Nutrition Bulletin

EMERGING RESEARCH

DOI: 10.1111/nbu.12342

Designing a research infrastructure on dietary intake and its determinants

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Abstract

Research on dietary intake and its determinants is crucial for an adequate response to the current epidemic of diet-related non-communicable chronic diseases. In order to respond to this challenge, the *RICHFIELDS* project was tasked with designing a research infrastructure (RI) that connects data on dietary intake of consumers in Europe, and its determinants, collected using apps and wearable sensors, from behavioural laboratories and experimental facilities and from other RIs. The main output of the project, an RI design, describes interfaces (portals) to collect data, a meta-database and a data-model to enable data linkage and sharing. The *RICHFIELDS* project comprises three phases, each consisting of three work packages, and an overarching methodological support work package. Phase 1 focused on data generated by consumers (*e.g.* collected by apps and sensors) relating to the purchase, preparation and consumption of food. Phase 2 focused on data generated by organisations such as businesses (*e.g.* retail data), government (*e.g.* procurement data) and experimental research facilities (*e.g.* virtual supermarkets). Phases 1 and 2 provided Phase 3 with insights on data types and design requirements, including the business models, data integration and management systems and governance and ethics. The final design will be used in the coming years to build an RI for the scientific research community, policy makers and businesses in Europe. The RI will boost interdisciplinary multi-stakeholder research through harmonisation and integration of data on food behaviour.

Keywords: big data, consumers, diet, food, public health, research infrastructure

Identifying the need for research infrastructures

Diet-related, non-communicable chronic diseases, such as obesity and cardiovascular diseases, have been identified as a key European societal challenge as they pose a significant threat to the health of the population of the European Union (EU) (WHO 2012). To respond to this challenge, recent EU initiatives have been funding relevant research (JPI HDHL 2012; European Commission 2017). Dietary habits are determined by physical, biological, psychological, economic and sociocultural factors (Sobal 1991), which all operate simultaneously and interactively (Sobal *et al.* 2014).

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A robust and dynamic scientific evidence-base on dietary determinants is needed for the research community, governments, civil society organisations and the private sector to effectively respond to the urgent diet-related public health and sustainability challenges.

The EU's Seventh Framework Programme (FP7) project *EuroDISH* previously mapped existing research infrastructures (RIs) in the health and food domain (Brown *et al.* 2017; Snoek *et al.* 2018). The DISH-model was used to distinguish information about determinants of dietary behaviour (D), intake of food and nutrients (I), its relation to status and functional markers of the body (S), and health and disease outcomes (H) (Brown *et al.* 2017). The *EuroDISH* project confirmed a current state of disparate and fragmented health and food RIs (Brown *et al.* 2017). It found that fewer RIs exist in the area of food choice determinants compared to the food intake, status and health areas, and that RIs linking food choice determinants with food intake are also lacking (Snoek *et al.* 2018). The resulting knowledge gaps are hindering evidence-based research, the design of effective public health nutrition strategies and the reformulation food products by the food industry (Brown *et al.* 2017).

The open data movement in research and innovative ways of collecting data, including user-generated (big) data, provide new opportunities to study diet, lifestyle and their determinants. Data can be collected real-time [*e.g.* with geographic information system sensors] at the individual and group level, and this could provide valuable information on associations between determinants of food choice and dietary intake. Data to study food consumption patterns can be collected through new media platforms such as Twitter (Abbar *et al.* 2014; Fried *et al.* 2014) and Instagram (Mejova *et al.* 2015; Sharma & De Choudhury 2015). Weber and Achananuparp (2016) used data from public food diaries collected using the app *MyFitnessPal* to construct models to predict whether users will or will not meet their daily caloric goals.

The 3-year *RICHFIELDS* RI design project commenced in October 2015 with funding from Horizon 2020's EU Research Infrastructures (including e-Infrastructures) Work Programme. The project was tasked with producing a design for a RI for data on food-related consumer behaviour. This will serve as a data platform to facilitate the efficient alignment, linkage and sharing of scientifically reliable and technically sound data in the domains of food choice determinants and intake, while simultaneously accounting for ethical, legal and social considerations key to being able to conduct breakthrough research, develop innovative solutions to societal challenges, and enable policy makers and food industries to develop, evaluate and implement effective food and health policies, products and services.

