https://doi.org/10.1038/s43016-024-00941-y

Periodic Table of Food Initiative for generating biomolecular knowledge of edible biodiversity

Andy Jarvis, Jenny Gallo-Franco, Julian Portilla, Bruce German, Daniel Debouck, Maya Rajasekharan, Colin Khoury, Anna Herforth, Selena Ahmed, Joe Tohme, Elizabeth Arnaud, Christopher D. Golden, Corinna Dawid, Stef de Haan, Fabrice DeClerck, Edith J. M. Feskens, Vincenzo Fogliano, Gayle Fritz, Christoph Hald, Robert Hall, Robbie Hart, Audrey Henry, Sanwen Huang, Danny Hunter, Bermet Imanbaeva, Andrew Lowe, Nancy J. Turner, Gengjie Jia, Elizabeth Johnson, Geetha Kalaiah, Salwa Karboune, Stefan Klade, Gina Rae La Cerva, Vincent Lal, Avraham A. Levy, Thingnganing Longvah, Mari Maeda-Yamamoto, Paul Minnis, Marilia Nuti, Mariaelena Octavio, Coralia Osorio, Lukas Pawera, Sonia Peter, Rajendra Prasad, Cassandra Quave, Howard-Yana Shapiro, Sheshshayee Sreeman, Warangkana Srichamnong, Roy Steiner, Muhabbat Turdieva, Tiziana Ulian, Tinde van Andel, Ren Wang, Lily Weissgold, Jianbin Yan & John de la Parra

The Periodic Table of Food Initiative addresses food biomolecular composition information gaps through a standardized, accessible and enabling platform based on analytical tools, data and capacity building. Data from 1,650 foods serve as starting point for demonstrating the capacity of this initiative to contribute to nutrition, health and food systems transformations.

Knowledge gaps in food composition are driven by the diverse nature of food itself, including variations caused by how it is produced, stored and distributed, and processed, coupled with technological and accessibility barriers[1]. Within the planet's edible biodiversity, an estimated 26,000 biomolecules occur, the overwhelming majority of which are unidentified and whose health effects are generally unknown, representing the 'dark matter' of nutrition[2].

Several existing databases strive to compile wider information about the nutritional composition of food biodiversity. The International Network of Food Data Systems (INFOODS) food composition database for biodiversity, for example, goes beyond the cultivated species level to emphasize variety, cultivar and race variation, as well as wild foods[3]. The US Department of Agriculture (USDA) FoodData Central's foundation foods[4] has integrated metadata on genetics and environmental factors including management and processing for foods in the USA. WikiFCD enables users to pursue research questions and projects that are currently difficult to explore[5]. These important advances noted that existing food composition resources generally focus on analysing major dietary staples with data on only one or a few cultivars and typically highlight no more than 150 biomolecules and key macro- and micro-nutrients.

A platform for biomolecular data

The Periodic Table of Food Initiative (PTFI) is building a global network of collaborators to uncover the biomolecular composition of the world's edible biodiversity[6], encouraging nutrition researchers and other food and agricultural professionals worldwide to profile edible biodiversity using standardized, advanced analytical approaches and centralized data processing tools.

Central to the PTFI's approach is bringing standardization in foodomics through innovations in metabolomics, lipidomics, proteomics, ionomics and glycomics, to characterize and quantify biomolecules in foods[6]. Through automated data processing tools and efficiencies achieved by integrated methods that are comparable, PTFI offers a model for innovation to enable research communities, policymakers and other food system stakeholders to answer questions around food, nutrition, human health, agriculture and the environment in ways that were not possible before.

The PTFI envisions contributing to the democratization of food biomolecular composition data through the development of, and ongoing support for, an open-access data platform and by providing educational offerings that empower scientists, practitioners and educators to use and apply food composition data to create food systems solutions. Data exploration tools such as API-based access to a food biomolecular database, opportunities to visualize data through the Verso MarkerLab platform and explore it in the American Heart Association's Precision Medicine Platform will enable global accessibility to these data. Integrating a sustainable food systems framework that will collect and link associated metadata on a range of environmental, agricultural, social and economic variables, the PTFI data platform will facilitate exploration of the diverse drivers of variation in food composition. Through community engagement and a transparent approach to access and benefit sharing based on international regulatory frameworks and other ethical considerations, the PTFI will seek to foster collaboration and mutual benefit across fields, cultures and geographies. Ultimately, the intention is that PTFI data will be harnessed to create evidence-based solutions to society's most pressing food and health challenges, including the global syndemic of obesity, undernutrition, environmental degradation, biodiversity loss and climate change.

Foods that merit prioritization

Building greater knowledge on the biomolecular composition of foods requires prioritizing foods for analysis. As a first step in this process, the PTFI embarked on a global consultation process to assemble a list of minimally processed, single species foods (with few exceptions) that are important from both a nutritional and a cultural perspective – reflecting the intrinsic link between biological and human cultural diversity (Fig. 1).

Eighteen regionally distinct lists were assembled by teams of agricultural researchers, biochemists, nutritionists, ethnobotanists and activists working in food-related institutions around the world. Each group nominated up to 150 regionally important foods using three selection criteria: foods most eaten in their region, foods with special cultural significance (even if not commonly consumed) and foods they believed would play a more important role in future diets. Contributors were free to interpret the criteria as they saw appropriate and to compile the data using methodologies most applicable to their circumstances, including consultation with colleagues, students and civil society groups, and drawing from existing regional and local lists. In total, 1,671 food nominations representing the Americas (North, Central and South, and the Caribbean), Asia, the Pacific region, Europe and Africa were submitted (Fig. 1).

In addition, an African orphan crops list was included as the regional African colleague list mentioned above was specifically dedicated to animals rather than crops. Seeking to identify and ensure inclusion of the most commonly consumed foods around the world, the Global Diet Quality Questionnaire (DQQ) and the list of foods contained in a resource created for the International Treaty on Plant Genetic Resources for Food and Agriculture, titled 'The Plants That Feed the World: baseline data and metrics to inform strategies for the conservation and use of plant genetic resources for food and agriculture'[7], were included. Together, the two lists amounted to 851 nominations. Two lists relevant to the future focusing on neglected and underutilized species[8] and another focusing on foods with high nutritional potential[9], in combination providing an additional 152 food items, were included.

The aggregated list was then shared with a range of food experts (Fig. 1) who identified imbalances, gaps and excesses or any other observations about the list. They noted gaps in foods from the South Pacific, fermented foods, seafood, insects and mushrooms. Partnerships to address those gaps resulted in 294 further nominations to the list. The group convened once more to review the list and to provide ideas on how to invite further nominations during future steps from a wider group of stakeholders around the world.

Standardization of terms was conducted, and pertinent supplementary information added, including taxonomic and vernacular names, food group ontology[10], IUCN Red List of Threatened Species on threat status and representation in nutritional databases of (USDA) FoodData Central[4] and Food and Agriculture Organization (FAO) INFOODS Global Food Composition Databases[3,11,12]. The nominations listed with an IUCN Red List threat status of critically endangered, endangered and vulnerable were excluded unless otherwise domesticated.

An emerging global list of foods

A total of 1,650 distinct foods were identified and/or nominated for biomolecular compositional analysis (Fig. 2). Nearly one-third of the foods (542) were nominated from multiple sources, indicating some degree of consensus among experts on their importance. Nearly two-thirds of the foods (1,108), however, were single sourced, indicating that many existing lists are neither comprehensive nor representative of the criteria for bioculturally relevant foods established in this study. A total of 476 foods were considered global in nature (broadly cultivated and consumed), with additional identified foods considered of regional importance originating from the Americas (290), Asia (355), Africa (176), the Pacific (311) and Europe (42).

In cross-checking the list of important foods with two major nutritional composition databases, it became apparent that, of the 1,650 foods identified through the PTFI process, approximately 22% (362) are reported in the food nutrient profile database of the USDA FoodData Central[4] and approximately 25% (405) in at least one of the three major FAO's INFOODS nutritional databases[3,11,12]. Inclusion within these databases requires at least one empirical study of nutritional composition; thus, inclusion can – in some cases – rely on studies reporting a very limited number of compounds. With a total overlap between the PTFI list and the USDA and/or FAO databases of only 33% (538 foods), and thus with over 1,000 foods on the PTFI list not currently included in these global compositional databases, the scientific understanding of the nutritional composition of the human diet remains largely unknown.

