational rations; (ii) propose a Ration-to-Readiness (R2R) framework with measurable controls; and (iii) outline a staged implementation approach for military health systems. The framework is intended for policy design and local adaptation; it is not presented as a validated clinical prediction rule.

2. Evidence Acquisition

This work was designed as an expert review with a structured evidence search. PubMed/MEDLINE was searched from database inception through July 31, 2026, and supplemented by targeted searches of official sources from the Codex Alimentarius Commission, the North Atlantic Treaty Organization, the United States Department of Defense, the Defense Logistics Agency, and relevant standards organizations. For reproducibility in this revision, the PubMed search logic was reconstructed from the concepts used in the original search and recorded as follows: ((military[Title/Abstract] OR soldier*[Title/Abstract] OR "armed forces"[Title/Abstract]) AND (ration*[Title/Abstract] OR "combat feeding"[Title/Abstract] OR "field feeding"[Title/Abstract] OR "meal ready to eat"[Title/Abstract] OR MRE[Title/Abstract])) AND (nutrition*[Title/Abstract] OR intake[Title/Abstract] OR energy[Title/Abstract] OR acceptab*[Title/Abstract] OR palatab*[Title/Abstract] OR foodborne[Title/Abstract] OR hygiene[Title/Abstract] OR packag*[Title/Abstract] OR "shelf life"[Title/Abstract] OR temperatur*[Title/Abstract] OR traceab*[Title/Abstract] OR recall[Title/Abstract] OR readiness[Title/Abstract])). No language restrictions were imposed; the end date was July 31, 2026. Reference lists of directly relevant reviews on military nutrition and rations were also examined.

Eligible sources included field and laboratory studies involving military personnel or military rations; outbreak

investigations; ration acceptability and consumption studies; packaging and stability research with clear operational applicability; and authoritative standards or policy documents. Sources were excluded if they addressed only civilian retail foods without a transferable military implication, lacked sufficient methodological detail, or duplicated a more complete report. This was an expert review rather than a systematic review: sources were selected by the authors according to the stated eligibility and operational-relevance criteria, and evidence was organized by failure pathway rather than by study design. The final narrative synthesis included 28 sources. Because the original iterative search was not managed with a PRISMA-style deduplicated screening log, a defensible retrospective number of records screened cannot be reported; no estimated screening count was introduced during revision.

A meta-analysis was not appropriate because missions, climates, ration systems, exposure durations, and outcomes varied substantially. The synthesis therefore emphasizes direction and operational significance rather than a pooled effect estimate, with greater interpretive weight given to directly observed intake or expenditure, controlled feeding studies, documented outbreaks, and current official standards. Framework development followed four steps: recurrent failure pathways were identified from the evidence; candidate preventive controls and verification measures were mapped from empirical studies, Codex/hazard analysis and critical control points (HACCP), ISO principles, and military policies; overlapping controls were consolidated into five governance domains spanning mission requirements to health-readiness feedback; and each domain was translated into leading indicators, locally calibratable triggers, corrective actions, and accountable functions. Table 1 distinguishes the empirical or standards basis from the author-proposed integration. The five-domain structure, combined dashboard, and illustrative trigger-action examples are conceptual synthesis elements that require prospective validation.

3. Results

3.1. The Ration System as a Readiness Pathway

A military ration creates readiness value only after the completion of an uninterrupted pathway: mission requirements are translated into a specification; ingredients and packaging are procured; products are manufactured and released; lots are stored and distributed; meals are prepared or opened correctly; personnel consume sufficient food and fluid; and adverse health or performance signals are returned to decision-

