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Nutrition labelling of foods should incorporate nutrient release rates

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Foods and diets form the basis for preventative approaches that reduce dependence on health systems and improve human wellbeing. Current food labelling is out of step with healthy diet recommendations but could be improved by including predicted nutrient release rates alongside nutrient contents. These rates can help quantify the effects of food processing on nutritional value and identify the fraction of food-derived nutrients available for nourishing the gut microbiota.

Nutrition messaging to consumers currently relies on two disparate approaches. One approach, often followed by public health agencies, leans heavily on epidemiological evidence from large cohort studies that track food intake and health outcomes over extended time periods. The global consensus from this approach is that whole-of-diet considerations are paramount and that diets associated with positive health outcomes are rich in plant foods and limited in foods based on refined ingredients such as fats and sugars. However, epidemiological findings are not always supported by clinical intervention studies and the focus on observational studies means that detailed mechanisms of action are difficult to discern in the context of whole diets. A second approach, usually followed for food labelling purposes, is to define nutritional value by chemical composition and calorific energy of individual foods against targets for daily consumption. This emphasizes contents of, for example, protein and fibre as positives and saturated fats, sugar and salt as negatives. Although this approach has the virtue of accurate chemical analysis methods and ease of consumer communication, it fails to consider the effects of the physical structure (architecture) of food or the combinations of foods in meals and how these impact nutrition and health outcomes. A limitation of both approaches is that recommendations are based on population and food averages and may also be skewed demographically based on epidemiology cohort composition.

Analysis of food molecular composition and whole-of-diet monitoring are difficult to combine because of the large differences in length scales that they involve. The characteristic scale of (food) molecules is the nanometre, whereas food is consumed (swallowed) in portions that are typically centimetre in scale. The challenge in reconciling data across these seven orders of magnitude in length scale can be appreciated through the thought experiment that if a 1 nm molecule is assigned a size of 1 m, then a 1 cm piece of food would be nearly as large as the world. There is little doubt that both the molecular ('1 m') scale and the food ('global') scale are important for understanding how foods influence nutritional outcomes, and each should therefore be captured by food labelling.

Although the details of structural hierarchy between the nanometre and centimetre scales define food architecture, quantification for labelling purposes is not possible because of the complexity and heterogeneity of food microstructures, such as solutions, emulsions, gels, composites, muscle fibres, plant cellular structures and their combinations. However, from a nutritional perspective, a major and consistent impact of food structural hierarchy is to influence the rate (and site) of nutrient digestion. This provides the opportunity to codify the effects of food architecture on nutritional outcomes as the feature that determines the rate and site of digestion of the nutrients present in a food.

Three examples of the impact of the rate and site of digestion of foods on nutritional outcomes are (1) the dynamics of nutrient uptake such as glycaemic responses to carbohydrates; (2) partitioning of nutrients between uptake in the small intestine and fermentation in the large intestine; and (3) control of short-term satiation and longer-term satiety (Fig. 1). In some cases, the relationships between nutrient digestion rates and food architecture are well understood, for example, the effect of dense food structures such as pasta or plant cellular structures such as legumes on starch digestion[1,2]. In these cases, the food architecture limits the access of digestive enzymes (amylases) and results in a slower rate of digestion of starch to glucose with consequent reductions in glucose uptake and insulin response as well as a greater likelihood of some starch escaping digestion in the small intestine and being transported to the large intestine for fermentation by the resident microbiota[3]. In other cases, there is clear evidence of a nutritional effect, but less understanding of the food architectures that can deliver the effect; for example, the strong effect on satiation and satiety of lipid, protein or carbohydrate infusion at the end of the small intestine[4–6]. This phenomenon, known as the 'ileal brake', results in the stimulation of appetite-suppressing hormones such as GLP-1, whose receptors are the targets for the recent wave of blockbuster diabetes and obesity drugs. Achieving some of the appetite-suppressing effect of these drugs through a food route depends on the control of nutrient release rates.

Measuring rates of nutrient digestion and release

The measurement of nutrient digestion and release rates and the partitioning between digestion and fermentation has previously been studied for individual nutrient types. For the specific example of starch digestion, nutrient digestion rate is related to the glycaemic index and the fraction undigested at the end of the small intestine is termed 'resistant starch'. Although both concepts have proved useful for appreciating the nutritional value of starch-containing foods, they also illustrate the current limitations in extending the information to a consistent food labelling approach. In the case of the glycaemic index, this is measured

