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Precision nutrition: Paving the path from potential to practice through systems science and ethical translation

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Governments worldwide have traditionally relied on population-level dietary guidance to enhance health outcomes. These broad strategies have substantially reduced deficiency-related disorders but now confront the far more complex challenge of chronic, diet-associated illnesses (Bailey and Stover, 2023). Precision nutrition (PN) seeks to bridge this gap by tailoring nutritional interventions based on individual or subgroup characteristics, including genetic, metabolic, microbial, and behavioral profiles (Zeisel, 2020). However, as this field evolves, it faces major scientific, ethical, and translational challenges that question how it can move from conceptual promise to equitable, evidence-based practice (Bailey and Stover, 2023).

PN debunks the idea of "one-size-fits-all" and advocates for individualized approaches that depend on the biological differences among people (Singar et al., 2024). A pioneering work in PN is the Food4Me trial, which showed that personalized dietary advice leads to better adherence to healthy eating patterns, sustained dietary improvements, and higher Healthy Eating Index scores compared to generic guidance (Livingstone et al., 2016). Subsequent research has extended these insights, illustrating that dietary responsiveness can be stratified by genetic variants, metabolic signatures, and microbiome composition (Lagoumintzis and Patrinos, 2023).

The multiomics revolution and systems nutrition

Advances in genomics, transcriptomics, proteomics, metabolomics, and microbiomics have enabled a holistic understanding of human nutritional responses (Ramos-Lopez et al., 2022). A multiomics approach uses information from different biological layers, such as genes, RNA, proteins, gut microbes, and metabolites, to get a full picture of a person's nutritional health (Lagoumintzis and Patrinos, 2023). This helps scientists not only understand a person's current health but also identify their unique "metabolic types" or "metabotypes," which explain why people respond differently to the same diet (Ramos-Lopez et al., 2022).

Modern bioinformatics tools like FastQC, STAR, and DESeq2, along with pathway analysis, help connect these molecular patterns to how people react to specific foods (Rosati et al., 2024). These tools have transformed nutrition research from a narrow, single-focus approach into a broader, system-based view that looks at how everything in the body works together (Kaput et al., 2017). Vergères et al. (2024) suggested creating shared data systems that combine molecular research with public health goals. This ensures that results are reliable and apply to large populations. Instead of designing completely individualized diets for each person, scientists recommend grouping people into clusters with similar biological traits, which makes it easier to apply PN (Figure 1) on a larger, population level.

From N-of-1 trials to AI-driven nutritional intelligence

From the point of view of research design, N-of-1 trials have emerged as a major avenue to provide the means for testing hypotheses at the individual level in PN research (Potter et al., 2021). In contrast to traditional randomized controlled trial designs, they are predicated on multiple

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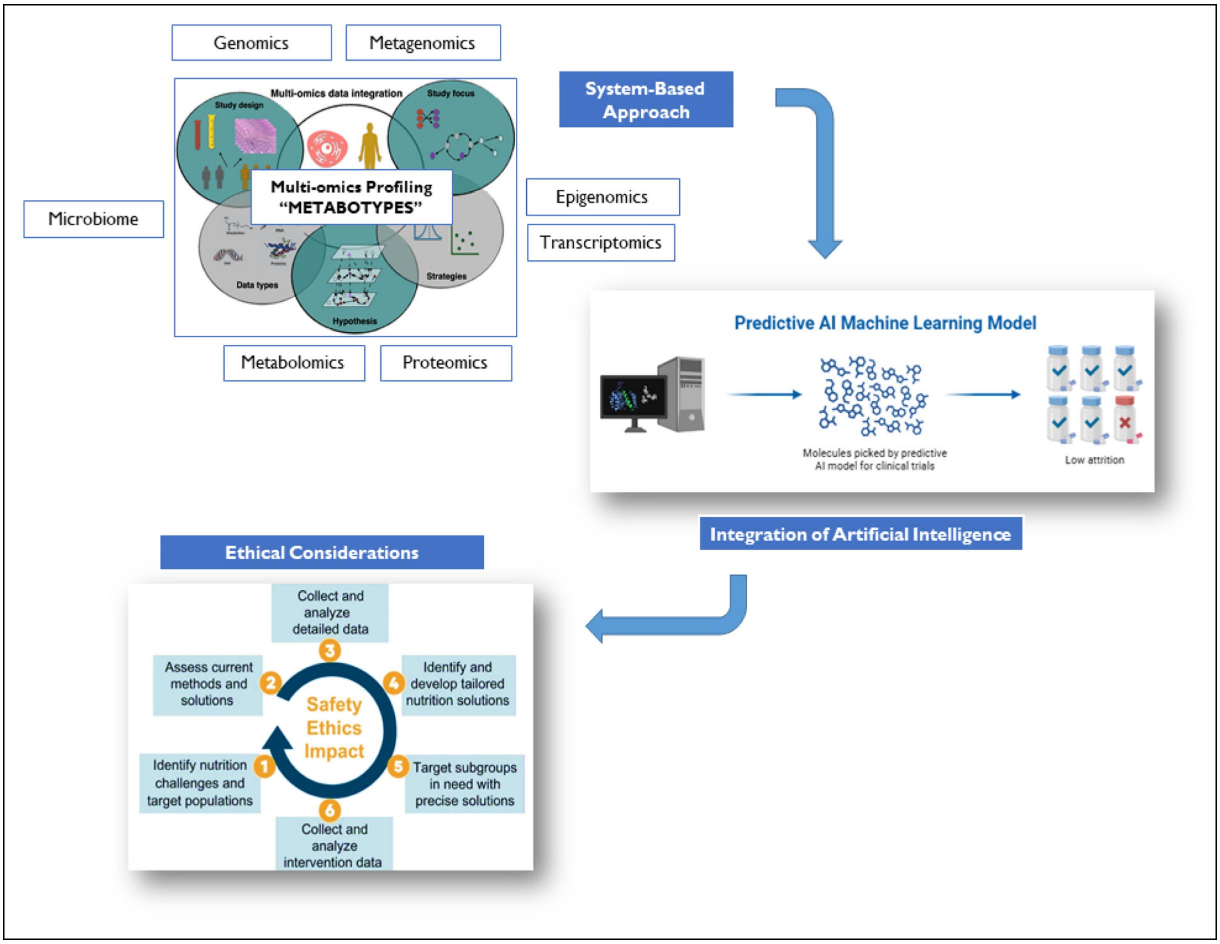

Figure 1. A conceptual model illustrating how multiomics profiling integrates with AI-driven data modeling to enable personalized dietary interventions, governed by ethical frameworks leading to public health impact.
AI: artificial intelligence.

repeated, personalized dietary interventions and permit the analysis of data from several individuals to provide more general insights at population levels. Such designs have been effectively applied to notable studies like the PRODUCE trial, a PN intervention study involving people with ulcerative colitis and Crohn's disease. This implies that N-of-1 designs can be implemented in both short- and long-term dietary behavior studies and enhance the precision of conclusions drawn since they allow repeated measures (Potter et al., 2021).

Similar advances in data analysis and interpretation are seen with the introduction of artificial intelligence (AI) into PN. Data acquired from multiomics, lifestyle, and sensors is fed into AI models to predict metabolic responses (such as postprandial glucose and lipids) with great accuracy (Arshad et al., 2025). It is also possible to use deep learning frameworks to uncover nonlinear relationships between genes, nutrients, and environmental exposures to deliver personalized dietary feedback. However, this area of development runs the risk of generating poorly defined algorithms and standard methods of validation and protection against algorithm bias (Lee et al., 2022; Panagoulias et al., 2025).

Ferreira et al. (2025) identified 654 studies employing AI models such as random forests, gradient boosting, and neural networks to predict glycemic responses, metabolic phenotypes, and disease risk. These models reveal nonlinear relationships that classical statistics might miss, offering potential for real-time, adaptive dietary recommendations. However, many AI-driven nutrition studies rely on limited, homogeneous datasets, often without external validation, risking overfitting and algorithmic bias (Ferreira et al., 2025; Lee et al., 2022; Panagoulias et al., 2025).

The implementation gap: Equity, ethics, and the future of PN

Despite breakthroughs, translating PN into everyday healthcare remains challenging. Luo et al. (2024) noted that while multiomics data can capture individual biological signatures, reproducibility remains limited due to cohort heterogeneity and incomplete standardization of analytical methods. Moreover, Kohlmeier et al. (2016) argued that many studies lack diversity, with most datasets derived from high-income populations, raising concerns about equity and generalizability. Recently, a National Institute of Health-led research initiative, *All of Us*, involving large and diverse population cohorts, provided an infrastructural backbone for equitable and reproducible PN. The research integrated electronic health records (EHRs), biospecimens, and genomic data from thousands of participants, setting a new standard for diversity and data utility (Ramirez et al., 2022). However, this study also suffered from data heterogeneity, inconsistent EHR systems, missing biospecimens, and uneven data quality, leading to lapses in model reliability and generalizability (Ramirez et al., 2022).

This leads to the conclusion that while multiomics tools can map biological individuality, their success depends on standardized, high-quality datasets and ethical governance (Mohr et al., 2024). In addition, equity remains a defining ethical test. If access to personalized diets and digital health tools is restricted to affluent populations, the approach risks widening health disparities (Maeckelberghe et al., 2023). The success of PN will depend not only on scientific breakthroughs but also on its ability to provide affordable, culturally adaptable, and accessible interventions. Governments and institutions must ensure that PN serves as a bridge, not a barrier, to nutritional equity. Ethical oversight in PN must evolve alongside data science. The collection and integration of multidimensional personal data raise serious privacy concerns. Regulations like the GDPR have established foundational safeguards, but global frameworks for consent, anonymization, and data governance are urgently needed.

The future of PN lies at the intersection of laboratory science, data analytics, and public health. Integration of epigenomic, metagenomic, and exposomic layers with clinical and behavioral data will illuminate how dietary exposures shape health trajectories. However, without cross-disciplinary collaboration, standardized methodologies, and ethical vigilance, PN risks remaining an elitist scientific ambition rather than a public health solution (Bailey and Stover, 2023). Training the next generation of researchers and practitioners in systems nutrition and computational biology will be critical to realize PN's transformative potential. Only through inclusivity, transparency, and rigorous science can PN fulfill its promise for all.

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References

Arshad MT, Ali MKM, Maqsood S, et al. (2025) Personalized nutrition in the era of digital health: A new frontier for managing diabetes and obesity. *Food Science & Nutrition* 13(10): e71006.

Bailey RL and Stover PJ (2023) Precision nutrition: The hype is exceeding the science and evidentiary standards needed to inform public health recommendations for prevention of chronic disease. *Annual Review of Nutrition* 43(1): 385–407.

Ferreira DD, Ferreira LG, Amorim KA, et al. (2025) Assessing the links between artificial intelligence and precision nutrition. *Current Nutrition Reports* 14(1): 1–17.

Kaput J, Perozzi G, Radonjic M, et al. (2017) Propelling the paradigm shift from reductionism to systems nutrition. *Genes & Nutrition* 12(1): 3.

Kohlmeier M, De Caterina R, Ferguson LR, et al. (2016) Guide and position of the international society of nutrigenetics/nutrigenomics on personalized nutrition: Part 2—ethics, challenges and endeavors of precision nutrition. *Lifestyle Genomics* 9(1): 28–46.

Lagoumintzis G and Patrinos GP (2023) Triangulating nutrigenomics, metabolomics and microbiomics toward personalized nutrition and healthy living. *Human Genomics* 17(1): 109.

Lee BY, Ordovás JM, Parks EJ, et al. (2022) Research gaps and opportunities in precision nutrition: An NIH workshop report. *The American Journal of Clinical Nutrition* 116(6): 1877–1900.

Livingstone KM, Celis-Morales C, Navas-Carretero S, et al. (2016) Effect of an internet-based, personalized nutrition randomized trial on dietary changes associated with the Mediterranean diet: The Food4Me study. *The American Journal of Clinical Nutrition* 104(2): 288–297.

Luo Y, Zhao C and Chen F (2024) Multiomics research: Principles and challenges in integrated analysis. *BioDesign Research* 6: 0059.

Maeckelberghe E, Zdunek K, Marceglia S, et al. (2023) The ethical challenges of personalized digital health. *Frontiers in Medicine* 10: 1123863.

Mohr AE, Ortega-Santos CP, Whisner CM, et al. (2024) Navigating challenges and opportunities in multi-omics integration for personalized healthcare. *Biomedicines* 12(7): 1496.

Panagoulias DP, Tsihrintzis GA and Virvou M (2025) Personalized nutrition applications using nutritional biomarkers and machine learning. In: *Artificial Intelligence-Empowered Bio-medical Applications*. Cham: Springer, 13–55.

Potter T, Vieira R and de Roos B (2021) Perspective: Application of N-of-1 methods in personalized nutrition research. *Advances in Nutrition* 12(3): 579–589.

Ramirez AH, Sulieman L, Schlueter DJ, et al. (2022) The All of Us Research Program: Data quality, utility, and diversity. *Patterns* 3(8): 100570.

Ramos-Lopez O, Martinez JA and Milagro FI (2022) Holistic integration of omics tools for precision nutrition in health and disease. *Nutrients* 14(19): 4074.

Rosati D, Palmieri M, Brunelli G, et al. (2024) Differential gene expression analysis pipelines and bioinformatic tools for the identification of specific biomarkers: A review. *Computational and Structural Biotechnology Journal* 23: 1154–1168.

Singar S, Nagpal R, Arjmandi BH, et al. (2024) Personalized nutrition: Tailoring dietary recommendations through genetic insights. *Nutrients* 16(16): 2673.

Vergères G, Bochud M, Chaparro CJ, et al. (2024) The future backbone of nutritional science: Integrating public health priorities with system-oriented precision nutrition. *British Journal of Nutrition* 132(5): 651–666.

Zeisel SH (2020) Precision (personalized) nutrition: Understanding metabolic heterogeneity. *Annual Review of Food Science and Technology* 11(1): 71–92.