There are inevitable gaps and inherent biases brought about by the nature of the source lists selected for inclusion and on the specific experience and knowledge of the regional experts consulted. The list is neither final nor prioritized among foods, except by noting foods that have been nominated more than once or appear in the other food databases queried. The list has not been validated by anyone other than those who were directly involved, nor do we present it as a definitive, complete or scientifically representative list of the world's food priorities. Furthermore, the exclusion of many processed and complex foods from the list means that it misses significant elements of the twenty-first century human diet. We hope that making the list accessible in its current form will provoke observers to point out further gaps and to nominate more foods to the list.

A globally coordinated approach

The geographical breadth and collaborative nature of the methodology affords PTFI foundational guidance on where to begin its analyses of the world's foods. We believe that the list demonstrates the vast wealth of biological diversity upon which humans rely for diets and nutrition and thus represents a sound point of departure for developing a dynamic data platform to ultimately catalogue the biomolecular composition and associated attributes of the planet's edible biodiversity.

As PTFI continues and the food list grows, we aim to engage a wider set of food and nutrition stakeholders – particularly those outside of the research community. We envision further focus on listing food diversity that is not currently well represented, for example that of fungi, bacteria, processed foods and complex dishes. We acknowledge that selection of foods from the list for biomolecular compositional analysis may impact the degree of their production and consumption, and, in turn, livelihoods and rights associated with those processes, and commit to working towards research that creates broad and equitable benefits.

To enhance the usefulness of the list, we are in the process of adding additional useful fields for each food, for example, degrees of consumption, roles in diets, seasonality and specific varietal preferences. Further work to understand the number of compounds already analysed for each food, alongside criteria such as importance in regional and global diets, is also ongoing and can help prioritize the specific foods that particularly warrant additional compositional analyses.

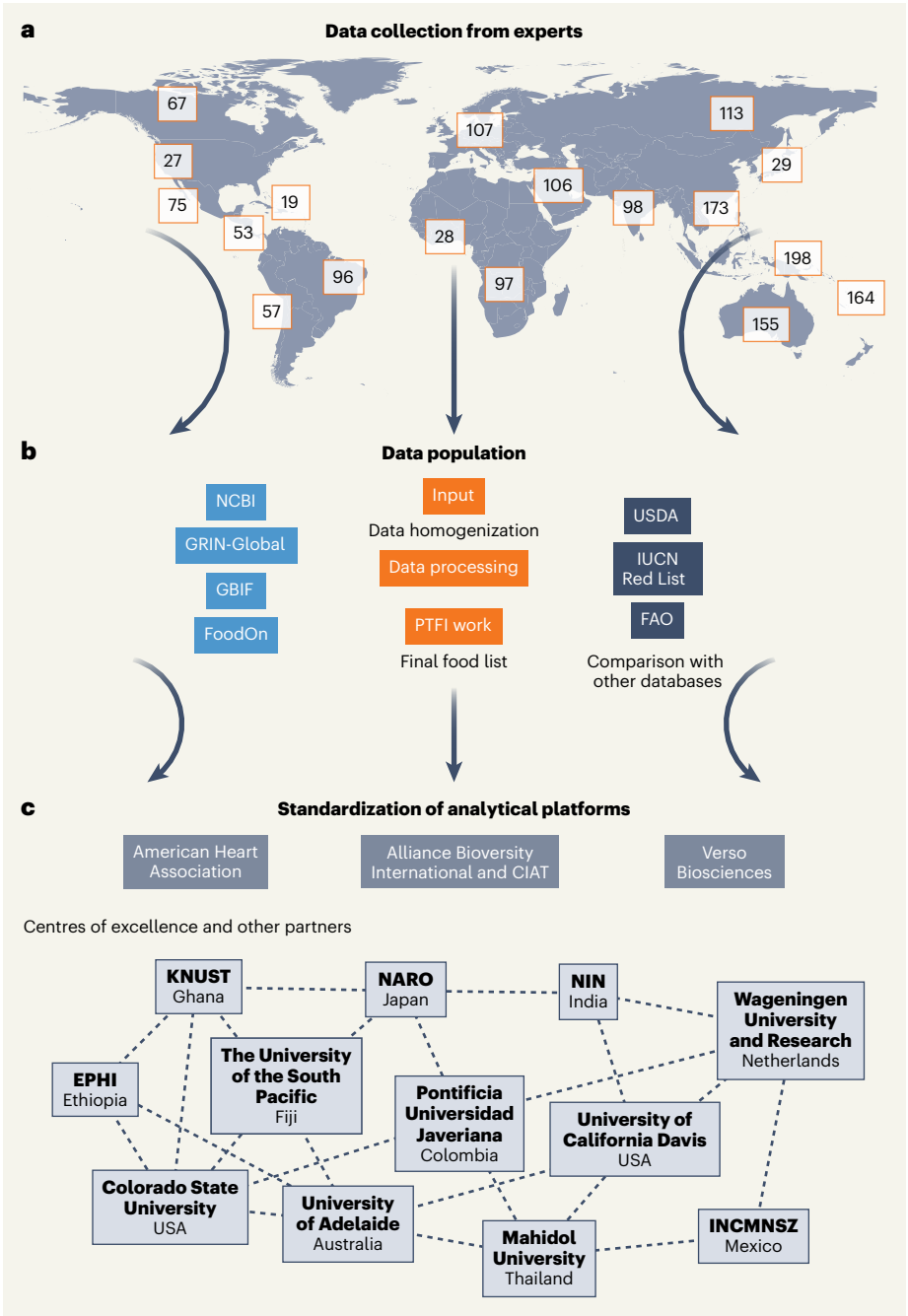

Fig. 1 | Flowchart of the reference food list development and subsequent activities. a, Data collection: experts from around the world compiled 18 regional lists featuring locally and regionally important foods. These lists were further enriched by incorporating additional foods sourced from pre-existing datasets. Finally, an expert panel scrutinized the complied nominations to ensure representation across diverse criteria including geography, biological form, evolutionary background, contribution to diet and nutrition, degree of processing, extent of domestication and organoleptic attributes. Each square on the map represents a list of foods with their corresponding number of nominations. **b**, Data supplementation and processing: the collected data from experts were homogenized and enriched with information from public databases[13]. **c**, Biomolecular analyses and data platform: the PTFI is establishing standardized analytical platforms to be used by various centres of excellence globally for the analysis of their own local foods. Publ. note: Springer Nature is neutral about jurisdictional claims in maps.

PTFI is using the list reported here as one of the starting points to engage with scientists globally to strengthen capacity and to evaluate and report on food biomolecular composition and associated attributes. The initiative will commence by standardizing diverse analytical platforms and developing data analysis and exploration tools. These tools will be made accessible to laboratories globally, granting

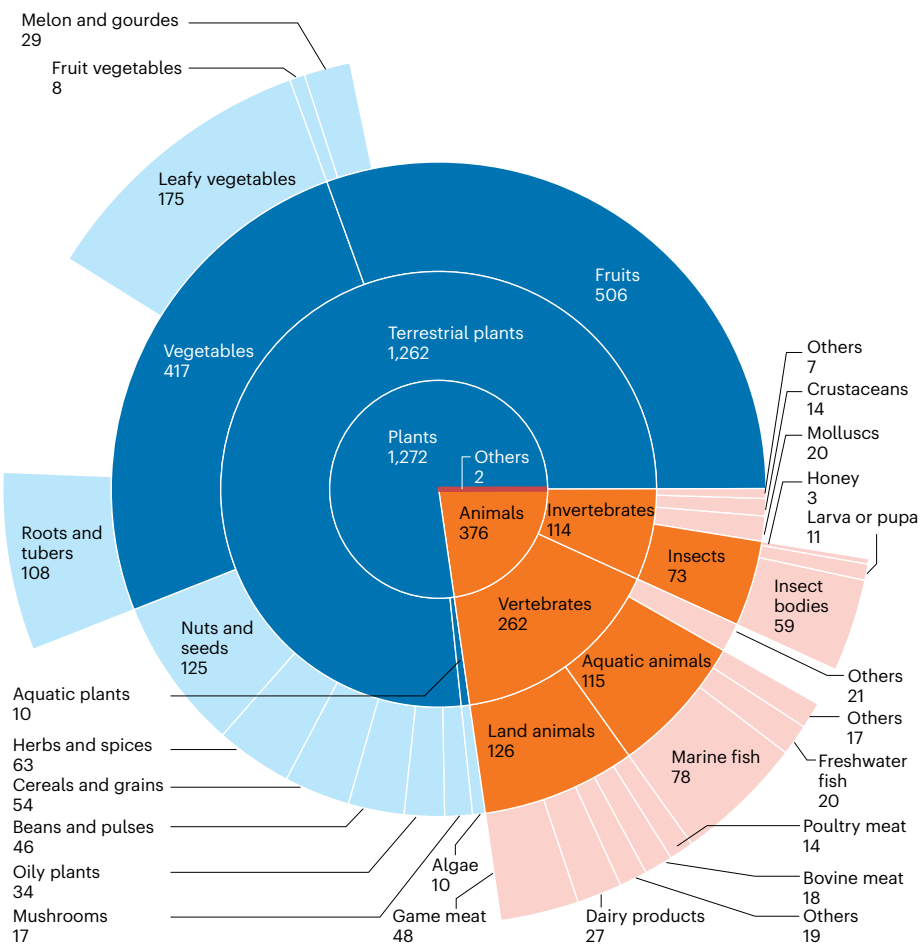

Fig. 2 | A hierarchical breakdown of foods listed. The centre of the graph denotes the broader classification level, while the outer edges depict the lower levels. The lighter colour within each group indicates the last hierarchical level within the respective category. Numbers are counts of foods in each category on the list.

them the autonomy to analyse the wide range of foods specific to each region towards addressing their unique nutritional challenges. This strategy will expand the use of PTFI tools and data at national and global levels, which we hope will, in turn, inform evidence-based national dietary guidelines, food and nutrition interventions, training of health-care professionals and overall public health programmes, among others.

To advance the positive contributions of food systems to human nutrition and health, as well as environmental sustainability, it is imperative to take a holistic approach, where food biomolecular composition is linked with the diverse factors that influence it, including production, transport and processing methods, infraspecific variation and biotic interactions. The specific varieties, geographical location, climate, management systems and preparation methods, among other variables, could impact biomolecular composition. PTFI therefore plans both to record these key associated attributes and to generate data on variation within these factors.

PTFI commits to ensuring that the planned activities will be accomplished following relevant policies and laws around access, benefit sharing and use of biodiversity, including by establishing access and benefit sharing agreements in alignment with international instruments such as the Nagoya Protocol of the Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Food and Agriculture.

Andy Jarvis[1] ✉, Jenny Gallo-Franco[2], Julian Portilla[3], Bruce German[4], Daniel Debouck[1], Maya Rajasekharan[1], Colin Khoury[1,5], Anna Herforth[6], Selena Ahmed[7], Joe Tohme[1], Elizabeth Arnaud[8], Christopher D. Golden[6], Corinna Dawid[9], Stef de Haan[10], Fabrice DeClerck[8,11], Edith J. M. Feskens[12], Vincenzo Fogliano[12], Gayle Fritz[13], Christoph Hald[9], Robert Hall[12], Robbie Hart[14], Audrey Henry[15], Sanwen Huang[16], Danny Hunter[8], Bermet Imanbaeva[17], Andrew Lowe[15], Nancy J. Turner[18], Gengjie Jia[16], Elizabeth Johnson[19], Geetha Kalaiah[20], Salwa Karboune[21], Stefan Klade[9], Gina Rae La Cerva[22], Vincent Lal[23], Avraham A. Levy[24], Thingnganing Longvah[25], Mari Maeda-Yamamoto[26], Paul Minnis[27], Marilia Nuti[28], Mariaelena Octavio[3], Coralia Osorio[29], Lukas Pawera[8], Sonia Peter[30], Rajendra Prasad[20], Cassandra Quave[31], Howard-Yana Shapiro[32], Sheshshayee Sreeman[20], Warangkana Srichamnong[33], Roy Steiner[34], Muhabbat Turdieva[8], Tiziana Ulian[35], Tinde van Andel[12], Ren Wang[36], Lily Weissgold[3], Jianbin Yan[16] & John de la Parra[34,37]

[1]International Center for Tropical Agriculture (CIAT), Cali, Colombia. [2]Pontificia Universidad Javeriana, Cali, Colombia. [3]Meridian Institute. [4]University of California, Davis, Davis, CA, USA. [5]San Diego Botanic Garden, Encinitas, CA, USA. [6]Harvard T.H. Chan School of Public Health, Boston, MA, USA. [7]American Heart Association, Dallas, TX, USA. [8]Bioversity International, Rome, Italy. [9]Technische Universität München, Munich, Germany. [10]International Potato Center, Lima, Peru. [11]EAT Foundation, Oslo, Norway. [12]Wageningen University & Research, Wageningen, The Netherlands. [13]Washington University, St. Louis, MO, USA. [14]William L. Brown Center, Missouri Botanical Garden, St. Louis, MO, USA. [15]Environment Institute, University of Adelaide, Adelaide, South Australia, Australia. [16]Chinese Academy of Agricultural Sciences, Shenzhen, China. [17]Department on Expertise of Agricultural Crops, Ministry of Agriculture of the Kyrgyz Republic, Bishkek, Kyrgyz Republic. [18]School of Environmental Studies, University of Victoria, Victoria, British Columbia, Canada. [19]Inter-American Institute for Cooperation on Agriculture (IICA), San José, Costa Rica. [20]University of Agricultural Sciences, Bangalore, India. [21]Faculty of Agricultural and Environmental Sciences, McGill University, Montréal, Québec, Canada. [22]Independent Researcher, Santa Fe, NM, USA. [23]The Institute of Applied Sciences, The University of the South Pacific, Suva, Fiji. [24]Department of Plant and Environmental Sciences, The Weizmann Institute of Science, Rehovot, Israel. [25]National Institute of Nutrition, Hyderabad, India. [26]National Agriculture and Food Research Organization (NARO), Tsukuba, Japan. [27]University of Oklahoma, Norman, OK, USA. [28]EMBRAPA, Río de Janeiro, Brazil. [29]Departamento de Química, Universidad Nacional de Colombia, Bogotá, Colombia. [30]Biocultural Education and Research Programme, St. James, Barbados. [31]Emory University, Atlanta, GA, USA. [32]College of Agricultural & Environmental Sciences, University of California, Davis, Davis, CA, USA. [33]Institute of Nutrition, Salaya campus, Mahidol University, Bangkok, Thailand. [34]The Rockefeller Foundation, New York, NY, USA. [35]The Royal Botanic Gardens, Kew, Ardingly, UK. [36]China National GeneBank, Shenzhen, China. [37]Harvard University, Cambridge, MA, USA.
✉e-mail: andy.jarvis@bezosearthfund.org

Published online: 08 March 2024

References

1. Greenfield, H. & Southgate, D. A. T. *Food Composition Data: Production, Management and Use* 2nd edn (eds Burlingame, B. A. & Charrondiere, U. R.) (FAO, 2003).
2. Barabási, A.-L., Menichetti, G. & Loscalzo, J. *Nat. Food* **1**, 33–37 (2020).
3. *FAO/INFOODS Food Composition Database for Biodiversity Version 2.1 – BioFoodComp2.1* (FAO, 2013).
4. US Department of Agriculture, Agricultural Research Service. FoodData Central, 2019. https://fdc.nal.usda.gov/ (accessed November 2021).
5. Thornton, K., Seals-Nutt, K. & Matsuzaki, M. Introducing WikiFCD: Many Food Composition Tables in a Single Knowledge Base. In *CEUR Workshop Proceedings* Vol. 2969 (CUER-WS, 2021).
6. Ahmed, S. et al. *Front. Nutr.* **9**, 874312 (2022).
7. Khoury, C. K. et al. *The Plants That Feed the World: baseline data and metrics to inform strategies for the conservation and use of plant genetic resources for food and agriculture.* IT/GB-/22/16.2/Inf.1 (FAO, 2022)
8. Ulian, T. et al. *Plants People Planet* **2**, 421–445 (2020).
9. Shaver, D. *Future 50 Foods: 50 foods for healthier people and a healthier planet* (Knorr and WWF, 2019).
10. Dooley, D. M. et al. *npj Sci. Food* **2**, 23 (2018).
11. *FAO/INFOODS Analytical Food Composition Database version 2.0 – AnFooD2.0* (FAO, 2017).
12. *FAO/INFOODS/IZiNCG Global Food Composition Database for Phytate Version 1.0 - PhyFoodComp 1.0* (FAO, 2018).
13. Jarvis, A. et al. The Periodic Table of Food Initiative (PTFI): An initial list of the world's food diversity for compositional investigation (Harvard Dataverse, 2024); https://doi.org/10.7910/DVN/M9TA1H

Acknowledgements

Funding was provided by the Rockefeller Foundation and Foundation for Food and Agriculture Research (FFAR).

Competing interests

J.d.P. and R.S. are employees of The Rockefeller Foundation, and they assisted in the conceptualization, design, decision to publish, and preparation of the manuscript. The other authors declare no competing interests.

Additional information

Peer review information *Nature Food* thanks Jessica Fanzo, Charlotte Milbank and Matthew Lange for their contribution to the peer review of this work.