EuroDISH's conceptual design as starting point

The conceptual design of the RI (Fig. 1) builds on the *EuroDISH* project (Snoek *et al.* 2018) and illustrates how different data sources of legally autonomous organisations can interact to enable the European research community to collaborate more effectively.

The conceptual design encompasses interfaces (portals) to collect data, a meta-database that provides information on the availability and accessibility of the data, and a data model that safeguards data comparability through methodology standardisation and calibration to enable data linkage and sharing.

The *RICHFIELDS* project explored the possibilities of using and combining different types of data: consumer-generated data, mostly real-time and *in situ*; business-generated data; and research-generated data from research laboratories, experimental facilities and from existing and developing RIs. Users of the data platform will be the scientific research community and also consumers, civil society, policy makers and the private sector. The services offered by the RI will include data sharing, standardisation, linking and quality assessment. Services for consumers could include diet advice, special offers and shopping list advice.

Structure of the RICHFIELDS project

RICHFIELDS comprises three phases (or design elements), each consisting of three work packages. The parallel Phases 1 and 2 each focused on different data types and together form the basis of the RI design developed in Phase 3 (Fig. 2). The specific aims of the three Phases were to:

- collect data generated by consumers when engaged in activities related to the purchase, preparation and consumption of food (Phase 1);
- identify data generated by business and research from laboratories and experimental facilities and other related RIs on purchase, preparation and consumption of food (Phase 2);
- design the RI including the business model, data integration and management, and governance and ethics (Phase 3).