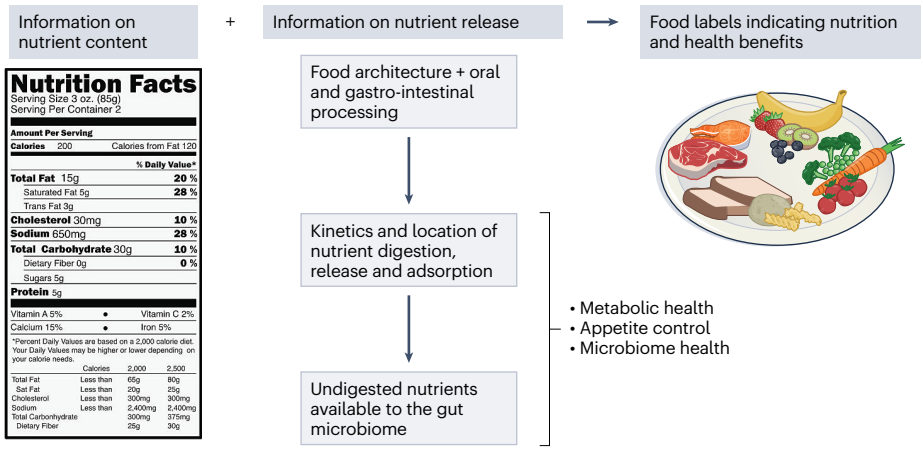

Fig. 1 | Nutrient labelling. Current food labelling is out of step with healthy diet recommendations but could be improved by including information on predicted nutrient release rates alongside nutrient content.

in vivo from the rise in blood glucose following ingestion of a test meal compared with a standard meal, averaging across 10–12 participants. The benefit of in vivo data is offset against the higher level of biological variation in values obtained compared with the chemical analysis of nutrient content; this has proved to be an impediment to global use in food labelling. Conversely, resistant starch is almost always estimated from in vitro digestion measurements, with experimental conditions that give similar numerical values to a limited dataset available from in vivo trials with ileostomy participants. In this case, in vitro accuracy is offset by the small amount of reliable in vivo reference data. Although there has been less emphasis on equivalent analyses of protein and lipid digestion, there is growing awareness of the role of nutrient uptake rates on, for example, satiation and satiety[4], and the consequences of protein and lipid partitioning between small intestinal digestion and large intestinal fermentation.

Similar considerations apply to calorific energy. Currently, energy content on food labels is usually determined through calculation based on food composition but does not consider the lower calorific value of nutrient gut fermentation compared with direct uptake or the zero calorific value of excreted food residues. For health-promoting food components such as whole nuts and legumes, the actual energy derived from consumption is considerably lower than the value that is used for food labelling[7], which is counter-productive to the drive for diets to contain a greater proportion of these food groups, particularly compared with refined ingredients that are completely absorbed in the small intestine but currently have the same calorific energy for labelling purposes.

Realizing the opportunity of including nutrient digestion rates and portioning of nutrients between digestion and fermentation to improve nutritional labelling should be based on accurate and reproducible laboratory (in vitro) analysis at the food level that can be calibrated against foods for which in vivo nutrient digestion rates and partitioning have been determined. In this way, the demands for accuracy in labelling can be matched with nutritional relevance through establishment of robust relationships to in vivo outcomes.

In vivo data collection and in vitro method standardization

To achieve the desired combination of accuracy and reproducibility from in vitro measurement and validated in vivo calibration for predicting nutrient release rates and quantifying the non-digested fraction that is available for gut microbiota fermentation, there is a need for comprehensive datasets of in vivo nutrient release and uptake and the fraction that escapes digestion in the small intestine following test meals. These datasets can then be used as a reference in the development of a standardized in vitro protocol for predicting nutrient release, digestion and uptake rates and the fraction undigested at the end of the small intestine for foods consumed.

Development of a dataset of in vivo nutrient release is a challenging target but would set the foundation for validation of an experimentally reproducible in vitro protocol that could be used for labelling alongside nutrient contents. However, recent developments in sampling methodologies and metabolomic analysis methods[8,9] provide confidence that a comprehensive dataset of in vivo nutrient release and partitioning is within reach given appropriate investment. In vitro conditions for digestion models have been proposed and widely used to define the nature and amounts of food digestion products[10]. Further refinement of such models[11] to predict nutrient digestion rates and undigested fractions is a realistic prospect, but standardization and robust testing would be needed[12]. This would lead to the prospect of food labelling that lists not only the amounts of all key nutrients and energy, but also their predicted release rate and the fraction available for nourishing the gut microbiota.

The information available from the proposed approach could go a long way towards reconciling composition and dietary pattern emphases in nutritional communication as well as allowing the effects of food processing conditions on nutrient release rate to be identified, leading to guidance on how to process foods either in the kitchen or the factory to have desired nutrient release rates. In this respect, the proposed approach is complementary to nutrient profiling[13] or food processing[14] classifications with the added benefit of producing quantitative, nutritionally relevant data. It is recognized that predicted in vitro values would only provide single-number values that fail to account for inter-individual differences or even intra-individual differences over time due to differences in, for example, digesta transit times[15], but it is a reasonable proposition that the relative values of release rate and fraction undigested between foods is likely to hold widely across populations, allowing informed choices between foods to be made based on nutritional value. A further application of

a validated in vitro methodology would be to predict the effects of different food storage, handling and preparation (cooking) conditions on nutrient release rates, providing further information and guidance for consumers.

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Competing interests

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