Table 1. The Five-Domain Ration-to-Readiness (R2R) Implementation Matrix ^a

R2R Domains	Minimum Information and Leading Indicators	Evidentiary Basis and Example Accountable Function	Illustrative / Locally Calibrated Trigger and Action
Domain 1: Mission profiling	Data: duration, workload, climate, altitude, resupply, preparation resources, demographics, dietary constraints. Indicators: predicted energy range, meal opportunities, water/fuel burden, special-diet coverage.	Basis: military energy-intake evidence and alliance/policy guidance; domain integration is author-proposed. Example function: operations planning with nutrition / preventive medicine.	Profile outside the locally validated ration envelope -> tailor menu, supplement, meal schedule, or resupply plan.
Domain 2: Product and supplier assurance	Data: nutrient specification, hazard analysis, supplier status, process/packaging validation, field usability. Indicators: release nonconformities, sensory acceptance, packaging defects, corrective-action age.	Basis: Codex/HACCP, military policy, packaging and usability evidence; domain integration is author-proposed. Example function: procurement / quality assurance with food-safety inspection.	Defect cluster or failed release criterion -> hold lot, investigate, substitute, and verify closure.
Domain 3: Logistics integrity	Data: lot location, thermal history, inspection status, remaining shelf life, disposition. Indicators: excursions, damaged cases, condition-adjusted shelf-life exceptions, unlocated-lot percentage.	Basis: packaging and shelf-life evidence plus military policy and ISO food-safety/traceability principles. Example function: logistics / supply with food inspection.	Locally defined exposure limit exceeded -> segregate stock and conduct risk-based inspection / disposition.
Domain 4: Consumption assurance	Data: representative component intake, waste, preparation time, meal access, body-mass trend. Indicators: issued-to-consumed energy ratio, rejected items, missed meal opportunities.	Basis: military ration-intake and acceptability evidence; sampling approach and trigger values require local validation. Example function: unit leadership with nutrition / food service.	Persistent subgroup or mission-phase gap -> protect meal time, redesign menu, alter portions, or reassess preparation burden.
Domain 5: Health-readiness feedback	Data: enteric symptoms, duty loss, complaints, affected lots, investigation and corrective-action status. Indicators: same-unit symptom clusters, duty-loss days, time to lot hold, recurrence after closure.	Basis: outbreak/surveillance evidence and traceability standards; integrated dashboard and trigger-action loop are author-proposed. Example function: preventive medicine / medical surveillance with logistics and command.	Signal above a locally calibrated threshold -> clinical assessment, epidemiology, lot hold/recall, and after-action review.

^a Evidence- and standards-informed controls are cited in the accompanying text. The five-domain integration, example accountable functions, combined dashboard, and trigger-action examples are author-proposed. All trigger values should be prospectively calibrated to local mission risk, baseline rates, and response capacity before routine use. Abbreviation: HACCP, hazard analysis and critical control points.

makers. Failure at any stage can nullify the quality achieved upstream.

Three distinctions are central. First, availability is not intake: issued kilocalories are a logistics measure, not a physiological exposure. Second, shelf life is conditional: the same calendar age can represent different remaining quality after temperate versus hot storage. Third, the absence of a reported outbreak is not equivalent to control: under-reporting, self-treatment, dispersed cases, and delayed laboratory confirmation may obscure a readiness-relevant signal. Table 2 translates these distinctions into auditable failure pathways.

3.2. Nutritional Adequacy Must Be Measured at the Point of Consumption

Military energy expenditure varies widely by task and environment. Reviews and field studies describe requirements that may exceed standard garrison needs during prolonged load carriage, cold-weather training, or special operations (1-4). In a Canadian Arctic-like exercise, approximately 5,685 kcal/d were available, whereas mean intake was only about 2,377 kcal/d, illustrating the large gap that may separate ration provision from consumption (3). British officer cadets also developed low energy availability during training, and a recent Reserve Officer Training Corps field exercise reported mean deficits of approximately 1,350 kcal/d in men and 975 kcal/d in women

(4, 5). These values are not universal thresholds, but they demonstrate why issue records alone cannot verify nutritional support.

Nutrient density adds a second layer. Canadian personnel consuming field rations achieved energy intakes similar to their home diets in one short exercise, yet inadequacies remained for selected micronutrients and food groups (8). A controlled 21-day Meal, Ready-to-Eat (MRE) trial found that a modern ration could maintain most measured nutritional and cardiometabolic indicators in healthy adults, supporting the value of sound formulation and fortification (9). However, the same controlled setting cannot reproduce missed meals, ration trading, menu rejection, or the increased requirements associated with field stress. Controlled adequacy and operational effectiveness should therefore be treated as complementary, not interchangeable, evidence.

Protein distribution, carbohydrate availability, iron status, calcium, vitamin D, and other micronutrients warrant mission-specific attention. Severe energy deficit accelerates loss of body mass and fat-free mass and can impair recovery, immunity, mood, and cognition; higher protein intake may attenuate, but cannot fully correct, inadequate energy intake (10, 11, 12). Needs and menu-use patterns also vary by sex, body size, and dietary restriction. Policy should specify both nutrient composition and representative intake sampling by task, environment, and mission phase.

Table 2. Failure Pathways Linking Ration-System Weaknesses to Readiness Consequences^a

Failure Pathways	Operational Mechanism	Readiness Consequence	Primary Controls and Verification
Requirement mismatch	One ration specification is applied across dissimilar workloads, climates, durations, or dietary needs.	Under-fueling, excess carriage weight, nutrient gaps, or avoidable waste.	Mission profile; measured expenditure/intake samples; sex- and task-stratified review.
Underconsumption	Limited meal time, poor temperature or palatability, menu fatigue, preparation burden, or inaccessible packaging.	Negative energy balance, impaired recovery, lower morale, and discarded food.	Component-level intake/waste; field acceptability; preparation-time and meal-opportunity audit.
Food contamination	Unsafe water; ill handlers, cross-contamination, inadequate cooking, or time-temperature abuse.	Clustered enteric illness, evacuation, diagnostic burden, and duty loss.	GHP/HACCP; water and sanitation checks; handler health; symptom-cluster triggers.
Product degradation	Heat, oxygen, freeze-thaw cycles, seal damage, pests, or mechanical stress.	Loss of safety, nutrient quality, acceptability, and user confidence.	Environmental qualification; data loggers/indicators; seal inspection; lot sampling.
Traceability failure	Lot identity is lost between supplier, warehouse, unit issue, and consumption.	Delayed containment, overbroad disposal, persistent exposure, and supply disruption.	Common identifiers; offline records; mock recalls; time-to-containment metric.
Feedback failure	Medical, complaint, waste, and logistics data remain in separate reporting channels.	Repeated defects and slow recognition of a system-level risk.	Joint dashboard; named owners; action thresholds; corrective-action closure audit.

^a Abbreviations: GHP, good hygiene practices; HACCP, hazard analysis and critical control points.

3.3. Acceptability and Usability Are Safety-Critical Design Variables

Palatability is sometimes treated as a secondary consumer preference, but in operational settings it governs dose: food that is discarded or exchanged delivers no nutrient value. A national survey of Canadian soldiers with Arctic experience found that food temperature, eating while moving, exercise schedules, and preparation equipment were key constraints; participants reported consuming only 61% - 71% of their rations, and 65% reported weight loss (13). Early military research similarly identified monotony, portion burden, limited eating time, and the effort required for preparation as causes of underconsumption (14).

Acceptability should be tested under representative field conditions, not by central-location taste panels alone. Useful outcomes include component consumption, preparation time, water and fuel requirements, opening with gloves, packaging litter, menu trading, gastrointestinal tolerance, and repeat acceptability. Protected meal opportunities and permission to eat during long tasks can be as important as formulation.

The design objective is not maximal liking; it is reliable consumption of a nutritionally appropriate amount without creating excessive preparation, waste, or food-safety risk. Menu variety, culturally acceptable options, vegetarian and medically indicated alternatives, and component-level modularity can improve this reliability. Procurement scoring should therefore include field consumption and usability alongside unit price, nutrient specification, and laboratory shelf-life results.

3.4. Food Safety Events Can Become Operational Events

Foodborne disease produces more than clinical morbidity. Clusters can remove multiple members of a unit at the same time, consume evacuation and diagnostic capacity, and reduce trust in the feeding system. A review of French armed forces surveillance from 1999 - 2009 identified 180 foodborne outbreaks involving 4,848 cases, with higher rates in overseas settings (15). Investigations in other forces have linked outbreaks to institutional kitchens, mass feeding, and deployed operations (16-18). Prospective and molecular studies also demonstrate that travelers' diarrhea and other enteric syndromes remain common enough to require active prevention and surveillance (19, 20).

Operational feeding combines several hazards: uncertain water quality, disrupted cold chains, bulk preparation, cross-contamination, inadequate hand hygiene, damaged packaging, pests, and pressure to retain food after time or temperature limits have been exceeded. The appropriate control model is preventive. The Codex General Principles of Food Hygiene integrate prerequisite good-hygiene practices with HACCP, requiring hazards to be identified, controlled, monitored, verified, and documented (21). Military adaptation must define who may release a lot, who can condemn food in the field, how safe water and sanitation are verified, and how operations continue when a control fails.

Surveillance should capture more than laboratory-confirmed outbreaks. Early indicators include same-unit clustering of vomiting or diarrhea, unexpectedly high use of antidiarrheal medication, food-handler illness, temperature excursions, packaging complaints, and repeated rejection of a specific lot. A low-burden reporting channel for medics, food-service staff, and commanders can shorten the interval from symptom onset to lot hold,

epidemiologic assessment, and corrective action. Duty-loss days and mission restrictions are particularly useful readiness outcomes.

3.5. Packaging and Shelf Life Are Environmental Controls

Operational packaging must preserve microbiological safety, nutrient content, sensory quality, and mechanical integrity while remaining light and usable. Studies of oxygen-absorbing systems, retort foods, frozen rations, and chocolate show that oxygen exposure, thermal history, freeze-thaw cycling, and tropical storage can change product quality and spoilage risk (22-25). These effects may occur before a package reaches its printed end date. Conversely, a properly controlled lot may remain fit throughout its validated shelf life.

Calendar-based stock rotation is therefore weaker than condition-informed control. Time-temperature indicators, warehouse and vehicle data loggers, inspection of seal and barrier defects, and statistically designed lot sampling can estimate remaining shelf life more accurately (26). The control system should distinguish safety failure from loss of quality or acceptability, because each requires a different disposition. Current MRE guidance illustrates the specification approach: a complete meal is designed to provide roughly 1,250 kcal and a three-year shelf life at 80°F, but its actual serviceability still depends on storage history and inspection.

Environmental qualification should represent the intended mission. Products destined for prolonged hot storage, high altitude, maritime environments, or repeated air transport require stress profiles and packaging tests that match those conditions. Procurement contracts should state sampling plans, acceptance criteria, accelerated and real-time stability requirements, and responsibilities for investigation when complaints cluster by lot.

3.6. Traceability and Surveillance Close the Control Loop

A ration system cannot manage a hazard it cannot locate. Minimum traceability should link the supplier, production lot, inspection and release status, storage location, unit issue, and disposition. Codex, ISO food-safety management, and ISO traceability principles support risk-based documentation and rapid withdrawal (21). Military policies similarly link nutrition standards, food-service safety, inspection, and combat-feeding research, although exact organizational arrangements vary.

The key test is whether a suspect lot can be identified, held, located across dispersed units, and reconciled within an operationally meaningful period. Mock recalls should measure time to containment, stock located, quantity

consumed or destroyed, and corrective-action closure. Offline capability is essential where connectivity is unreliable.

The same identifiers should link complaints and medical signals to lots. This creates a learning system: a rise in gastrointestinal symptoms, packaging defects, or component waste can trigger a targeted hold or investigation, while a recurring underconsumption pattern can lead to menu redesign, changes in portioning, or altered meal schedules.

3.7. The Ration-to-Readiness Framework

The proposed R2R framework organizes governance into five domains (Table 1). Its structure was derived by grouping the recurrent failure pathways in Table 2 into a sequential control chain: mission requirement, product release, logistics preservation, actual consumption, and health-readiness feedback. Empirical military studies and authoritative standards support many component controls, whereas the five-domain integration, example ownership assignments, and trigger-action architecture are author-proposed synthesis elements. Table 1 makes that evidentiary status explicit. The first domain, mission profiling, defines the nutritional and operational requirement using duration, task intensity, climate, altitude, resupply, preparation resources, demographic composition, and dietary constraints. Published standards and alliance examples can inform planning, but widely cited targets must be adjusted to local measurement and mission reality.

The second domain, product and supplier assurance, combines nutrient specification, sensory and usability testing, supplier qualification, process control, packaging validation, and lot release. The third domain, logistics integrity, protects the released product through condition-aware storage, transport monitoring, first-expired-first-out rotation, inspection, and documented exception management. These controls are primarily standards- and evidence-informed; their consolidation into adjacent R2R domains is part of the proposed governance model.

The fourth domain, consumption assurance, assesses whether personnel can and do eat the ration. This does not require continuous individual surveillance. Representative unit sampling - short weighed-waste studies, structured component return counts, rapid digital diaries, and pre/post exercise body-mass trends - can identify systematic gaps. Results should be stratified by mission phase and relevant personnel characteristics without turning nutrition monitoring into punitive performance management. Trigger values in this domain are illustrative and should be calibrated to local baselines and mission risk.

The fifth domain, health-readiness feedback, integrates preventive-medicine, clinical, logistics, and user data. A small dashboard can combine enteric illness incidence, duty-loss days, packaging defects, lot complaints, recall performance, and consumption indicators. Each measure requires a locally assigned accountable function and a pre-agreed, locally calibrated trigger. A trigger initiates a bounded response - such as enhanced sampling, a temporary lot hold, menu substitution, protected meal time, or a formal outbreak investigation - followed by documented closure.

The framework is deliberately based on closed loops. Specifications are revised using field evidence; suppliers receive lot-level feedback; logistics decisions account for environmental exposure; and commanders receive a readiness-relevant interpretation rather than isolated nutrition or inspection data. This approach makes ration governance an operational risk process rather than a sequence of unconnected technical checks. The proposed ownership arrangements and action thresholds should be treated as testable implementation hypotheses rather than validated universal rules.

3.8. Staged Implementation in Military Health Systems

Implementation can begin without a new enterprise information system. In phase 1, a multidisciplinary steering group maps the existing process from specification to medical reporting, assigns locally accountable functions, and selects a limited dashboard. Baseline process measures should include lot-traceability completeness, handling of temperature excursions, timeliness of corrective-action closure, component waste or consumption sampling, gastrointestinal-illness reporting, complaints, and duty loss. The accountable function may differ by force structure; [Table 1](#) therefore lists examples rather than mandatory organizational titles.

Phase 2 should pilot the framework in one high-risk setting, such as a hot-weather exercise, a remote training area, a ship, or a prolonged field deployment. A minimum prospective evaluation set should cover five dimensions: process (traceability completeness, time to containment, corrective-action closure); health (enteric-symptom incidence or clusters); readiness (duty-loss days, missed meal opportunities, and relevant body-mass/performance trends); cost (waste, disposal, emergency resupply, investigation, and staff time); and equity (special-diet coverage and subgroup differences in meal access or consumption). Feasibility assessments should also document missing data, staff workload, reporting burden, time-to-action, and unintended consequences such as operational delay or reduced trust in monitoring.

Phase 3 should scale only elements that are feasible, change decisions, or demonstrate a favorable risk-benefit profile, while standardizing identifiers, training, audit methods, and after-action review. Lower-capacity settings need not deploy continuous digital surveillance: sentinel sampling, paper or offline registers, periodic component-return counts, and a small spreadsheet dashboard can support the same control logic. Unit-level or de-identified indicators should be preferred; any necessary individual-level data should be minimized, access-controlled, retained only as required, and separated from disciplinary decision-making. Implementation therefore requires protected staff time, basic training in nutrition/food safety and data handling, clear authority for lot holds and outbreak response, and locally appropriate privacy governance ([Table 3](#)).

3.9. Interpretation, Limitations, and Research Priorities

The available evidence supports a simple conclusion: ration effectiveness cannot be inferred from nutrient composition or quantities issued. Field data repeatedly show underconsumption during demanding training ([3](#), [4](#), [5](#), [8](#), [13](#)), whereas controlled feeding demonstrates that well-designed shelf-stable rations can maintain short-term nutrient status in healthy adults ([9](#)). These findings are not contradictory; they locate the implementation gap between formulation and use. The same logic applies to food safety: validated processing and packaging are essential, but field hygiene, thermal history, traceability, and rapid surveillance determine whether protection persists.

The R2R framework extends existing standards by adding two links that are often weak: consumption assurance and explicit readiness feedback. It also treats acceptability as a control variable. This is important because an unpopular but nutrient-complete component can produce predictable under-fueling, and an unnecessarily complex preparation step can create both consumption and hygiene failures. A systems view encourages trade-offs to be evaluated before procurement: for example, a slightly higher unit cost may be justified when a product reduces waste, fuel use, preparation time, or duty loss. Conversely, adding calories without validating consumption may increase weight and waste without improving energy balance.

Health information must be used proportionately. Unit-level or de-identified indicators are usually sufficient; necessary individual data should be protected and separated from disciplinary decisions. Monitoring should detect system failure, not blame personnel for food that was inaccessible, unacceptable, or impractical.

Table 3. Minimum Evaluation Set for Prospective R2R Pilot Testing

Evaluation Dimension	Minimum Pilot Indicators	Interpretation / Feasibility Question
Process	Traceability completeness; time to lot containment; temperature-excursion handling; corrective-action closure.	Can the control be performed reliably and quickly with available staff and systems?
Health	Enteric symptom incidence or same-unit clusters; food-handler illness; adverse-event reporting.	Does surveillance identify actionable safety signals without excessive reporting burden?
Readiness	Duty-loss days; missed meal opportunities; representative body-mass or performance trends where appropriate.	Are observed signals temporally and operationally relevant to mission performance?
Cost	Ration waste/disposal; emergency resupply; investigation costs; staff time; avoidable stock loss.	Do avoided losses or improved decisions justify implementation resources?
Equity	Special-diet coverage; subgroup differences in meal access, consumption, or adverse effects.	Does implementation benefit mission-relevant subgroups without creating systematic access gaps?

Several evidence limitations remain. Many studies have small samples, short exercises, male-dominant cohorts, self-reported intake, or ration systems specific to one country. Laboratory shelf-life findings do not fully reproduce combined field stressors, and outbreak surveillance underestimates unreported disease. Controlled MRE studies also show that processed ration diets can alter gut microbial composition without necessarily increasing inflammation or intestinal permeability, but the operational significance of these changes remains uncertain (27, 28). In addition, the R2R framework is an author-developed conceptual synthesis: the consolidation into five domains, ownership examples, dashboard structure, and trigger-action rules have not undergone external validation or prospective calibration. They may therefore reflect interpretive choices and may not transfer unchanged across forces, climates, missions, data systems, or resource settings. Consequently, the framework should be validated against illness, duty loss, body-mass and performance trends, waste, cost, user confidence, feasibility, and equity before broad implementation.

Priority research includes multicenter evaluation across climates; sex- and task-stratified intake; comparison of consumption-monitoring methods; validation of time-temperature and remaining-shelf-life models; and economic evaluation including waste and duty loss. Cluster-randomized or stepped-wedge designs may suit meal-time, menu, or traceability interventions. Reports should identify ration version, thermal history, available and consumed energy, mission schedule, environment, and demographic composition.

4. Conclusions

Operational rations should be managed as a military health and readiness system. Compliance at manufacture or issue is only the starting point; safety and nutritional value must be maintained throughout logistics,

preparation, and real-world consumption. The five-domain R2R framework links mission profiling, product and supplier assurance, logistics integrity, consumption assurance, and health-readiness feedback through measurable indicators, example accountable functions, and locally calibrated corrective actions.

Military health systems can begin with a small pilot, common lot identifiers, representative intake measurement, mock recalls, and a joint after-action process. Prospective external validation is required before adopting universal thresholds or attributing outcome improvements to the framework. Reframing the governing question from “Was a ration issued?” to “Did the feeding system safely sustain the force?” provides a testable basis for evaluating whether integrated ration governance can reduce under-fueling, enteric disease, waste, and mission disruption.

Acknowledgements

The authors thank AJA University of Medical Sciences for scientific and educational support and for providing research infrastructure. This acknowledgment does not indicate financial sponsorship.

Footnotes

AI Use Disclosure: OpenAI’s ChatGPT was used extensively for conceptual refinement of the R2R framework; drafting and language editing of the Abstract, Context, Evidence Acquisition, Results, Discussion, and Conclusions sections; initial reference suggestions; and manuscript formatting. It was not used to generate primary data or figures. All authors critically reviewed, corrected, and verified the scientific content and references, and they accept full responsibility for the final manuscript.

Authors' Contribution: Study concept and design: A. N.; Methodological input: M. C. and M. D.; Acquisition of data and literature: A. N., M. C., and M. D.; Analysis and interpretation of evidence: A. N., M. C., and M. D.; Drafting of the manuscript: A. N.; Critical revision of the manuscript for important intellectual content: M. C. and M. D., with final revision by A. N.; Statistical analysis: Not applicable, as this Expert Review involved no meta-analysis or quantitative statistical synthesis; Administrative and technical support: M. D.; Study supervision: A. N. All authors critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Conflict of Interests Statement: The authors do not declare any conflicts of interests for this study.

Data Availability: No new dataset was generated or analyzed for this review.

Funding/Support: This work received no specific grant or external funding.

References

- Tharion WJ, Lieberman HR, Montain SJ, Young AJ, Baker-Fulco CJ, DeLany JP, et al. Energy requirements of military personnel. *Appetite*. 2005;**44**(1):47-65. [PubMed ID: 15604033]. <https://doi.org/10.1016/j.appet.2003.11.010>.
- Margolis L, Crombie A, McClung H, McGraw S, Rood J, Montain S, et al. Energy requirements of U.S. Army Special Operation Forces during military training. *Nutrients*. 2014;**6**(5):1945-1955. [PubMed ID: 24824290]. [PubMed Central ID: PMC4042567]. <https://doi.org/10.3390/nu6051945>.
- Ahmed M, Mandic I, Desilets E, Smith I, Sullivan-Kwantes W, Jones PJ, et al. Energy balance of Canadian Armed Forces personnel during an Arctic-like field training exercise. *Nutrients*. 2020;**12**(6):1638. [PubMed ID: 32498229]. [PubMed Central ID: PMC7352380]. <https://doi.org/10.3390/nu12061638>.
- Edwards VC, Myers SD, Wardle SL, Siddall AG, Powell SD, Needham-Beck S, et al. Nutrition and physical activity during British Army officer cadet training: Part 1-energy balance and energy availability. *Int J Sport Nutr Exerc Metab*. 2022;**32**(3):195-203. [PubMed ID: 35393372]. <https://doi.org/10.1123/ijsnem.2021-0190>.
- Frick KA, Bordonie NC, Clouse KG, Roberts MD, Frugé AD, Wadsworth DD, et al. Energy expenditure exceeds nutritional intake of ROTC members during a field training exercise. *J Funct Morphol Kinesiol*. 2025;**11**(1):3. [PubMed ID: 41562721]. [PubMed Central ID: PMC12821694]. <https://doi.org/10.3390/jfmk11010003>.
- Sotelo-Díaz I, Blanco-Lizarazo CM. A systematic review of the nutritional implications of military rations. *Nutr Health*. 2019;**25**(2):153-161. [PubMed ID: 30623731]. <https://doi.org/10.1177/0260106018820980>.
- Lenferna De La Motte KA, Schofield G, Kilding H, Zinn C. An alternate approach to military rations for optimal health and performance. *Mil Med*. 2023;**188**(5 - 6):e1102-e1108. [PubMed ID: 34908149]. <https://doi.org/10.1093/milmed/usab498>.
- Ahmed M, Mandic I, Lou W, Goodman L, Jacobs I, L'Abbé MR. Dietary intakes from ad libitum consumption of Canadian Armed Forces field rations compared with usual home dietary intakes and military dietary reference intakes. *Mil Med*. 2023;**188**(1 - 2):e205-e213. [PubMed ID: 34117489]. <https://doi.org/10.1093/milmed/usab222>.
- McClung HL, Armstrong NJ, Hennigar SR, Staab JS, Montain SJ, Karl JP. Randomized trial comparing consumption of military rations to usual intake for 21 consecutive days: nutrient adequacy and indicators of health status. *J Acad Nutr Diet*. 2020;**120**(11):1791-1804. [PubMed ID: 32828737]. <https://doi.org/10.1016/j.jand.2020.06.018>.
- O'Leary TJ, Wardle SL, Greeves JP. Energy deficiency in soldiers: the risk of the athlete triad and relative energy deficiency in sport syndromes in the military. *Front Nutr*. 2020;**7**: 142. [PubMed ID: 32984399]. [PubMed Central ID: PMC7477333]. <https://doi.org/10.3389/fnut.2020.00142>.
- Pasiakos SM, Cao JJ, Margolis LM, Sauter ER, Whigham LD, McClung JP, et al. Effects of high-protein diets on fat-free mass and muscle protein synthesis following weight loss: a randomized controlled trial. *FASEB J*. 2013;**27**(9):3837-3847. [PubMed ID: 23739654]. <https://doi.org/10.1096/fj.13-230227>.
- Gaffney-Stomberg E, Lutz LJ, Rood JC, Cable SJ, Pasiakos SM, Young AJ, et al. Calcium and vitamin D supplementation maintains parathyroid hormone and improves bone density during initial military training: a randomized, double-blind, placebo-controlled trial. *Bone*. 2014;**68**:46-56. [PubMed ID: 25118085]. <https://doi.org/10.1016/j.bone.2014.08.002>.
- Lavergne FV, Laroche-Nantel R, Prud'Homme D, Giroux I. Facteurs influençant l'apport alimentaire en rations des soldats canadiens dans l'Arctique: un sondage national [Factors influencing ration intake of Canadian soldiers in the Arctic: a national survey; article in French]. *Can J Diet Pract Res*. 2023;**84**(1):54-57. [PubMed ID: 36004738]. <https://doi.org/10.3148/cjdp-2022-021>.
- National Academies Press. *Not Eating Enough*. Washington, DC: National Academies Press; 1995. <https://doi.org/10.17226/5002>.
- Mayet A, Manet G, Decam C, Morisson D, Bédubourg G, Pommier de Santi V, et al. Epidemiology of food-borne disease outbreaks in the French armed forces: a review of investigations conducted from 1999 to 2009. *J Infect*. 2011;**63**(5):370-374. [PubMed ID: 21840337]. <https://doi.org/10.1016/j.jinf.2011.08.003>.
- Mustafa MS, Jain S, Agrawal VK. Food poisoning outbreak in a military establishment. *Med J Armed Forces India*. 2009;**65**(3):240-243. [PubMed ID: 27408256]. [PubMed Central ID: PMC4921362]. [https://doi.org/10.1016/S0377-1237\(09\)80013-0](https://doi.org/10.1016/S0377-1237(09)80013-0).
- Schwaber MJ, Grotto I, Balicer RD, Davidovitch N, Zelikovitch Y, Huerta M. Infectious diarrheal outbreaks in the Israeli military, 1988-2002. *Mil Med*. 2005;**170**(7):634-637. [PubMed ID: 16130648]. <https://doi.org/10.7205/MILMED.170.7.634>.
- Mccown M, Grzeszak B. Public health foodborne illness case study during a Special Operations Forces deployment to South America. *J Spec Oper Med*. 2010;**10**(4):45-47. [PubMed ID: 21442591]. <https://doi.org/10.55460/FVEV-P2ND>.
- Riddle MS, Rockabrand DM, Schlett C, Monteville MR, Frenck RW, Romine M, et al. A prospective study of acute diarrhea in a cohort of United States military personnel on deployment to the multinational force and observers, Sinai, Egypt. *Am J Trop Med Hyg*. 2011;**84**(1):59-64. [PubMed ID: 21212203]. [PubMed Central ID: PMC3005493]. <https://doi.org/10.4269/ajtmh.2011.10-0093>.
- Walters WA, Reyes F, Soto GM, Reynolds ND, Fraser JA, Aviles R, et al. Epidemiology and associated microbiota changes in deployed military personnel at high risk of traveler's diarrhea. *PLoS One*. 2020;**15**(8): e0236703. [PubMed ID: 32785284]. [PubMed Central ID: PMC7423091]. <https://doi.org/10.1371/journal.pone.0236703>.
- FAO and WHO. *General Principles of Food Hygiene*. Rome: Codex Alimentarius Commission; 1969. <https://doi.org/10.4060/cc6125en>.

22. Gomes C, Castell-Perez ME, Chimbombi E, Barros F, Sun D, Liu JD, et al. Effect of oxygen-absorbing packaging on the shelf life of a liquid-based military operational ration component. *J Food Sci.* 2009;**74**(4):E167-E176. [PubMed ID: 19490321]. <https://doi.org/10.1111/j.1750-3841.2009.01120.x>.
23. Karthikeyan JS, Desai KM, Salvi D, Bruins R, Schaffner DW, Karwe MV. Effect of temperature abuse on frozen army rations: Part 2- predicting microbial spoilage. *Food Res Int.* 2015;**76**(Pt 3):587-594. [PubMed ID: 28455041]. <https://doi.org/10.1016/j.foodres.2015.07.012>.
24. Bui LTT, Coad R. Military ration chocolate: the effect of simulated tropical storage on sensory quality and acceptability. *Food Chem.* 2014;**160**:365-370. [PubMed ID: 24799250]. <https://doi.org/10.1016/j.foodchem.2014.03.084>.
25. Catauro PM, Perchonok MH. Assessment of the long-term stability of retort pouch foods to support extended duration spaceflight. *J Food Sci.* 2012;**77**(1):S29-S39. [PubMed ID: 22260129]. <https://doi.org/10.1111/j.1750-3841.2011.02445.x>.
26. Albrecht A, Ibaldo R, Raab V, Reichstein W, Haarer D, Kreyenschmidt J. Implementation of time temperature indicators to improve temperature monitoring and support dynamic shelf-life in food logistics. *J Packag Technol Res.* 2020;**4**(1):23-32. [PubMed ID: 32685915]. [PubMed Central ID: PMC7357777]. <https://doi.org/10.1007/s41783-019-00080-x>.
27. Karl JP, Armstrong NJ, McClung HL, Player RA, Rood JC, Racicot K, et al. A diet of U.S. military food rations alters gut microbiota composition and does not increase intestinal permeability or inflammation. *J Nutr Biochem.* 2019;**72**: 108217. [PubMed ID: 31473505]. <https://doi.org/10.1016/j.jnutbio.2019.108217>.
28. Karl JP, Armstrong NJ, Player RA, Rood JC, Soares JW, McClung HL. The fecal metabolome links diet composition, food processing, and the gut microbiota to gastrointestinal health in a randomized trial of adults consuming a processed diet. *J Nutr.* 2022;**152**(11):2343-2357. [PubMed ID: 36774101]. <https://doi.org/10.1093/jn/nxac161>.