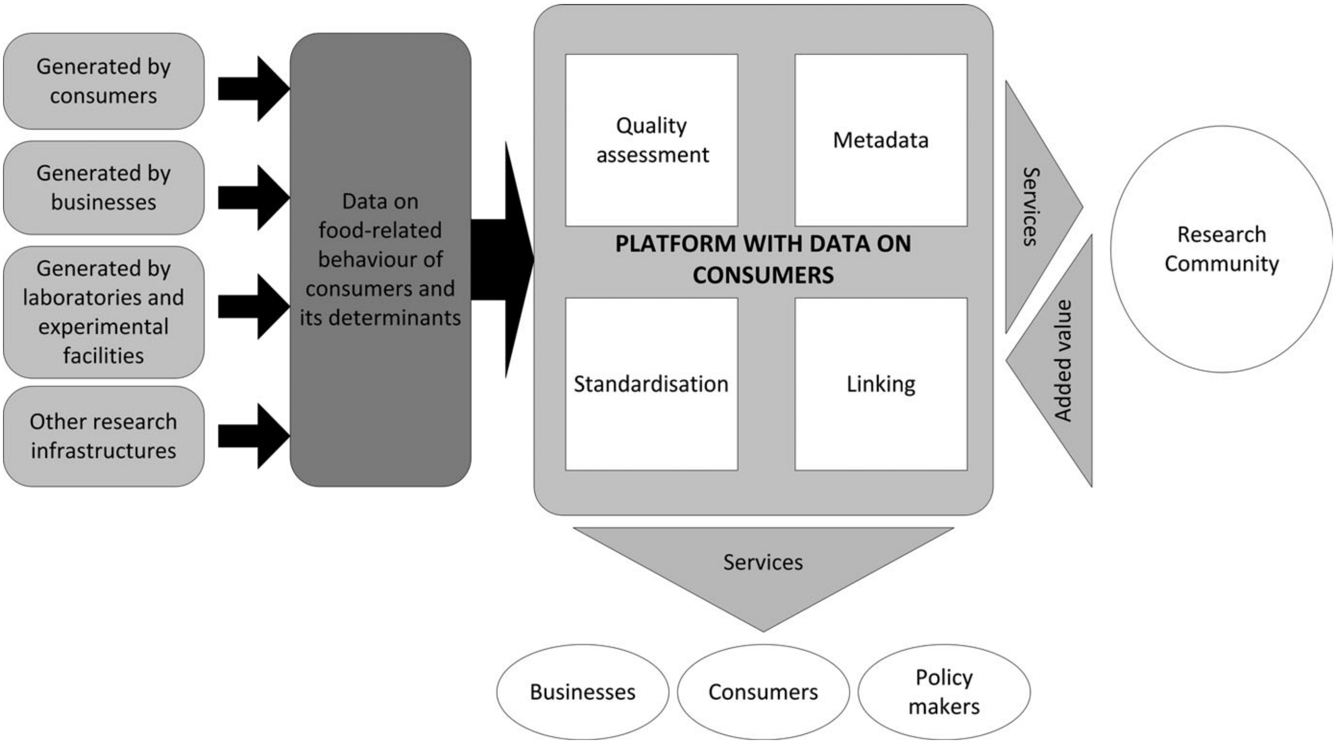

Figure 1 Conceptual design of the research infrastructure on dietary intake of consumers and its determinants.

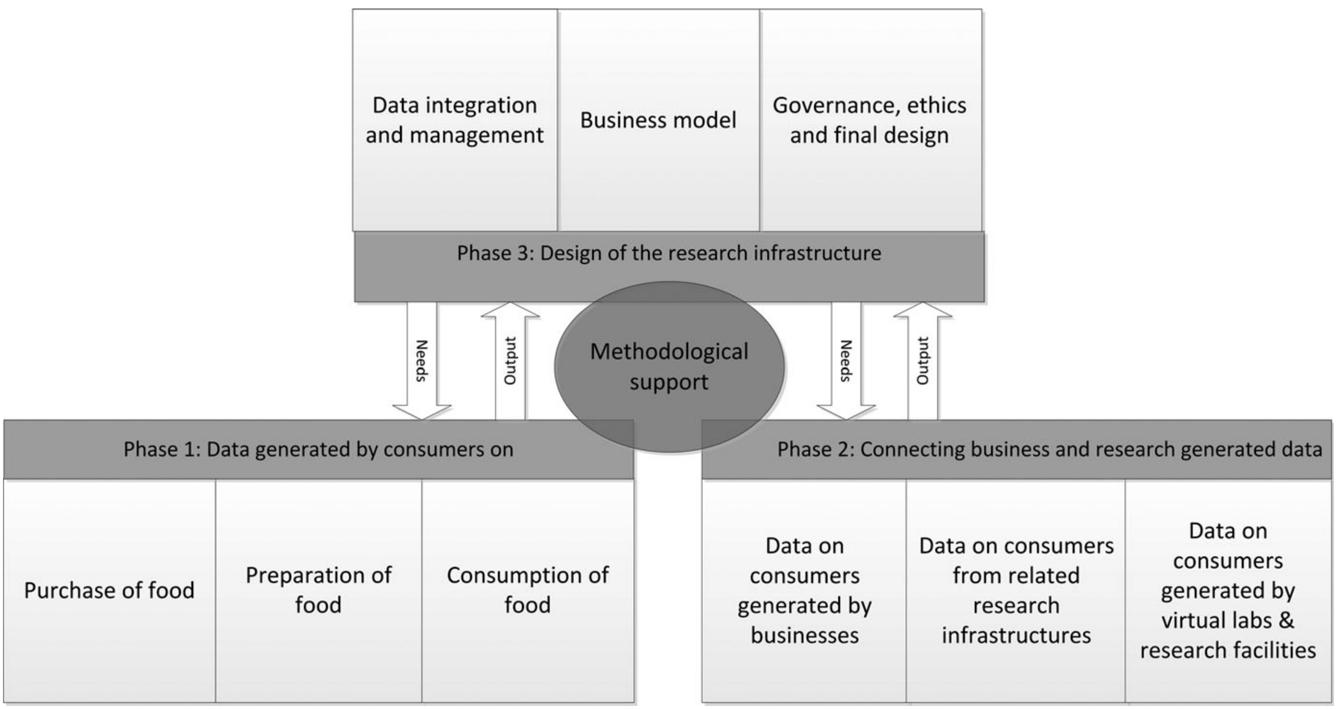

Figure 2 Structure of the RICHFIELDS project.

