frontiers | Research Topics

Nutrition and sustainable development goal 12: Responsible consumption

Edited by
Graziana Difonzo, João Miguel Rocha, Fatih Ozogul, Monica Rosa Loizzo, Laura Rossi, Muhammad Bilal Sadiq, Ximena Schmidt Rivera, Elena Velickova and Luca Secondi

Published in
Frontiers in Nutrition
Frontiers in Sustainable Food Systems
Frontiers in Sustainability

ISSN 1664-8714
ISBN 978-2-8325-4706-9
DOI 10.3389/978-2-8325-4706-9

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Nutrition and sustainable development goal 12: Responsible consumption

Topic editors

Graziana Difonzo — University of Bari Aldo Moro, Italy
João Miguel Rocha — University of Porto, Portugal
Fatih Ozogul — Çukurova University, Türkiye
Monica Rosa Loizzo — University of Calabria, Italy
Laura Rossi — Research Centre on Food and Nutrition, Italy
Muhammad Bilal Sadiq — Forman Christian College, Pakistan
Ximena Schmidt Rivera — Brunel University London, United Kingdom
Elena Velickova — Saints Cyril and Methodius University of Skopje, North Macedonia
Luca Secondi — University of Tuscia, Italy

Citation

Difonzo, G., Rocha, J. M., Ozogul, F., Loizzo, M. R., Rossi, L., Sadiq, M. B., Rivera, X. S., Velickova, E., Secondi, L., eds. (2024). *Nutrition and sustainable development goal 12: Responsible consumption*. Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-8325-4706-9

Table of contents

frontiers | Frontiers in Nutrition

TYPE Editorial
PUBLISHED 22 March 2024
DOI 10.3389/fnut.2024.1394417

OPEN ACCESS

EDITED AND REVIEWED BY
Elena Ibañez,
Spanish National Research Council (CSIC), Spain

*CORRESPONDENCE
Muhammad Bilal Sadiq
✉ bilalsadiq@fccollege.edu.pk;
✉ m.bilalsadiq@hotmail.com

RECEIVED 01 March 2024
ACCEPTED 13 March 2024
PUBLISHED 22 March 2024

CITATION
Sadiq MB, Secondi L, Velickova E, Rocha JM, Rossi L, Schmidt Rivera X, Difonzo G, Loizzo MR and Ozögul F (2024) Editorial: Nutrition and sustainable development goal 12: responsible consumption.
Front. Nutr. 11:1394417.
doi: 10.3389/fnut.2024.1394417

Editorial: Nutrition and sustainable development goal 12: responsible consumption

Muhammad Bilal Sadiq[1]*, Luca Secondi[2], Elena Velickova[3], João Miguel Rocha[4,5,6], Laura Rossi[7], Ximena Schmidt Rivera[8], Graziana Difonzo[9], Monica Rosa Loizzo[10] and Fatih Ozögul[11,12]

[1]School of Life Sciences, Forman Christian College (A Chartered University), Lahore, Pakistan, [2]Department for Innovation in Biological, Agri-food and Forestry Systems, University of Tuscia, Viterbo, Italy, [3]Faculty of Technology and Metallurgy, Saints Cyril and Methodius University of Skopje, Skopje, North Macedonia, [4]Centro de Biotecnologia e Química Fina – Laboratório Associado (CBQF), Escola Superior de Biotecnologia, Universidade Católica Portuguesa, Porto, Portugal, [5]Laboratory for Process Engineering, Environment, Biotechnology and Energy (LEPABE), Faculty of Engineering, University of Porto, Porto, Portugal, [6]Associate Laboratory in Chemical Engineering (ALiCE), Faculty of Engineering, University of Porto, Porto, Portugal, [7]Council for Agricultural Research and Economics-Research Centre for Food and Nutrition (CREA Food and Nutrition), Rome, Italy, [8]Department of Chemical Engineering, College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge, United Kingdom, [9]Department of Soil, Plant and Food Science, University of Bari Aldo Moro, Bari, Italy, [10]Department of Pharmacy, Health and Nutritional Sciences, University of Calabria, Rende, Italy, [11]Department of Seafood Processing Technology, Faculty of Fisheries, Cukurova University, Adana, Turkey, [12]Biotechnology Research and Application Center, Cukurova University, Adana, Turkey

KEYWORDS

food waste, sustainable consumption, sustainable development goals, food supply chain, consumer awareness

Editorial on the Research Topic
Nutrition and sustainable development goal 12: responsible consumption

Food is the core element of sustainability and it is an integral component of sustainable development goals (SDGs). The food system contributes between 25–34% of the global greenhouse gas emission, together with other detrimental environmental impacts including biodiversity loss, acidification of soils, etc. Approximately, 30% of the produced food is lost or wasted on a global scale, which involves postharvest loss, processing and distribution loss and wastage at a consumer level. A rapid rise in global population and food losses collectively compromise food security and SDGs. The effective management of food waste and byproducts can minimize the challenges of food security and environmental hazards associated with the disposal of food waste. Implementation of effective strategies and control measures can reduce food loss and enhance food availability. These strategies include integrated supply chain models, raising awareness, redistribution, effective models for recovery of value-added products, and management of disposals. Among SDGs, the target of SDG 12 (sustainable consumption and production) is addressed to significantly reduce food waste at all levels of food supply chain i.e., farm to fork.

Food loss and waste

On a global scale food loss and waste (FLW) is a major hurdle in achieving sustainable food systems. A food system involves all stages of the supply chain i.e., from farm to fork. Around one-third proportion of globally produced food is lost or wasted. Food loss corresponds to post-harvest loss, whereas food waste is primarily associated with the consumer level (1). The term food loss and waste highlight all the food resources including byproducts, secondary metabolites and all other edible components which can be used as a food or can enter food chain but either lost or wasted during preharvest, post-harvest, processing, distribution, and consumption levels. The magnitude of food waste generated is usually self-reported and based on predictions. Comprehensive analyses about economic, environmental and recycling impacts of food waste are extremely important for developing FLW management policies as highlighted in the systematic review by Bilali et al.

Contributing factors of food loss and waste and control strategies

The globalization and industrialization of food processing, high demand for animal protein, changes in eating habits and lifestyle are major hurdles toward the achievement of sustainable food system. In developing countries, a major proportion of food is wasted at postharvest level due to lack of infrastructure and technology, whereas in developed countries consumer level wastage predominates (2). Tonini et al. reported that lack of food management and excessive purchase of perishable foods are predominant reasons of food waste in households with children. It is important to identify the potential factors and magnitude of food waste generated at each scale, i.e., at production, processing distribution and consumer levels. The implementation of audit and accountability can contribute toward minimization of food waste. Cook et al. in their study identified the important factors which influence the implementation of food waste audits in foodservices.

Due to diversified nature of food, the contributing factors for FLW can be lack of an appropriate technology, infrastructure, seasonal variability, variations in supply and demand, poor logistics, poor packaging, and storage (3). In their study Afriyie et al. highlighted the importance of food storage at consumer level. Consumer awareness and basic training about food storage can ensure food security and safety. FLW can be minimized by effective food supply chain management (SCM), raising awareness, improved logistic framework, digitalization of supply chain and sharing responsibility with different stakeholders of the entire food chain.

Sustainable consumption and recovery of value-added components

A strong coordination among all stakeholders is the backbone of sustainable food consumption model. The development of sustainable food SCM requires integration between the concepts of sustainability and SCM (4). The modification of dietary habits toward the use of organic fruits and vegetables, fiber enriched foods and exploration of alternative protein sources can contribute to sustainable food systems. For food policy makers, tools based on information, market and regulatory aspects are integral to developing a sustainable system (5). As mentioned by Grant and Rossi (a), there is dire need to develop national platforms to support the awareness programs and implementation of FLW management policies.

Lange and Nakamura proposed that edible insects can play a role in sustainable food systems due to the presence of high-quality protein, nutrients and associated environmental benefits. Food waste and byproducts can also be explored for valuable components, which can be utilized as functional ingredients in the food chain. Yeast protein is of great interest as an alternative protein due to ease of scale-up, relatively low-cost and nutritional value. Gärtner et al. in their study formulated vegan spread powders by using torula yeast as an alternative source of protein and observed variations in sensory acceptance with change geographical origin of the consumers. The food product development and marketing strategies should also consider consumer preferences based on cultural variations to avoid new food product failure.

The concept of food waste valorization was taken up by Chaklader et al. who reported that fish waste can be used as a source of functional protein hydrolysates, which can be used as a functional ingredient in aquafeed. The concept of responsible food consumption is directly linked with food waste prevention. In their study, Grant and Rossi (b) reported that consumers who follow the dietary guidelines are well aware of the concept of responsible consumption and limitations of food waste. Lack of adherence to dietary guidelines can comprise the health status of individuals. A similar concern was raised by Temesgen et al. who reported that approximately 80% of pregnant females in Ethiopia did not receive iron and folic acid supplements during required intervals due to non-adherence.

In summary, articles in this Research Topic highlight the importance of FLW and its impact on responsible consumption. To meet future needs and attain a sustainable food system, it is extremely important to implement the policies at national and global level to manage food waste, recover valuables from byproducts and ensure awareness among food chain stakeholders.

Author contributions

MS: Conceptualization, Writing – original draft, Writing – review & editing. LS: Writing – review & editing. EV: Writing – review & editing. JR: Writing – review & editing. LR: Writing – review & editing. XS: Writing – review & editing. GD: Writing – review & editing. ML: Writing – review & editing. FO: Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The guest editors would like to thank the authors for their contributions in this Research Topic and the reviewers for the valuable evaluation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

1. Lemaire A, Limbourg S. How can food loss and waste management achieve sustainable development goals? *J Cleaner Prod.* (2019) 234:1221–1234. doi: 10.1016/j.jclepro.2019.06.226

2. Porter SD, Reay DS, Higgins P, Bomberg E. A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. *Sci Total Environ.* (2016) 571:721–9. doi: 10.1016/j.scitotenv.2016.07.041

3. Food Wastage Footprint (Project). *Food wastage footprint: impacts on natural resources: summary report*. Food & Agriculture Organization of the UN (FAO) (2013). Available online at: http://www.fao.org/docrep/018/i3347e/i3347e.pdf (accessed February 16, 2024).

4. Govindan K. Sustainable consumption and production in the food supply chain: a conceptual framework. *Int J Prod Econ.* (2018) 195:419–31. doi: 10.1016/j.ijpe.2017.03.003

5. Reisch L, Eberle U, Lorek S. Sustainable food consumption: an overview of contemporary issues and policies. *Sustainability.* (2013) 9:7–25. doi: 10.1080/15487733.2013.11908111

frontiers in Nutrition

POLICY AND PRACTICE REVIEWS
published: 27 January 2022
doi: 10.3389/fnut.2021.787982

The Italian Observatory on Food Surplus, Recovery, and Waste: The Development Process and Future Achievements

*Federica Grant**† and Laura Rossi†*

Council for Agricultural Research and Economics—Research Centre for Food and Nutrition (CREA Food and Nutrition), Rome, Italy

Food loss and waste (FLW) is an environmental, social, and economic problem. Countries all around the world are looking for efficient strategies to prevent and reduce FLW, as recommended by target 12.3 of the Sustainable Development Goals (SDGs) of the United Nations. The European Union (EU) is strongly committed to helping solve the FLW issue, setting up the Platform on Food Losses and Food Waste, and adopting the Farm to Fork Strategy. Italy has also adopted a consolidated approach toward this issue, in particular through the redistribution of food surplus to those in need, a policy that was instituted with the Gadda Law 166/2016. Importantly, this normative framework also provided for the establishment of the National Observatory on Food Surplus, Recovery, and Waste [Osservatorio sulle Eccedenze, i Recuperi e gli Sprechi Alimentari (OERSA)]. This article describes the creation and development of the OERSA, as the technical entity supporting national FLW policies. One of the first actions taken by the OERSA was that of mapping the FLW initiatives that were being implemented along the entire food supply chain in Italy. This gave the OERSA a solid foundation on which to begin working on two different fronts: (1) Collecting data regarding the primary production sector and at the consumer level and (2) Establishing educational programs and awareness campaigns. The data collected by the OERSA highlight that, although several actors of the Italian supply chain are already conscious of the causes of FLW, new strategies that focus on innovation and cooperation should be encouraged.

Keywords: food loss, food waste, food donation, legislative framework, measurements, Italy

OPEN ACCESS

Edited by:
Rakesh Bhardwaj, National Bureau of Plant Genetic Resources (ICAR), India

Reviewed by:
Luca Secondi, University of Tuscia, Italy
Guobao Song, Dalian University of Technology, China

****Correspondence:***
Federica Grant
federica.grant@crea.gov.it

†These authors have contributed equally to this work and share first authorship

Specialty section:
This article was submitted to Nutrition and Sustainable Diets, a section of the journal Frontiers in Nutrition

Received: *01 October 2021*
Accepted: *29 December 2021*
Published: *27 January 2022*

Citation:
Grant F and Rossi L (2022) The Italian Observatory on Food Surplus, Recovery, and Waste: The Development Process and Future Achievements. Front. Nutr. 8:787982. doi: 10.3389/fnut.2021.787982

INTRODUCTION

Food loss and waste (FLW) prevention and reduction are among the political priorities for national governments and international organizations. It is a subject that is attracting increasing interest, spurring researchers to work on developing prevention, valorization, and management strategies (1–3). The FLW issue is included in the Sustainable Development Goals (SDGs), a universal call for action addressed to all the countries to promote prosperity and protect the planet. The 17 SDGs were adopted by all the United Nations Member States in 2015 as a part of the 2030 Agenda for Sustainable Development, which set out a 15-year plan to achieve these SDGs (4). Each SDG is organized in measurable and monitorable targets. Target 12.3, which aims by 2030 to halve per capita global food waste at retail and consumer levels and reduce food losses along production and supply chains, including postharvest losses, is included in the framework of SDG 12 related to sustainable

consumption and production patterns. This means that the entire agri-food chain, from primary production to consumers, must be considered in connection with the FLW prevention strategies.

FLW is a priority also for the European Union (EU) and its member states. In fact, the European Commission (EC) with the Waste Framework Directive (2008/98/EC) (5) defined a "hierarchy" in food waste management to be applied by the EU member states. This strategy, which was further implemented and adapted (1, 3, 6), considers the prevention and reuse of food for human consumption, as the most preferable options, followed by reuse for animal feeding and byproducts, recycling (including composting), and energy recovery, while waste disposal through landfills should be considered as a last resort.

In 2016, the EC established the EU Platform on Food Losses and Food Waste (7), a public and private initiative coordinated by the Directorate-General for Health and Food Safety (DG SANTE), which includes the EU institutions, experts, and stakeholders. The Platform supports all the actors in the definition of food waste prevention measures, the sharing of best practices, and the evaluation of the progress that has been made over the years. In addition, the FLW question is a part of the EU Farm to Fork Strategy released in 2019 (8), a program that aims to achieve sustainable production, processing, distribution, and consumption together with the prevention of FLW.

The Italian normative and cultural background from which the FLW activities were derived is related to the management of food surplus and its redistribution to those living in poverty. The objective of this article is to describe the Italian actions related to FLW and, in particular, the establishment and development of the National Observatory on Food Surplus, Recovery, and Waste [*Osservatorio sulle Eccedenze, i Recuperi e gli Sprechi Alimentari (OERSA)*], a technical entity setup under the scientific guidance of the Council for Agricultural Research and Economics [Consiglio per la Ricerca in agricolture e l'analisi dell'Economia Agraria (CREA)], the national research institution responsible for food, nutrition, and agricultural research (9, 10).

The research questions addressed in this article were: (i) before the establishment of the OERSA, what was the scenario in Italy concerning FLW, in particular regarding the different sectors of the supply chain? (ii) what process was followed in the development of the OERSA and how could this be replicated in other contexts? and (iii) how has the work of the OERSA contributed to tackling the FLW problem in Italy and how can the data collection and methodologies of OERSA be exploited in further research?

This article provides a contribution to the research discussions on food waste action policies and how our experience could be applied in other countries. The description given in this article of the establishment of the OERSA could be used as an example of field work carried out in this area, especially for the identification of key work directives. In addition, the sharing of the main findings of the OERSA, underlining the criticalities related to FLW in Italy, and putting forward different possible solutions to this issue, can provide valuable information based on a concrete experience that could increase the impact of future actions.

The methodology for the preparation of this article was shaped according to the objectives of the work. The OERSA results presented in the following sections were taken from preexisting studies published in scientific papers or scientific-technical reports presented to stakeholders, the main conclusions of which were subsequently elaborated for the purposes of this article. Triangulation was employed throughout the process of data gathering and analysis, comparing bibliographic material, observations, and documents produced within the OERSA framework to obtain information for the future development of the OERSA itself and food waste policies in Italy.

ITALIAN POLICY AND ACTIONS ON FLW: THE NATIONAL OBSERVATORY

Normative Framework

Italy has adopted a consolidated approach toward food surplus management and redistribution to those in need, codified by a well-defined regulatory process originating in the so-called Good Samaritan Law (155/2003) (11). This law simplified the food donation procedures supporting non-profit organizations in the distribution of food charities. In 2016, an important step forward was taken in the regulatory process with the introduction of the 166/2016 Law (12) that to some extent anticipated the 2030 UN Agenda recommendations. This law provides measures aimed at encouraging food and pharmaceutical surplus redistribution as social solidarity actions through the simplification of bureaucracy, tax deductions, and subsidies either for public or private donors. The objectives of this normative act can be summarized as follows:

- Promoting the recovery and donation of surplus food, primarily to humans, especially to those in need.
- Reducing the environmental impact of FLW through actions that aim to decrease waste and to increase the life cycle of products through reuse and recycling.
- Supporting research activities and increasing consumer and institution awareness, focusing on educating young people.

The Italian board responsible for the FLW activities is the permanent table for combatting waste and promoting food assistance [Food Waste Permanent Table (FWPT)] coordinated by the Ministry of Agricultural, Food, and Forestry Policies. The FWPT organizes activities to reduce food waste at the national level with the aim of disseminating knowledge and sharing data among the key actors in the production system, scientific experts, and society as a whole. The FWPT includes representatives from all the actors of the supply chain (primary sector, manufacturing, industry, retail, and food services), representatives of different Ministries (Health, Environment, and Economic Development), charitable organizations, and Non-governmental Organizations (NGOs) working on food distribution. In this context, the 166/2016 Law established the National Observatory on Food Surplus, Recovery, and Waste as a technical independent entity tasked with collecting and disseminating information and statistics, policy, and best practices related to (i) surpluses along the food supply chain; (ii) food recovery and reuse for human consumption; and (iii) food waste at the household level.

TABLE 1 | Assessment of actions and projects related to the food loss and waste in Italy as a benchmark of the OERSA development.

Sector	Main findings
Primary sector	The Regional Agency for the supply in agriculture (AGREA) set up a platform which collects data and information on the recovery of agricultural products. Food recovered for human distribution varies from 6,881 tons to 27,671 per year. Peaches, clementine, melons, watermelons, onions, nectarines, kiwis, plums, pears and apples were the foods items collected most frequently.
Wholesale sector	The Italian network of markets (*Italmercati*) quantified the amount of fruit and vegetables products recovered from the market and donated through charities that accounted for 4,000 tons in 2016, corresponding to a monetary value of 8 million euros. Recovery actions were concentrated in northern Italian regions with the markets in Milan and Verona covering 70% of the donations.
Retail sector	The National Consumers' Cooperative Organization (ANCC-COOP) during the period 2013-2016 found that between 1.2 and 1.4% of food in their supermarkets became surplus. The food surplus redistribution accounted for 6,000 tons, 80% of which consisted of fresh and perishable products.
Food service sector	The National Association of Catering Companies that has an Observatory on catering and nutrition (ORICOM-ANGEM) in 2015 performed a survey in a sample of school canteens in Northern Italy aimed at making a qualitative, quantitative and economic estimation of food waste. Meal leftovers were 12.5% of the food prepared, especially side dishes. For each meal, the waste was estimated at a monetary value of 0.18 euro.
Life project, an integrated approach, from the industry to the consumer	This project undertook an in-depth analysis across different stages of the food supply chain, focusing on food industries, large-scale distribution and consumers. A survey carried out in 2018 among 40 companies highlighted that 60% of food surplus consisted of meat and cured meat, pasta and bakery products, frozen and "IV gamma" products. In the retail sector, fresh products such as dairy products, fruit, vegetables, meat, and fish had greater excess than processed food. 90% of the food surplus was disposed of into landfill and only 10% was donated to non-profit organizations. The consumer survey highlighted that the categories of food that created the highest amount of waste were fruit, vegetables and prepared meals, with bread proving to be the food that was thrown away the most often. The main causes of waste were the presence of mold, passing the best before date and changes in sensory characteristics. Nevertheless, 70% of the sample reported knowing the difference between use-by and best before date.
Recovery sector/ Charity organizations	The information platform of the Banco Alimentare organization represents a valuable information source in terms of the accuracy and the large number of data collected, as well as for the coverage of the national territory. The database analysis highlighted that, as a result of Law 166/2016, from 2016 to 2017 the quantity of food recovered increased of 2,100 tons. The collection of this data makes it possible to establish which sectors are keener on surplus donation respect to those in which actions to promote donations are needed.

Development of the National Observatory OERSA

The initial steps in the development of the OERSA consisted of a benchmark assessment of the FLW actions of the members of the FWPT. Semi-structured individual interviews were held with the key representatives of the FWPT who provided documentation, strategy, and policy documents where available. For the semi-structured interviews, a broad framework of open questions was used, allowing the dialog to be shaped and adjusted to follow the line of the most informative topic areas emerging from the responses of the interviewee. Interviews were then matched with the documentation provided and triangulation was carried out, comparing interview material, observation, and documents from the various sources. Based on this information, a map of the FLW initiatives was produced to identify potentialities and barriers for a further reduction in FLW, the actors and stakeholders involved along the food chain, and overall to gain an insight into the stage of development of the national FLW polices. An evaluation of the level of initiatives was then done in terms of projects and best practices including the degree of involvement of local communities, the availability of impact indicators and monitoring data, and the added value of the initiative. Critical issues, improvement practices already implemented, strategies, and overall good practices for the prevention of food surpluses and waste were collected and compared for monitoring purposes.

The level of integration of the results collected from different stakeholders was described in terms of performance and output of ongoing actions. The strengths and weaknesses of the different approaches, common intervention, and entry points as well as gaps to be filled were identified. The results of this assessment are shown in the first-year report of the OERSA (13) and summarize in **Table 1**.

The meetings with the key informants of the FWPT showed their willingness to share knowledge and data and at the same time allowed the OERSA members to identify in which sector further studies and interventions needed to be undertaken. As a result, the OERSA developed two directives as a guide for the actions to be implemented:

Directive Action 1: To Fill Information Gaps

- Collecting primary sector data and information through the Agencies for Agricultural Supply, at the national and regional levels, carrying out an exploratory survey on the primary sector companies.
- Collecting information at distribution and consumer level.
- Carrying out an exploratory survey on the food service sector.
- Carrying out qualitative and quantitative surveys with consumers.

Directive Action 2: To Improve Policy and Intervention Actions

Carrying out educational programs aimed at increasing the awareness of food chain operators and consumers of the importance of preventive actions to be established, alongside counteractions for food surplus redistribution and recovery. Two other actions aimed at reducing or preventing FLW during redistribution were identified: the optimization of the use of

instruments that guarantee the correct storage of fresh and processed foods and the improvement of the logistic structure of charitable organizations.

ACTIONABLE RECOMMENDATIONS IN ITALY

Main Results of the OERSA Data Collection

In accordance with these two action directives, during their first 2 years of activity, the OERSA carried out an assessment on household food waste and an evaluation of food surplus, losses, and waste in the primary sector (Directive action 1). These activities were considered as a valuable tool in drawing up policy actions (Directive action 2). During coronavirus disease 2019 (COVID-19) pandemic, considering the exceptionality of the situation, the OERSA undertook a special assessment to monitor the food habits of Italian consumers and to understand their attitude toward food waste during the period of lockdown between March and April 2020. The results of the data collection were collected in 3 reports (13–15) and 3 peer-review publications (16–18).

The OERSA household food waste measurement was the first assessment done at the national level with a representative sample of the Italian households. The data were collected using the methodology developed by van Herpen et al. (19) that allowed a comparison with other European countries (20). The survey involved a representative sample of 1,142 Italian households. The Italian families wasted, on average, 370 g of food per week—a quantity that is in line with that of the Netherlands (365 g/week) and progressively different from Germany (425 g/week), Hungary (464 g/week), and Spain (534 g/week). Perishable products, such as fresh fruit and vegetables, bread, and non-alcoholic drinks, were those with the highest level of waste. Unused (43.2%) or partly used (30.3%) products were the categories thrown away most frequently. There was a significant association between household food waste and preventive practices and the ability to reduce the amount of food that had to be thrown away. The detailed results of this study were released through an OERSA report (in Italian) (13) and a scientific paper (16). Data on household food waste were further linked and duly elaborated with the data on food product purchases in supermarkets and large-scale retailers as the amount of food bought and its economic value (18). This study aims to evaluate the weight and monetary values of food waste among a sample of the Italian families, which reported a total amount of 399 kg of food waste per week (4.4% of the weight of the overall food purchased), corresponding to a monetary value of €1,052 (3.8% of the overall food expenditure). Clustering the food groups according to waste quantity, typology, and monetary value, it was possible to show that price has a role in the generation of food waste, as the lower the unitary cost, the higher the quantity of waste. Consequently, foods with high unitary costs were those less likely to be thrown away.

The OERSA studies for the second-year report focused on agricultural production (14). Two assessments were carried out for this purpose. The first was an analysis performed on preexisting data on agricultural surpluses. The results showed that in 2017, about 3% of fruit and vegetables were left unharvested. Losses were greater in the area of vegetable cultivation (4%) than fruit cultivation (2.6%). Data concerning unharvested fruits and vegetables vary significantly for every product and can fluctuate considerably depending on the harvest every year. Focusing on single crops was helpful to identify the most problematic production with a high risk of market imbalances. The establishment of the Producer Organization (PO) system that brings together farming companies and cooperatives created competitive advantages in preventing criticalities generated by food surpluses and, therefore, also food waste—in the case that the surpluses were distributed to the poor. In 2017, 32,237 tons (0.3% of production) of fruits and vegetables were collected as surplus, the majority of which (82%) were subsequently distributed for consumption by those in need.

Considering the importance of the POs in the redistribution system, a survey of the 17 POs was then carried out. The four fruit supply chains with the highest market excess (apples, kiwis, peaches, and plums) were analyzed, to evaluate the percentage of the production, main causes, and possible interventions regarding the food surplus generation. The tendency to generate food surplus was higher for plums, lower for kiwis, and variable for apples and peaches. The POs declared that the primary reasons that led to food surplus were changes in weather conditions (86.1%), the presence of parasites or phytopathologies (63.9%), alongside problems related to the shape or the size of the products (61.1%). The main food surplus destination was human redistribution (64.9%), followed by distillation (40.5%), composting (35.1%), and the processing industry (18.9%). These figures demonstrated the efficiency of the POs system in preventing food waste by the redistribution of surpluses to the poor.

The OERSA special issue on COVID-19 (15) aimed to evaluate how the Italian habits changed during the lockdown period, the determinants of the changes, and the effect on food waste prevention. The results showed that the lockdown in Italy improved the overall quality of diet, but had negative effects both on the quantity of food consumed and on the levels of physical activity. This situation led to a general increase in body weight and to an exacerbation of the sedentary lifestyle that were already common in Italy. In addition, it highlighted that nearly 80% of respondents were sensitive to food waste, signaling the increased awareness of the Italian consumers of the negative consequences of throwing away food (17).

OERSA Practical Outcomes

As mentioned above, the data collected by the OERSA were aimed to provide a benchmark assessment as a reference for further monitoring as well as to improve policy and intervention actions. The first step in the development of the recommendations was centered at a consumer level, which was also the main food chain sector analyzed by the OERSA. The results of the assessment (13–18) allowed the OERSA to understand which behaviors are more closely connected with the wasting of food. The high prevalence of fresh products that were

thrown away is in line with the perception of not having a clear idea of how to store these kinds of food correctly. In addition to this, wasting unused and partly used food rather than leftovers points to the fact that the consumers may have had difficulties in understanding whether a product was still edible, but also in having adequate equipment or space to store the food. Moreover, price plays a role in generating waste, considering that the Italian consumers tended to throw away less costly foods that were bought in higher quantities.

The OERSA awareness campaigns were based on the observatory results which were also confirmed by other studies carried out in different samples (21–23) and in different settings (24–27).

Several different tools were used for drawing up the recommendations, specifically:

- Website: The OERSA official website (to go live soon) was setup describing in detail how the OERSA was established, its mission, and its main tasks. The website is considered the best communication tool between the OERSA and those who are interested in the subject of FLW. In addition, on the CREA—food and nutrition center website—there is a section[1] that briefly describes the work of the OERSA, where documents and papers are published.
- Weekly updates on social networks: The OERSA created a profile on various social networks where scientific content is published. The Facebook[2] and Instagram[3] profiles are in Italian, while its Twitter[4] account is in English and had around 250 followers at the time of publication. The idea behind the use of social networks was to involve several population groups and to reach an international public. In fact, even with summarized and simplified content, the social network is likely to permit a more immediate diffusion of information than the official websites.
- The Second Edition of the National Nutrition Day carried out in 2019 was dedicated to food waste and was entitled "Nutrinformation: Waste on the Plate"[5]. Representatives from all the levels of the supply chain, from the primary sector to the distribution level, participated in this event, alongside academic researchers, representatives from government ministries, and students. It was an occasion to share knowledge and experience and demonstrate a high level of interest in the topic of FLW. To be as practical as possible and go beyond providing purely academic information, a catering school involved in food waste prevention projects was asked to prepare the lunch using recipes made from leftovers, giving a first-hand view of how to avoid waste.
- A chapter dedicated to FLW was included in the Italian Food-based Dietary Guidelines that were updated in 2018 by the CREA Food and Nutrition Research Center (28). The last chapter of the guidelines deals with sustainable diets and the food waste prevention issue is presented as one of the main strategies to pursue the sustainability goals.

Several other communication strategies aimed at preventing FLW were put in place by the observatory. Among these is the "Decalogue against Food Waste," a set of 10 recommendations (29) that can be publicized in schools, events, and information sessions. The 10 recommendations are shown in **Figure 1**.

Another educational tool produced as a food waste (FW) prevention actionable recommendation was a booklet with creative recipes (30) showing how to use no longer fresh foods that have been in the fridge for a while as well as how to prepare meals with leftovers.

In Italy, in addition to the OERSA, other actors are actively involved in developing strategies against food waste.

- The Waste Watcher International Observatory (31) was setup in 2013 as a spin-off of the University of Bologna. The Waste Watcher International Observatory provided data on household food waste and studied the behaviors of consumers in terms of food management. In the recent years, circular economy and sustainability issues have also been included in its activity. A national awareness campaign called "Zero Waste" involving experts, both in the private and public sectors, and citizens organized various activities with the aim of sharing best practices in the prevention of food waste and general waste, to reduce the waste of water and energy and optimize the use of land.
- The Food Sustainability Observatory (32) was setup in 2017 by the School of Management, Polytechnic University of Milan, and deals with the analysis and dissemination of best practices for innovation aimed at increasing the sustainability of production, focusing on the circular economy model in the agri-food system and on a more sustainable supply chain model. This observatory conducts research, awareness campaigns, and promotion activities for the food supply actors.

DISCUSSION

The policy framework described above shows that the OERSA is actively pursuing the directive objectives established during its development. The OERSA plays a pivotal role in Italian action related to FLW, as a technical entity is able to produce reliable data that can be used as a driver for policy actions. According to recent European estimates (33), consumers generate the highest amount of food waste. Educational programs could be one of the main strategies to tackle the problem and the recommendations developed by the OERSA are coherent with this. Increasing the awareness of consumers, who influence the entire supply chain production, can positively influence the management of the agri-food system, which, in turn, can reduce the generation of FLW. Regarding the primary sector—the second largest contributor to food waste after consumption level (33), the OERSA studies have given a positive contribution by adding information on this aspect. However, some areas have remained largely unexplored in terms of direct measurements. The data collected by the OERSA

[1]https://www.crea.gov.it/web/alimenti-e-nutrizione/-/osservatorio-sugli-sprechi-alimentari
[2]https://www.facebook.com/OERSA-103469301798441/
[3]https://www.instagram.com/oersa_ita/
[4]https://twitter.com/_OERSA
[5]https://www.crea.gov.it/-/nutrinformarsi-lo-spreco-nel-piatto

FIGURE 1 | The 10 recommendations made by the OERSA to prevent food waste by consumers.

concerned only fruit, but research needs to be done also for vegetables, cereals crops, and animal products. For example, high discard rates are reported for fishing (10.1% of annual catches) called bycatches (34). In this case, although the donation process could run into difficulties related to the management of this kind of product, alternative destinations for the discard, such as the processing industry, could be identified.

The food supply actors pointed out that one of the main destinations of the surplus food recovered is that of donations for human consumption. This finding was supported by data collected by the Banco Alimentare Organization (35), highlighting that redistribution for human consumption is a strategy that is now consolidated across the food supply chain in Italy. The Banco Alimentare activity and similar non-profit initiatives that work on the Italian area are the main consequences of the incentives and subsidies established by Italian regulations, in particular by the Law 166/2016. However, even though this approach respects the food waste hierarchy order, there is always a variable amount of food that unavoidably becomes waste. In addition, the recovery process involves costs for the storage and the management of food surplus or in some cases also for processing it before it can be donated. The expense for food surplus management was estimated at between 0.05 and 0.1 €/kg for manufacturing companies, 0.4 and 0.8 €/kg for retail shops, and 1.5 and 2 €/kg for restaurants and canteens in Italy (36). As previously mentioned, the donation of food surpluses is an important aspect of the Italian normative framework and the OERSA was developed in view of this. However, considering the food waste hierarchy, the circular economy (CE) strategy action plan (37) may be an efficient solution to achieve sustainable production patterns (38, 39). For example, reusing food waste for animal feed (40, 41) maybe one of the more suitable options to insert a food product that could, otherwise, be thrown away back in the food supply chain.

Nevertheless, the food waste hierarchy stresses prevention as a priority strategy. In their systematic review, Redlingshöfer et al. (42) stated that there are many problems related to the adoption of actions aimed at the hierarchy of principles including that of prevention. The analysis pointed out that food waste prevention presents many obstacles such as insufficient public participation, perceived high costs, inadequate stakeholder engagement, and uncertainty in terms of policy performance. Additionally, models

for improvement, examples, and best practices to create new policies in food waste prevention are insufficiently reported. The OERSA tried to overcome these criticisms and in consideration of the actions described in this article, it could be said that Italy is in a good position regarding the amount of data collected and the robust methodologies followed, which are then used as drivers to develop educational programs, awareness campaigns, and cooperation between the different sectors of the supply chain. In fact, although there are some aspects that need improvement, as a consequence of the commitment of the government to the FLW problem through the well-established legislation process starting with the Law 155 and ending with the Law 166, Italy has developed and implemented various policies (43) over the years, having increased the interest in FLW prevention and reduction.

Considering the European scenario, the OERSA recommendations are in line with the recommendations for action developed by the EU Platform on Food Losses and Food Waste (44). In fact, for the entire supply chain, the EU advocates cooperation between different actors of the agri-food system, an aspect strongly compatible with the nature of the OERSA, which originates from the FWPT and, therefore, includes representatives from the entire supply chain. At the consumer level, the EU focuses on establishing guidelines for the correct storage, management, and use of food and leftovers at home and for planning the shopping at the supermarket or at grocery stores. All these aspects are fully addressed by the OERSA communication campaigns and are compatible with the results of consumer surveys. For the primary sector, although the OERSA has not yet established specific guidelines, the dialog with the POs highlighted some points that also the EU recommends should be improved, i.e., a better alignment between supply and demand, allowing easy access to innovative strategies and strengthening financial support to farmers. A similar situation can be observed at the donation level. In this case, a common viewpoint can be seen regarding the innovation and modernization of the donation organization structure, together with the idea that donation is the best destination for food surplus.

Thanks to its work, the OERSA has obtained a comprehensive overview of the FLW phenomenon and has developed initiatives and strategies that have evolved in Italy over the years. Periodical meetings with the FWPT and with the actors that are tackling the FLW problem should be encouraged, following the EU recommendations regarding the creation of cooperation between different sectors. Concerning in particular the work of the OERSA, it is important that it is completed following the remaining directives, with the aim of carrying out studies on the distribution and foodservice sectors. The foodservice area needs particular attention considering that, due to the scarcity of data collected until now, it is impossible to obtain realistic estimates and an understanding of the causes of FLW in this sector. Obtaining this kind of information will provide instruments to improve the management of meals and to better design menus, which is of particular importance when referred to the school canteens (45–47). In fact, helping children to become aware of the consequences of food waste means educating future generations with appropriate sensitivity to this problem.

To conclude, the OERSA initiatives for tackling the FLW problem could represent a cornerstone and a valuable experience strictly connected not only to the environment, but also with diet and nutrition. The OERSA will continue its work looking for innovative proposals aimed at making production more efficient, in terms of a reduction in food losses or better management of food surplus, to reduce the environmental impact of the supply chain. The work on food waste at the household level and, in general, at the consumer level is inextricably linked to food consumption, food behavior, and other dietary aspects linked to nutrition and to the promotion of a varied, healthy, and sustainable diet.

AUTHOR CONTRIBUTIONS

FG and LR equally contributed to conceiving, writing, and reviewing the manuscript. LR was responsible for overall supervision, project administration, and funding acquisition. Both authors have read and agreed with the published version of the manuscript.

FUNDING

This study was supported by the Italian Ministry of Agricultural, Food, and Forestry Policies under Grant 1456/2018 Annual Program against food waste. The funder had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

REFERENCES

1. Papargyropoulou E, Lozano R, Steinberger J, Wright N, Ujang Z. The food waste hierarchy as a framework for the management of food surplus and food waste. *J Clean Prod.* (2014) 76:106–15. doi: 10.1016/j.jclepro.2014.04.020
2. Priefer C, Jörissen J, Bräutigam K-R. Food waste prevention in Europe—a cause-driven approach to identify the most relevant leverage points for action. *Resour Conserv Recycl.* (2016) 109:155–65. doi: 10.1016/j.resconrec.2016.03.004
3. Teigiserova DA, Hamelin L, Thomsen M. Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy. *Sci Total Environ.* (2020) 706:136033. doi: 10.1016/j.scitotenv.2019.136033
4. Sustainable Development Goals. Available online at: https://www.un.org/sustainabledevelopment/ (accessed September 3, 2021).
5. EUR-Lex. *Access to European Union Law*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098 (accessed September 27, 2021).
6. EU SCIENCE HUB-*The European Commission's science and knowledge service. Brief on food waste in the European Union*. Available online at: https://ec.europa.eu/jrc/en/publication/brief-food-waste-european-union (accessed September 12, 2021).

7. European Commission. *EU Platform on Food Losses and Food Waste*. Available online at: https://ec.europa.eu/food/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste_en (accessed September 27, 2021).
8. European Commission. Farm to Fork Strategy. Available online at: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_it (accessed September 27, 2021).
9. Crea-Food and Nutrition. *Osservatorio sugli sprechi alimentari*. Available online at: https://www.crea.gov.it/en/web/alimenti-e-nutrizione/-/osservatorio-sugli-sprechi-alimentari (accessed September 27, 2021).
10. Crea-Food and Nutrition. Available online at: https://www.crea.gov.it/en/web/alimenti-e-nutrizione (accessed September 27, 2021).
11. Gazzetta Ufficiale. *LEGGE 25 giugno 2003, n.155* Available online at: https://www.gazzettaufficiale.it/eli/id/2003/07/01/003G0174/sg (accessed September 27, 2021).
12. Gazzetta Ufficiale. *LEGGE 19 agosto 2016, n. 166* Available online at: https://www.gazzettaufficiale.it/eli/id/2016/08/30/16G00179/sg (accessed September 27, 2021).
13. L'Osservatorio sulle Eccedenze, sui Recuperi e sugli Sprechi Alimentari. *Ricognizione delle misure in Italia e proposte di sviluppo. Rapporto finale prima annualità*. (2019). ISBN 978-88-3385-006-1.
14. L'Osservatorio sulle Eccedenze, sui Recuperi e sugli Sprechi Alimentari. *Le potenzialità del primario e del consumatore nella gestione delle eccedenze. Seconda annualità*. (2021). ISBN 978883385 1013.
15. L'Osservatorio sulle Eccedenze, sui Recuperi e sugli Sprechi Alimentari. *L'impatto dell'emergenza covid-19 sulle abitudini alimentari degli italiani del periodo della quarantena di Marzo-Aprile*. (2020). Special Issue.2021. ISBN 9788833850962.
16. Scalvedi ML, Rossi L. Comprehensive measurement of italian domestic food waste in a european framework. *Sustainability*. (2021) 13:1492. doi: 10.3390/su13031492
17. Grant F, Scalvedi ML, Scognamiglio U, Turrini A, Rossi L. Eating habits during the COVID-19 lockdown in italy: the nutritional and lifestyle side effects of the pandemic. *Nutrients*. (2021) 13:2279. doi: 10.3390/nu13072279
18. Aureli V, Scalvedi ML, Rossi L. Food waste of italian families: proportion in quantity and monetary value of food purchases. *Foods*. (2021) 10:1920. doi: 10.3390/foods10081920
19. van Herpen E, van Geffen L, Nijenhuis-de Vries M, Holthuysen N, van der Lans I, Quested T. A validated survey to measure household food waste. *MethodsX*. (2019) 6:2767–2775. doi: 10.1016/j.mex.2019.10.029
20. van Geffen LEJ, van Herpen E, van Trijp H. *Quantified Consumer Insights on Food Waste: Pan-European Research for Quantified Consumer Food Waste Understanding. Report of the EU Project REFRESH Deliverable 1.4. 2017*. (2017). Available online at: https://eu-refresh.org/quantified-consumer-insights-food-waste (accessed September 3, 2021).
21. Annunziata A, Agovino M, Ferraro A, Mariani A. Household food waste: a case study in southern italy. *Sustainability*. (2020) 12:1495. doi: 10.3390/su12041495
22. Falasconi L, Cicatiello C, Franco S, Segrè A, Setti M, Vittuari M. Such a shame! a study on self-perception of household food waste. *Sustainability*. (2019) 11:270. doi: 10.3390/su11010270
23. Gaiani S, Caldeira S, Adorno V, Segrè A, Vittuari M. Food wasters: profiling consumers' attitude to waste food in Italy. *Waste Manag*. (2018) 72:17–24. doi: 10.1016/j.wasman.2017.11.012
24. Bravi L, Francioni B, Murmura F, Savelli E. Factors affecting household food waste among young consumers and actions to prevent it. a comparison among UK, Spain and Italy. *Resour Conserv Recycl*. (2020) 153:104586. doi: 10.1016/j.resconrec.2019.104586
25. De Laurentiis V, Corrado S, Sala S. Quantifying household waste of fresh fruit and vegetables in the EU. *Waste Manag*. (2018) 77:238–251. doi: 10.1016/j.wasman.2018.04.001
26. Silvennoinen K, Katajajuuri J-M, Hartikainen H, Heikkilä L, Reinikainen A. Food waste volume and composition in Finnish households. *Br Food J*. (2014) 116:1058–68. doi: 10.1108/BFJ-12-2012-0311
27. Szabó-Bódi B, Kasza G, Szakos D. Assessment of household food waste in Hungary. *Br Food J*. (2018) 120:625–38. doi: 10.1108/BFJ-04-2017-0255
28. Various authors. *Linee Guida per Una Sana Alimentazione Revisione 2018*. (2019). ISBN 9788833850375. Available Online: https://www.crea.gov.it/en/web/alimenti-e-nutrizione/-/linee-guida-per-una-sana-alimentazione-2018 (accessed 21, 2021).
29. ll decalogo per evitare di sprecare gli alimenti in casa. Available online at: file: https://C:/Users/pc1/Downloads/decalogo%20antispreco%20(1).pdf (accessed September 30, 2021).
30. Spuntini creativi anti-spreco. Available online at: file: https://C:/Users/pc1/Downloads/Spunti(ni)%20CREAtivi%20GdN2%202019.pdf (accessed September 30, 2021).
31. Spreco Zero-Last Minute Market. Available online at: https://www.sprecozero.it/waste-watcher/ (accessed September 28, 2021).
32. Politecnico Milano. School of Management. Food Sustainability Obsercatory. Available online at: https://www.som.polimi.it/en/research/research-lines/food-sustainability-observatory/.
33. Caldeira C, De Laurentiis V, Corrado S, van Holsteijn F, Sala S. Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. *Resour Conserv Recycl*. (2019) 149:479–88. doi: 10.1016/j.resconrec.2019.06.011
34. FAO. The State of World Fisheries and Aquaculture 2020. In brief. Sustainability in action. Rome.
35. Banco Alimentare. Cosa facciamo. Available online at: https://www.bancoalimentare.it/it/cosa-facciamo (accessed Semptember 30, 2021).
36. Garrone PM, Melacini M, Perego A. *Surplus food management against food waste. Il recupero delle eccedenze alimentari. