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Abstract

Personalised nutrition (PN) has advanced rapidly in digital assessment and advice, yet translation into scalable, real-world production of foods that are tailored to individual needs remains a key challenge. We present a comprehensive digital PN service that integrates data-driven nutrition advice with a flexible food manufacturing platform, enabling the production of foods tailored in nutritional composition, micronutrient content, product size, texture, flavour and colour on-demand: about 230,000 different personalised food products could be produced. This system was implemented in three distinct field labs, including a military setting, a hospital, and an elite female athletes cohort, demonstrating technical feasibility, sensory acceptance, and consumer engagement. Our findings support the technological flexibility and viability of PN food manufacturing, highlight consumer acceptance challenges, and identify directions for future research toward scalable, health-promoting personalised foods. We introduce a novel framework for adaptive food manufacturing, potentially transforming how future food systems respond to population heterogeneity.

Main: Scientific Integration of Data-Driven Nutrition Advice and Smart Food Production in Field Lab Studies

Individuals exhibit substantial variability in their physiological responses to foods and nutrients, as well as in their preferences, behaviours and psychological-social context. Even genetically identical twins can show markedly different metabolic responses to identical meals, illustrating the limits of uniform dietary recommendations[1]. These insights have stimulated the emergence of personalised nutrition (PN), which aims to tailor dietary strategies to individual biological, behavioural and contextual characteristics to optimise health and performance[2, 3]. Evidence suggests that PN can improve dietary behaviours more effectively than generic approaches, with modest benefits for cardiometabolic health[4-6].

Although the concept of tailoring diets to individual characteristics is longstanding, the current form of PN has emerged since the mid-2000s, driven by advances in omics technologies, data science, artificial intelligence (AI) and digital nutrition and lifestyle platforms that provide personalised advice on meal plans and supplements[7-9]. These digital services enable consumers to monitor dietary intake, health and other lifestyle behaviours. At the same time, scientific focus has shifted from single gene polymorphism-based nutrition advice towards more holistic systems biology approaches that integrate biological, physiological and social data[10].

Despite these technological advances, translating data-driven insights into sustained dietary behaviour change continues to be a major bottleneck. Many consumers have difficulties to adhere to a healthy diet and sustain motivation over time. Research indicates that food choices are predominantly influenced by convenience, personal preferences and everyday habits, rather than by deliberate health considerations[11, 12].

Recent evidence suggests that embedding personalised nutrition in tangible food formats may substantially lower the behavioural and cognitive burden associated with implementing dietary advice in daily life[13]. These findings highlight the need for food production systems that can translate personal requirements directly into physical food products that are personalised and convenient. However, current food production systems are optimised for scale, efficiency and standardisation, targeting population groups rather than individuals. Therefore, fully personalised food cannot be produced at scale.

In response to these challenges and opportunities, this study details the development of a comprehensive methodology for the design, manufacturing, and delivery of personalised nutrition products using a flexible food manufacturing platform (FFMP). Our approach, as depicted in figure 1, begins with the collection and integration of personal data and preferences, enabling the prediction and generation of individual nutritional requirements. These requirements are fulfilled by a Personalised Nutrition Product (PNP) as a nutritious in-between meal, designed as a composite product allowing wide nutritional flexibility by varying composition, portion size, texture, and flavour. The manufacturing process of PNP employs 3D food printing technology, chosen for its capacity to create varied 3D fillable shapes from interchangeable materials, and to enable automated, digital-driven production. Combined with precise dosing, robotics and process automation, an unprecedented number of food product variations can be created. The workflow and manufacturing process developed are shown in Supplementary Video.

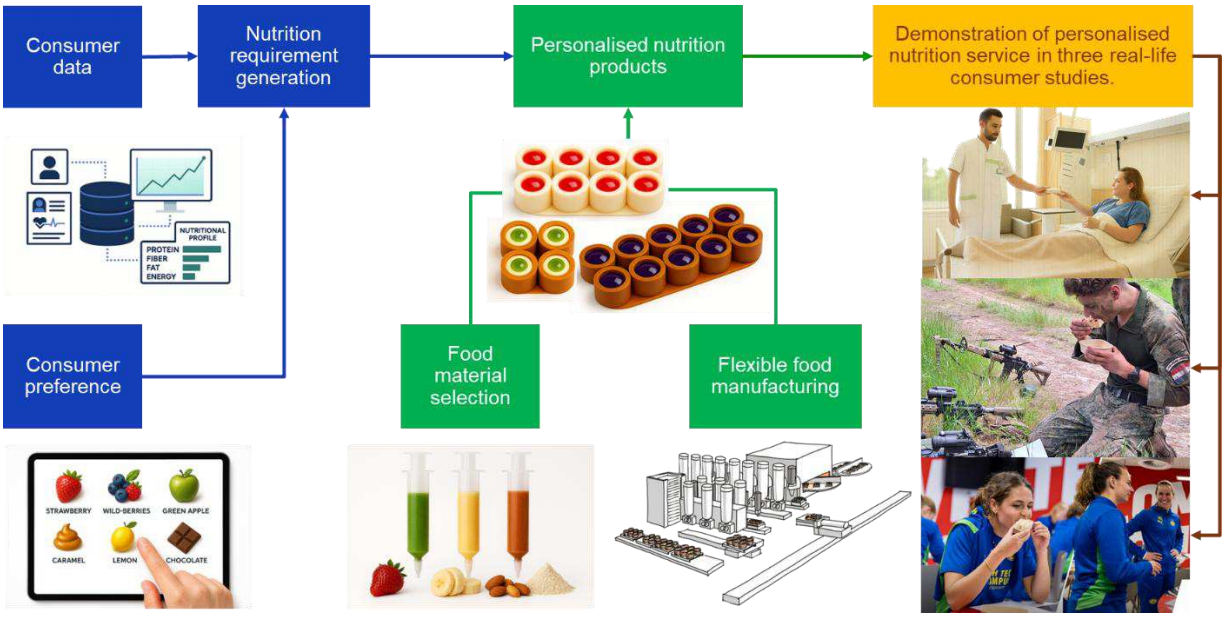


Figure 1. Workflow of the personalised nutrition service developed

The feasibility of the entire PN service was demonstrated and evaluated in three real-world field labs with distinct requirements: a military cohort (n=25, 2 weeks) focused on performance[14]; a hospital setting (n=87) supporting recovery and wellbeing[15]; and an elite female athlete group (n=22, 3 days) addressing menstrual complaints. Sensory acceptance, consumer engagement with the technology and service, and feedback from food and nutrition professionals were systematically collected and analysed. The results of these diverse use cases demonstrated the flexibility and viability of the technology, as well as consumer acceptance challenges and opportunities for further research toward scalable, health-promoting personalised foods.

Results

From a personalised nutrition advice to a food composition target

To translate PN advice into a concrete food composition target, we adopted the strategy described by Hoogh[16] as a starting point and extended it to enable direct coupling with food formulation and manufacturing constraints. This translation was applied across three distinct use cases: a hospital setting focused on patient wellbeing and recovery, a military setting focused on physical and cognitive performance in the field, and an elite female sports setting addressing performance in combination with hormonal and menstrual health.

For each use case, health benefit domains were defined in close collaboration with local stakeholders and field lab owners, ensuring alignment with context specific physiological and practical requirements. Across settings, these domains broadly included muscle health, immune and gut health, and mental performance, while their relative importance differed. Individual data that could be feasibly and ethically collected were subsequently selected to inform these domains. In the military and female athlete contexts, this included anthropometric and demographic characteristics, validated short dietary intake screeners and health questionnaires, whereas in the hospital setting the dominant health benefit domain was selected by healthcare professionals based on available clinical data.

PN recommendations were subsequently translated into quantitative food composition targets using a rule based reasoning framework and expressed as target ranges for energy density and macro- and micronutrient content. This translation was guided by evidence-based sources such as health claims, systematic reviews, meta-analyses and expert guidelines, while simultaneously accounting for formulation feasibility and the operational limits of the flexible food manufacturing platform. Crucially, nutritional targets were not defined independently of the food product, but were directly linked to predefined material formulations including doughs, fillings, micronutrient powders and sensory options, as described in the next section. By integrating personal data, health benefit domains, formulation rules

and flavour selection into a single algorithm, this approach generated executable product specifications that could be directly realised through the flexible manufacturing process.

The design concept of PNP

With PNP we aimed to fulfil a wide variety of food composition targets; empower consumers choice; and provide a fresh, multi-texture eating experience. The design concept developed to achieve each aspect is depicted in figure 2.

The casing was 3D printed into cylindrical unit cells with a closed bottom, providing a firm base for the PNP. After optional baking to achieve the desired texture and firmness, fillings were deposited in the cavities of the casing. Both casing and filling materials contain variable macronutrient compositions, including proteins, carbohydrates, dietary fibres, and fat. Optionally, micronutrient powders such as vitamins, minerals and bioactive compounds can be dosed at the bottom of the casing to achieve specific micronutrient compositions. The portion size can be changed by the amount of unit cells of the product. Finally, a topping was dosed in small amount, not for nutritional purpose but to empower the consumer to choose flavour, colour and taste based on their personal preferences, since consumer empowerment and participation in the food creation process are hypothesised to contribute to consumer acceptance of the technology and diet intervention[17].

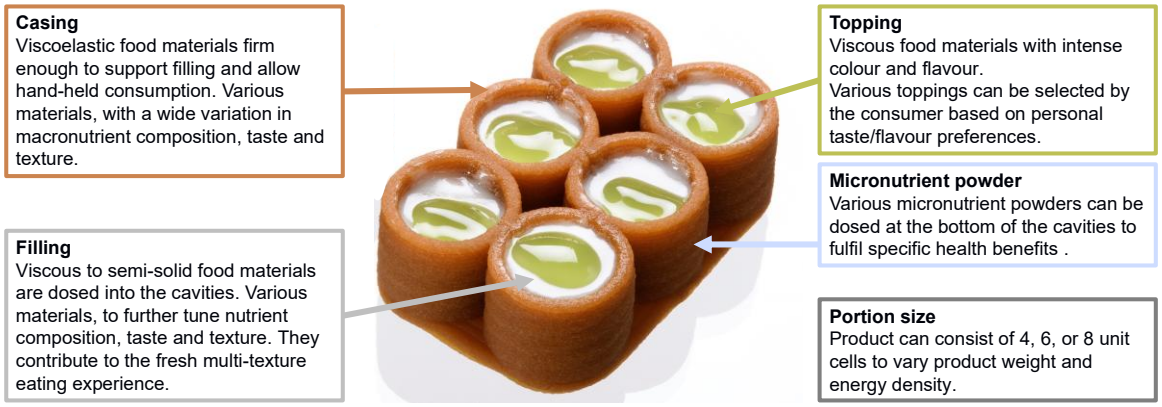


Figure 2. Design concept of a personalised nutrition product (PNP).

Development of food materials for nutrient flexibility

Three main categories of casing material were developed: cereal dough – rich in carbohydrates and energy; protein bar – high in protein with complete amino acid composition; and cellular ink – based on fruit or vegetable cell wall materials and rich in dietary fibres. These casings cover a wide variation of nutritional values, which were further expanded by variants with specific ingredients linked to support certain health benefit domains. For example, a cereal dough rich in almond was developed to achieve a material rich in tree-nuts and poly-unsaturated fatty acids for the benefit domain immune health. A cellular ink was formulated based on dried plum and was high in soluble fibres for the benefit domain gut health. Beta-glucan and soluble corn fibre were included in several casing formulations to increase dietary fibre content and at the same time achieve sugar reduction.

Since the casings were 3D printed, the development of these casing formulations was guided by physics-based approaches to ensure a robust printability. The materials developed were yield-stress fluids, characterised and modelled by rheology[18]. The print quality was evaluated by image analysis[19]. The food engineering approaches combined provided a wide freedom between nutritional compositions and product texture[20].

Fillings with a wide variety of food material compositions, taste and texture were designed to expand the nutritional diversity further, and to contribute to the palatability of the PNP. Selected food materials included chocolate ganache, peanut butter, fruit purees and liquid dairy-like fillings, each with distinct rheological behaviour and flowability at ambient temperature. For accurate and repeatable dosing of different materials at sufficient speed, a gear pump system was installed, that proved to be suitable for the full range of filling materials.

Food grade micronutrient powders such as caffeine, beta-alanine, leucine, iron, and zinc were selected that were free-flowing, to allow automatic dosing. The advantage of including micronutrients as powders is that the proven effective dosage for health benefits is usually too high to be met via food formulations with a limited product intake size.

Finally, seven toppings (caramel, chocolate, summer fruit, strawberry, green apple, orange and citrus fruit) were available for the consumers to choose freely based on their preference and appetite.

An overview of the nutritional values of the casings and fillings can be found in Table 1 and details of the formulations can be found in Supplementary Table S4-Table S12.

Flexible Food Manufacturing Platform for manufacturing PNP

A Flexible Food Manufacturing Platform (FFMP) was designed and built in-house. The platform combines food material shaping by 3D printing with flexible dosing of soft and powder food materials, to enable digitally controlled and automated manufacturing of PNP. To best match the food composition target defined for individual needs, a combination of the closest matching food materials was selected and the required processing settings were turned into a machine-code to be executed by the FFMP to manufacture the PNP. The FFMP is a modular system of which the components and processing are depicted in Figure 3 and shown in Supplementary Video.

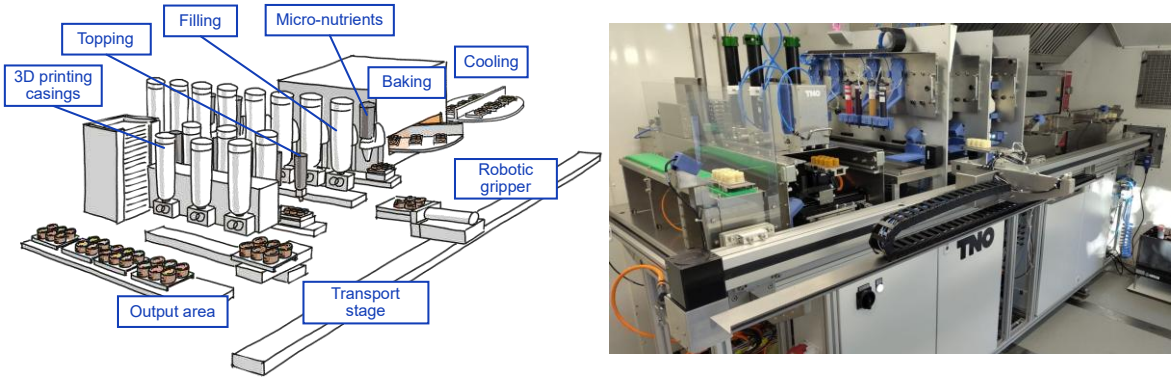


Figure 3: Schematic overview (left) of the Flexible Food Manufacturing Platform (FFMP) and realisation of the FFMP (right). The system combines 3D printing with precise dosing, robotics and process automation to allow autonomous production of a wide variety of PNPs.

Each FFMP module corresponds to a station for material deposition or processing. PNPs were transported between stations by a robotic gripper carrying the product holder. Deposition stations were arranged perpendicular to the transport robot, creating a compact and scalable layout.

On a daily basis, the machine was loaded with cartridges containing fresh food materials. An information string containing the PNP definition was input to the production process. All these strings were automatically combined, grouped and translated into a list of machine readable instructions for the daily order. The production process was highly automated: an operator was only required to load the FFMP with food materials and to off-load the produced PNPs. During the field labs, the FFMP typically produced 25 PNPs with an average weight of 80 grams within a 4 hour period. To our knowledge, this is the first time that a personal nutritional advice has been translated into a ready-to-eat product with such a high degree of automation.

Food material selection and combination

Based on the needs of the consumer population in a certain use case, a selection of maximum six casings, seven fillings, seven toppings and seven micronutrients could be loaded into the FFMP. Choosing between three product sizes, and dosing of zero to three different micronutrient powders per PNP, allowed a total of 229,320 possible variations. Table 2 presents example PNPs of each field lab, illustrating the broad range of nutritional compositions achieved. Since the toppings dosage was low in amount and in nutritional differentiation, their nutritional contribution was considered negligible.

Real-life implementation and sensory evaluation of the PNP

The methodology was implemented in three real-life field labs (military, hospital, and female athletes) to evaluate technical feasibility and sensory acceptance.

In the military setting, we produced PNP for military personnel focused on enhancing their physical performance during an intense infantry training programme. Physical and mental issues are common among military personnel, including gastro-intestinal symptoms, musculoskeletal problems and sleep disturbances[21-24]. PN may help mitigate these issues, while supporting vigilance and physiological recovery[25]. Twenty-five soldiers consumed 229 PNPs over ten consecutive days. Overall liking and sensory attribute scores were modestly positive (Table 3). Repeated exposure did not significantly affect product liking, although some initially positive attitudes shifted towards neutrality over time. The principal findings from this field study are reported elsewhere[14].

In the hospital setting, we produced PNP for patients focused on supporting recovery and overall wellbeing. For many patients, improving their nutritional intake was a key priority, as malnutrition and reduced appetite are common and associated with longer hospital stays, greater body mass loss, and increased mortality and morbidity[26,27]. For patients with obesity and/or diabetes, PNPs that support glycemic control, appropriate energy intake, and adequate nutrient intake may improve metabolic and clinical outcomes[28]. Eighty-seven patients received 137 PNPs during the study period. Overall liking and sensory attribute scores were slightly positive (Table 3). Willingness to re-order was rated just below a neutral score. The principal findings from this field study are reported elswhere[15].

In an elite female sports setting, we produced PNPs to support performance and the menstrual cycle. Despite the perceived importance of evidence-based nutrition for performance, athletes often exhibit sub-optimal dietary behaviour, highlighting the need for practical nutritional solutions[29]. Draper et al[30] demonstrated that nutrient-related metabolites fluctuate across the menstrual cycle, shifting between anabolic and recovery states, highlighting opportunities to support hormone-related health through nutrition. During a three-day field study at the training facilities of an elite female soccer team, twenty-two players (22.57 ±4.14 years) consumed a total of 60 PNPs to support performance and well-being by helping them cope with menstruation and training load. From the 60 PNPs delivered, 34 were considered tasty enough to reorder (4.2±1.7 on a Likert scale 1-7) (Table 3). Also, the fact that the products were enriched to provide additional health benefits was appreciated. Further taste optimisation may improve PNP acceptance among athletes, as taste was the main reason for not reordering.

Interestingly, overall appreciation of the PNPs was similar in the three field labs, despite differences in target groups, backgrounds or needs (Table 3). The scores showed only moderate acceptance, as can be expected from concept products, indicating that the sensory quality of products need further optimisation. This suggests that the methodology and product design can be applied across diverse user groups or settings. If product appreciation can be further improved, the approach may have broad application potential across populations with different nutritional needs and preferences.

Discussion

Although an impressive amount of about 230,000 different PNPs could be produced, the nutritional target for a PNP in this study was still a compromise between the PN advice and the nutritional value achievable in a PNP. The main limitations encountered were products high in polyunsaturated fatty acids or rich in specific ingredients like creatine, caffeine or psyllium fibre. Incorporating such ingredients that require relatively high levels of consumption or that markedly alter food rheology, texture, and taste remains a challenge for the development of future foods.

Consumer acceptance of the products and the entire service are critical drivers for the long-term success of the technology. Due to the massive number of possible combinations of casings, fillings, toppings and micronutrient powders, it remains a challenge to avoid selection of sensory incongruent combinations that would lead to unfavourable consumer perception. A potential solution is to integrate a feedback loop

into the user interface. This would allow consumers to refine their next product based on their personal taste preferences, enhancing their active participation in the co-creation of their PNPs.

The entire service in its current maturity is protracted. The PNP currently needs to be ordered one day in advance. While personal data acquisition and recipe generation are fully automated, the translation of the personalised recipe into the manufacturing process still relies on manual loading of the FFMP. Eliminating this remaining manual step would enable true on-demand production and may become increasingly feasible through recent advances in AI-driven process automation. The algorithm must also be capable of making trade-offs to fulfil multiple dietary requirements, especially to limit the selection of casings and fillings per field lab to prevent food waste. The average production time was about 9 minutes, whereas the lead time varied typically between 30 and 70 minutes per PNP. Although further optimisation of processing speed is possible, on-demand food provision as fast as a vending machine is not possible. However, the flexible manufacturing provides freshly prepared foods and allows the use of fresh- and high moisture food materials which are not possible in packaged foods.

An important next step is to assess whether sustained consumption of PNP produced using this PN service leads to measurable health benefits. While health outcomes were not evaluated in the current field labs, the developed technology and infrastructure are available for further clinical trials to investigate its efficacy to achieve enhanced health benefits, performance and wellbeing in individuals.

Conclusion

This work demonstrates the feasibility of translating PN from nutrition advice into manufacturing and delivery of actual food products tailored to individual needs and preferences across diverse user groups. We showed for the first time how the personal nutritional requirements of individuals can be fulfilled through an end-to-end PN food production service, integrating data-driven nutrition advice with a flexible food manufacturing platform for the production and delivery of PNP.

Using this system, approximately 230,000 PNPs could be produced, differing in nutritional composition, micronutrient content, product size, texture, flavour and colour. The technological feasibility and flexibility of the approach were demonstrated in three real-life field studies involving military personnel, hospitalised patients and elite female athletes. Across these settings, the system proved adaptable to highly different contextual and physiological requirements. Although the personalised foods and technology were less mature than established commercial food products, consumer evaluations ranged from neutral to slightly positive, demonstrating the viability of the technology.

The technology and infrastructure developed provide a robust foundation for future intervention studies evaluating the efficacy of PNPs to achieve measurable health benefits in specific populations or clinical contexts. This work introduces a novel framework for adaptive food manufacturing in which nutritional requirements are translated into food products at the point of production, potentially transforming how future food systems can respond to population heterogeneity.

Methods

Generation of personalised nutrition advice

Generation of personalised advice

The development of personalised nutritional advice was structured in accordance with the sense-reason-act framework[16]. For sensing, specific input parameters and validated measurement methodologies were selected to assess individual characteristics relevant to the targeted health benefits within the three field lab settings. For reasoning, appropriate knowledge rules were determined, which were chosen based on their scientific substantiation and suitability for translating input parameters into actionable nutritional guidance (Supplementary Table S1). For act, a standardised modality was employed, utilising the FFMP to operationalise the personalised recommendations in a consistent PNP format.

Sensing- Personal data

To establish a robust framework for PNP development, an initial set of overarching nutritional objectives was defined, covering key domains related to health, performance and recovery. This foundational step guided the formulation process, which occurred in parallel with other project phases. Input parameters were subsequently adapted to reflect the specific characteristics of the target population and the field lab setting, allowing for context-dependent modifications to the nutritional recommendations.

For each field lab, structured consultations were conducted with domain experts to define relevant health benefits tailored to the specific context, an overview can be found in Supplementary Table S2. Following the identification of targeted health outcomes, pertinent metrics corresponding to these outcomes were selected for integration into the reasoning framework. The selection process prioritised metrics based on their relevance, validity and the feasibility of data collection from participants. Notably, in the hospital field lab, individual-level personal data were not accessible.

Reasoning – Personalised nutrient recommendations model

A first set of general overarching nutrient recommendations that suit the focus on performance and recovery was provided to the formulation team.

Fast carbohydrates, or simple carbohydrates, are rapidly digested and absorbed, resulting in swift increases in blood glucose and providing immediate energy—particularly beneficial before or during exercise[31, 32].

Slow carbohydrates, or complex carbohydrates, are digested more gradually, ensuring a steady and sustained release of energy to support prolonged mental and physical activity. Additionally, slow-releasing carbohydrates help minimize post-meal blood sugar spikes, which is particularly relevant in the context of metabolic diseases such as diabetes[33].

Healthy fats, particularly omega-3 fatty acids, are increasingly recognized for their potential benefits in athletic performance and recovery. These nutrients play an important role in reducing inflammation, promoting muscle repair, and enhancing overall resilience[34].

Next, evidence-based basic macronutrient profiles were developed per field lab. For the hospital field lab, general nutrition guidelines were used as a starting point[35]. In the military field lab, military nutrition guidelines for readiness and performance according to Army Regulation 40-25 (AR 40–25/OPNAVINST 10110.1/MCO 10110.49/AFI 44–141) served as input for adjustments. For the elite female sport setting, the UEFA statement for nutrition in elite football was taken into account[36].

The process for evaluating nutrient-health benefit relationships and selecting appropriate micronutrients was conducted in a structured, evidence-based manner. Initially, the European register of health claims was queried to identify relevant, substantiated nutrition and health claims associated with specific health objectives. This step provided a regulatory foundation and ensured alignment with established European

standards. Next, a health taxonomy was used in combination with a text mining strategy to query for nutrient-health relationships in PubMed.

A comprehensive list of appropriate micronutrients was compiled. Each micronutrient was further assessed for suitability based on dosage, sensory attributes (including flavour), and extrudability potential, ensuring both scientific validity and product acceptability. This methodology enabled the development of evidence-based, targeted nutritional recommendations tailored to specific health outcomes.

Final nutritional recommendation algorithms and decision trees for the field labs were developed to translate individual data into personalised product guidance[14, 15] and Supplementary Table S3. In the hospital setting, a decision tree methodology was employed, whereas algorithmic approaches were utilised for the military and female sport field labs to take personal data into account. These frameworks translated personal data into PNP recommendations by matching individual characteristics and health objectives with appropriate macronutrient compositions and targeted micronutrient additions.

Flexible Food Manufacturing Platform

For the creation of the PNP, a Flexible Food Manufacturing Platform (FFMP) was designed and built by the consortium. The different food components of the PNP and the steps necessary to process these, are reflected in the modular layout of the FFMP, as shown in Figure 3. For detailed machine architecture, we refer to supplementary Fig.S1-Fig.S3.

Each functional module is a physical station that is responsible for either adding a food material or a processing step. This modular approach also allows for ‘easy’ scale up. Most core components in the FFMP were developed and realized in house. On a daily basis, the machine is loaded with fresh food materials. Besides these, an information string is input to the production process. This string is output from the personalized nutrition process and contains all the information that is needed to define one fully personalized PNP. In the daily order, all these strings are automatically combined, grouped and translated into a print job that contains machine readable instructions. The production process is highly automated. An operator is only required to load the FFMP with food materials and to off load the produced PNP. During the field labs, the FFMP typically produced 25 PNP with an average weight of 80 grams over a 4 hour period. For details over the production process, we refer to supplementary Fig.S4-Fig.S9.

Orders for each PNP are encoded in a string that defines all properties of the PNP that can possibly be varied in and by the FFMP. This string is output from the nutritional advice process and input to the production process. A bespoke software application at the production site, parses these order strings into so-called ‘machine recipes’. These recipes hold a list of precise machine instructions in XML format for the FFMP to follow so as to create the PNP according to that specific order. For production efficiency, recipes are then automatically clustered according to specific common properties. Finally, this clustered set of recipes together form the print job to be run on the FFMP. For details over machine control, we refer to supplementary Fig.S10.

The application also warns if there is a chance of running out of stock for certain food formulations during production and builds in a pause at a suitable moment during production, to allow for a manual refill of food materials on the machine. During the field labs, a print job typically held between 15 and 30 orders.

Food formulations used in the FFMP are kept in 360 mL and 30 mL polypropylene cartridges (Vieweg, Germany) that are prefilled off-site where special tooling is available for the air-free filling of the cartridges. The cartridges have been specifically tested for food safety. After filling, the cartridges are kept in cold storage until the day of production.

Before each field lab, the nutritional advice team, the food preparation team and the production team align on the loadout of the FFMP, i.e. they specifically agree on which food materials will be available on the machine during production. This loadout may vary between field labs, as the emphasis on various nutrients may and did change between the field labs.

Food material formulations

The formulations and preparation methods of the casings, fillings, toppings and micro-nutrients can be found in supplementary information Table S4-Table S12.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

All authors declare that they have no competing interests.

Ethics approval and consent to participate

All participants provided signed informed consent for inclusion in the study. Participants' data were collected under the Personal Data Protection Act and used pseudo-anonymised.

Ethical clearance for the military study was obtained from the WUR Research Ethics Committee (REC) under approval number 2024-041.

Ethical clearance for the hospital study: A declaration confirming that the study did not fall under the Medical Research Involving Human Subjects Act was obtained (NR 2023-64). Subsequently, the research protocol was approved by the local ethical committee of Ziekenhuis Gelderse Vallei, Ede, the Netherlands (NR 2403-020). The study was conducted in accordance with the ethical standards outlined in the World Medical Association of Helsinki Declaration of 1975.

Ethical clearance for the female elite athletes was obtained from the TNO review committee under approval number 2024-637

Contributions

MN, BT, FH and SW conceptualized the study and wrote the original draft of this paper. MH lead the design and realisation of the manufacturing platform, FH and SW developed the methodology and lead the PN advice system. BT and MN designed the PNP and performed the food research. SH lead the consumer studies. MN, FH and SW acquired funding. JvU coordinated and supervised the overall project. MN and BT created the visuals and MH edited the video. All authors contributed to interpreting the results, provided comments and edits to the manuscript and approved the final submission.

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Tables

Table 1: Overview of energy and nutritional values of the food materials.

	Energy (kcal/100 g)	Protein (g 100g)	Carbohydrate (g/100g)	Sugar (g/100g)	Fiber (g/100g)	Fat (g/100g)	SAFA[1] (g/100g)	PUFA[2] (g/100g)
Cereal Dough [a]	430.3	7.1	49.9	12.0	2.2	22.8	**11.0**	0.3
Cereal Almond [b, c]	399.9	10.4	43.8	12.2	3.7	21.6	6.1	2.7
Cereal Fibre-rich [a, b]	402.1	6.3	44.5	**6.3**	9.9	22.1	10.5	0.6
Protein bar [a, c]	282.4	**38.1**	24.8	17.3	**0.0**	5.4	0.9	3.1
Protein – medium sugar [b]	266.6	36.1	24.3	13.3	5.0	5.4	0.9	3.1
Protein – low sugar [b]	252.9	36.1	21.5	8.9	6.4	5.4	0.9	3.1
Cellular – Carrot [a, b, c]	252.2	1.3	55.6	**55.6**	9.3	**0.1**	**0.0**	**0.0**
Cellular – Plum [a, b]	214.1	0.8	53.3	23.7	**25.9**	0.3	0.1	0.2
Chocolate Ganache [a, b, c]	535.0	6.4	43.0	40.0	**0.0**	35.3	9.0	8.8
Apple Puree [a,b]	144.7	0.8	34.9	23.6	3.5	0.2	**0.0**	**0.0**
Strawberry Banana puree [a, b, c]	**86.0**	0.6	**19.5**	17.0	1.1	**0.1**	**0.0**	**0.0**
Pear Puree [a, b, c]	193.0	**0.1**	47.4	32.8	3.2	0.3	**0.0**	0.2
Peanut butter [a]	**660.0**	26.0	22.0	7.3	6.7	**52.0**	7.3	**14.0**
Yoghurt [a, b], custard [a, b], cheese fillings [b, c]	278.1	4.2	**57.6**	15.2	7.3	0.8	**0.0**	**0.0**

Casings and fillings used for each field lab are denoted as [a] military field lab; [b] hospital field lab or [c] elite female athletes. [1] SAFA = Saturated Fatty acids, [2] PUFA = Poly-unsaturated Fatty Acids. The highest (blue) and lowest (orange) values per macronutrient are indicated in bold.

Table 2: Example PNPs to illustrate how different health benefits are supported by nutritional composition and energy density achieved through selection and combination of food materials.

			
Health benefits	Blood glucose regulation	Recovery & Menstrual health	Luteal phase
Casing	Cellular – plum	Cereal almond	Protein bar
Filling	Yoghurt	Strawberry banana	Pear puree
Topping	Green apple	Summer fruit	Summer fruit
Micronutrients	None	Leucine: 2200 mg Iron: 226 mg Folic acid: 48 mg Vitamin B12: 51 mg	Iron: 48mg
Portion size (g)	**40**	70	100
Energy (kCal)	**98**	186	247
Protein (g)	1.0	6.5	**22.9**
Carbohydrate (g)	22.2	23.4	33.8
Sugar	**7.8**	10.0	23.5
Fibre	**6.6**	1.8	1.3
Fat (g)	0.2	8.7	3.4
Unsaturated (g)	0.2	**6.2**	2.8

Table 3: Sensory evaluation on taste and texture attributes, and willingness to eat again for all PNPs (n=413) consumed in the three field lab studies (Military n=229; Hospital n=124; Athletes n=60)

Sensory aspect	Mean score (SD) 9-point Hedonic scale [1]		
	Military	Hospital	Athletes
Overall liking	5.9 (1.6)	5.7 (2.1)	5.8 (1.7)
Appearance	6.0 (1.3)	6.2 (1.7)	5.6 (1.6)
Mouthfeel/texture	5.8 (1.6)	6.2 (1.7)	5.5 (1.7)
Taste	6.1 (1.6)	5.8 (2.1)	6.0 (1.8)
Aftertaste	5.7 (1.7)	5.7 (2.0)	5.8 (1.6)
Freshness	6.0 (1.4)	6.5 (1.9)	5.8 (1.5)
	Mean score (SD) 7-point Likert scale [2]		
Willingness to eat again	4.2 (1.7)	3.5 (2.3)	4.2 (1.7)

[1] Assessed on 9-point Hedonic scale, ranging from extremely unappealing (1) to extremely appealing (9). [2] Assessed on 7-point Likert Scale, ranging from not at all (1) to very much (7)

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