To ensure methodological consistency across Phases 1 and 2, a specific work package provided methodological support (see Fig. 2) including defining and harmonising concepts and methods to facilitate integration.

Phase 1: Data generated by consumers

Due to the heterogeneity of the food supply and consumers lifestyles across European sub-regions, gathering data on dietary habits and health-related consumer behaviours is scientifically challenging (Stefler & Bobak 2015). Questionnaires, focus groups, observational methods and interviews are widely used research tools for collecting food-related consumer behaviour data. New technology-driven research tools are slowly on the rise using, for example, the TwitteR software package (Vidal *et al.* 2015), tracking technologies (in tourism studies) (Shoval & Ahas 2016), and brain imaging (in sensory sciences) (Horska *et al.* 2016; Reichert *et al.* 2018).

The *RICHFIELDS* RI design project considered three important food-related behaviours: purchase, preparation and consumption. Key research questions include: what food do people eat, in what quantity and what frequency? What food-related behaviours are associated with which dietary patterns? What are the demographic and personal characteristics of people with different diets? What are their attitudes, normative beliefs and social motivations, reasoning, emotions, towards health and sustainability? What is the social and built environment in which the behaviour is carried out?

As well as providing insights regarding food-related behaviour *per se*, the consumer-generated data can be used to derive health-related dietary data; for example, energy and nutrient intakes, dietary quality (nutrient density, energy density), which in turn may be related to energy balance (sedentary behaviour, physical activity, body size and composition), health status (blood lipids, blood pressure, overweight, chronic diseases) and lifestyle (sleep, stress) factors. Consumer data on purchase, preparation and consumption of food can be generated real time and *in situ*, using innovative information and communication technology (ICT) technologies (*e.g.* apps). Tools for consumer-generated data, including wearable technology, are expected increasingly to become an integral part of society (Research 2 Guidance 2015).

Phase 1 identified food-related data that is being actively or passively generated by consumers through the use of tools such as apps and sensors. Examples include banking transactions from which food-related purchase can be estimated, food-related search internet behaviour (*e.g.* recipes, restaurant reviews) and the use of apps to record food intake or disclose food-related images or text. The large scale generation of such data has the potential to provide data for the purpose of research. In order to determine consumers' willingness to share their food-related data, quantitative research was conducted in eight European countries (France, Germany, Italy, The Netherlands, Slovenia, Spain, Sweden and the UK) to provide insights as to the type of food-related data being generated, and the extent to which people are willing to share data with scientists, government and business that produce or sell foods and drinks. The survey also collected data on determinants of willingness to share data.

RICHFIELDS developed a set of quality criteria for the evaluation of consumer-generated data in terms of its scientific relevance and technical and legal governance. This includes the legal limitations, organisational restrictions, confidentiality and privacy concerns related to the collection, integration and dissemination of consumer-generated data and the technical protocols and standards for data access and data processing. Information about these topics is crucial for developing the blueprint of a data platform, such as *RICHFIELDS*, as well as for its data governance structure.

Phase 2: Data generated by business and research

Phase 2 identified and investigated how the data platform could be connected with data generated by businesses and the research community (see Fig. 2).

Business-generated data

The use of business-generated data was examined through interviews with representatives from businesses and agencies that are already collecting data on different aspects of food consumption. Two types of business-generated data were investigated in case studies, namely data generated in business-to-business interactions, where consumers purchase foods in retail stores, and data generated in business-to-government interactions, in which the food is sold by wholesalers to governments for use in welfare catering. The first is referred to as purchase and the second as procurement. The cases studies focussed on how ICT (*e.g.* software applications for data import and export, smartcards, near field communication tools, data meshes) is being and could be used to make data collection more convenient. The feasibility and the ethical issues of the data capture were also examined.

Research-generated data

This work package focused on how data generated through research in smart lab settings can be included in a future data platform, with a particular emphasis on how new technologies and devices are being used in physical laboratories and research facilities across Europe to study behavioural nutrition under experimental conditions. Such new facilities have spread in the wake of the increased interest in studying dynamics of food choice and the behavioural design of food environments. The challenges and opportunities associated with extracting laboratory data were explored in three case study food laboratories and facilities: Restaurant of the Future located at Wageningen University (www.wur.nl/en/Expertise-Services/Facilities/Restaurant-of-the-Future-4.htm), Foodscape Lab located at Aalborg University, Copenhagen (www.capfoods.aau.dk/technical/FoodScapeLab/), and the Fake Food Buffet at ETH Zurich (Bucher *et al.* 2012). The experimental research settings in these laboratories and facilities add important scientific value by enabling data exchange and cross-validation between the research settings. They can also be used to test hypotheses about how consumers behave in real-life consumer environments (*e.g.* supermarkets, restaurants, home kitchens) and investigate bio-psychological mechanisms of food choice. All three facilities are controlled laboratory settings that allow for data collection under well-defined conditions, two of which, the Restaurant of the Future and the Foodscape Lab, also provide options for collecting data in real-life eating environments (campus canteens). In the Foodscape Lab and the Restaurant of the Future, experiments can be carried out using real food as well as virtual food environments such as virtual supermarkets and virtual buffets, where virtual reality (VR) technology is used and behavioural data is collected digitally in real-time (Mikkelsen *et al.* 2016a,b). At the Fake Food Buffet in ETH Zurich, food replicas, as well as real food, are used in experiments (Mikkelsen *et al.* 2016a,b). As developing and maintaining such kinds of lab facilities is rather costly and technology intensive, it was important to determine how protocols, devices, skills, and data can best be exchanged across the facilities and how a RI might play a role in this. An inventory of other experimental research facilities generating data concerning purchase, preparation and consumption of food has also been compiled.

The potential for delivering data to the platform from other relevant existing and developing RIs related to consumers' food intake, health, and lifestyle in Europe was explored in a separate work package, focusing first on food composition and food attributes data (Finglas *et al.* 2014). This included approaches to and challenges of integrating data on non-nutrient bioactives and food allergens, as well as the possibility of including data on branded foods. This was followed by a focus on linking to data related to food intake created within the framework of standardised dietary monitoring systems using agreed standard methodologies, such as GloboDiet (Dietary Exposure Assessment Group 2016). The work also included studying links to data collected in the context of clinical interventions [*e.g.* by European Clinical Research Infrastructure Network (ECRIN; www.ecrin.org) and European Commission (EC)-funded projects such as the *European Nutritional Phenotype Assessment and Data Sharing Initiative* (*ENPADASI;* www.enpadasi.eu) and *QuaLiFY* (www.qualify-fp7.eu)], and data on lifestyle factors, such as exercise, stress and sleep behaviour [*e.g.* EC-funded project *PREventive Care Infrastructure based On Ubiquitous Sensing* (*PRECIOUS;* www.thepreciousproject.eu)].

Phase 3: Design of the research infrastructure

Phase 3 designed the business model, the data integration and data management, and the governance of the RI (see Fig. 2). In general, designing data platforms with many data suppliers and data users involves highly complex sets of network externalities between and within different user groups (Reuver *et al.* 2015). In designing data platforms, different methods are applied; for example, the Design Science Research Methodology (DSRM) for open data platforms (Alexopoulus *et al.* 2014), Architecture Analysis and Design Language (AADL) for big data driven physical systems (Zhang *et al.* 2015) and sometimes a completely new architectural design is developed (Simmon *et al.* 2015). Taking a stakeholder and technology-oriented perspective, that accounts for both data providers and end-users, as well as technical restrictions associated with different data sources, is key to successful platform design (Schreieck *et al.* 2016). It is important to engage stakeholders throughout the design process (Michener *et al.* 2012) as their willingness to share data will determine the success of the data platform.

Business model

To develop a sustainable business model for the RI that provides value to its users, the benefits of various business models have been explored in terms of their value proposition (*i.e.* the services provided to the different users of the RI, such as scientists, consumers and businesses), the supply chain configuration (*i.e.* the way services are produced and provided to users), and the revenue model (*i.e.* the financial mechanisms that determine and regulate economic flows among all stakeholders). These business models were then subjected to a socioeconomic performance assessment, estimating the order of magnitude of investment needed, long-term turnover, and turnover impact for different participating organisations (private companies, research institutes). In order to assess their feasibility, these alternative business models were presented to relevant groups of stakeholders. Based on their feedback the final business model was further developed and subjected to performance forecast analysis focusing on indicators, such as net present value and payback time, to estimate its sustainability.

Data integration and management

The proposed data integration and data management procedures are based on state-of-the-art ICT for collecting big data from consumers, such as sensors, digital pictures, videos, purchase transaction records and GPS signals. Interfaces (portals) for different groups of users of the data platform, tailored to their specific needs, are key elements of the RI design. These user requirements were considered through evaluating similar multi-sided data platforms, based on innovative cloud and big data technology, such as Future Internet space (FIspace; www.fispace.eu), Just Eat (www.just-eat.com), Big Data Public Private Forum (www.big-project.eu), and evidence-based European RIs and projects such as the *European Food Information Resource* (*EuroFIR*; www.eurofir.org 2016), *NuGO* (an Association of Universities and Research Institutes focusing on the joint development of the research areas of molecular nutrition, personalised nutrition, nutrigenomics and nutritional systems biology) (www.nugo.org.), and *ECRIN* (www.ecrin.org), which mostly use relational databases to store data. In order to link different types of data, the *RICHFIELDS* project's new semantic data model is based on existing standard ontologies and incorporates aspects from the domains investigated in Phase 2. Together with a data provenance concept (*i.e.* who provided the data, in what context and how the data were dealt with), the architecture of the RI has been designed to enable full data integration. Functional and technical standardisation will ensure that apps can communicate with the proposed data platform.

Governance and ethics

The governance of the proposed RI encompasses the use of institutional and authority structures and forms of collaboration to allocate resources (*e.g.* money, people) to coordinate activities and control joint action across the network of participating organisations (Provan & Kenis 2007). The success of the RI based on the *RICHFIELDS* project's design will depend on the appropriate governance of all involved organisations with their datasets and resources (apps, sensors), their facilities (research laboratories, experimental facilities) and related services (cloud, interfaces). The RI governance structure deals with privacy, data protection, RI ownership of data, ownership of the RI, intellectual property rights, transparency and trust. In particular, consumer concerns about the (mis)use of their personal data, which includes their food-related behaviour, needs to be considered (European Commission 2015). The design of the proposed RI's governance structure also considers developments in digital technology and scientific research (e-science) software and the European Commission's ambition to make all scientific data open. Stakeholder views on the different governance models were sought and used to shape the final proposed RI governance structures and their alignment with the business model and the data model. The final design of the RI will be accompanied by a roadmap (including the financial strategy) for the actual building of the RI.

Challenges

Food-related data generated by consumers is of inherent interest to researchers and currently remains largely inaccessible and disconnected from the scientific community. Consequently, an important legal issue is whether consent has been obtained for use, for example, in research, and if not, how it might be obtained. It must be clear for which purposes the research community and businesses will use the data generated by consumers (Umhoefer *et al.* 2015).

A second challenge is whether each participating data provider will be willing to share its data with (some of) the other parties as data users. The ambition to develop the European public-private RI is challenging due to the different 'cultures' of academia, food enterprises and European consumers.

The quality of the data is another concern. A key question is whether the data are fit for purpose. Another challenge is designing a sustainable, operational RI. This means that the RI must be flexible enough to adapt to new emerging technical data collection tools, such as implantable devices (*e.g.* microchips inserted into the human body), and to different forms of self-monitoring occurring in society: private, pushed, communal, imposed and exploited self-tracking (Lupton 2014). The RI also needs a sustainable business model that can withstand financial setbacks in the future. The ambition is to design a RI that copes with these challenges and overcomes the current data fragmentation between individual level and its environment in research, business and policy, and provides adequate services to tackle the societal challenge of diet-related non-communicable chronic diseases.

Stakeholder participation, consortium management, and dissemination

Generation and use of (big) data on food-related behaviours of consumers depends on the willingness to share data from a broad range of stakeholders: consumers, researchers, app providers and developers, food retailers, food and beverage industries, restaurants and caterers. Therefore, the engagement of these stakeholders in the design is crucial. Key stakeholders have provided input to *RICHFIELDS* through stakeholder platforms and workshops.

The *RICHFIELDS* consortium comprises 16 organisations from 11 EU Member States and one organisation from a non-EU Member State. The coherency and scientific quality of the work packages within each phase was coordinated and overseen by a scientific coordinator. To align the work and ensure coherency between the phases, the scientific phase coordinators regularly met as part of the Scientific Coordination Team. Together with the overall project coordinator and the project manager they formed the Project Management Team. The project also benefited from the expertise and networks of the members of the external Project Advisory Board, all active in the private and public sectors or scientific community, who provided input on stakeholders' needs and feedback about the progress and (preliminary) results.

Scientific papers (*e.g.* on measuring food choice and consumption behaviour, on linked data sharing) will document and disseminate the project's scientific results. In addition, the results have been, and will be, discussed with peers and stakeholders at conferences during and after the project's lifetime. A website (www.richfields.eu) provides project partners, stakeholders and other interested parties with information about progress and outputs. As well as the use of Twitter and LinkedIn, an annual electronic newsletter provides partners and stakeholders with project updates. Finally, in September 2018, the final RI design and roadmap will be presented to researchers, businesses and policy makers at a conference in Brussels.

Acknowledgements

The Consortium partners are: Wageningen Economic Research (NL), the German Institute of Food Technologies (DE), European Food Information Resource AISBL (BE), Jožef Stefan Institute (SI), Wageningen University (NL), University of Surrey (UK), RISE Research Institute of Sweden, Aalborg University (DK), Javier de la Cueva & Asociados (ES), Swiss Federal Institute of Technology (CH), European Food Information Council (BE), Quadram Institute Bioscience (UK), Institute of Industrial Technologies and Automation-National Research Council of Italy (IT), Centre for European Nutrition and Health (FR), Aalto University (FI), GS1 Denmark (DK). The Scientific Coordination Team are: Prof. Pieter van't Veer (chair; Wageningen University), Professor Monique Raats (coordinator Phase 1; University of Surrey), Professor Bent Egberg Mikkelsen (coordinator Phase 2; Aalborg University), Mr. Krijn Poppe (coordinator Phase 3; Wageningen Economic Research) and Dr. Paul Finglas (accessory member; Quadram Institute Bioscience). The members of the Project Advisory Board, appointed in June 2016, are: Dr. Inge Tetens (Chair; University of Copenhagen), Dr. Igor Spiroski (IPH Macedonia), Mrs. Anneke van Kollenburg (ENECO), Dr. Harriet Teare (University of Oxford), Mr. Fred van Alphen (IT manager), Mr. Christian Graversen (Welfare Tech) and Dr. Marijntje Bakker (JPI HDHL).

Conflict of interest

The authors have no conflict of interest to declare.

Funding

The *RICHFIELDS* project has received funding from the European Union's *Horizon 2020* Research and Innovation Programme under grant agreement No 654280 (www.richfields.eu).

Authors' contributions

MJB was responsible for the integration of the contributions of the co-authors. KZ and PvtV contributed to the background and the conceptual design section. AG and MR formulated the section about Phase 1 concerning data generated by consumers; BM and PF contributed the section about Phase 2 focusing on data generated by business and research; and KP and MJB were responsible for the content of the section about Phase 3 concerning the design of the RI. KZ contributed to the section about consortium management, stakeholder participation and dissemination. All authors were responsible for the final discussion section. All authors read and approved the final manuscript.

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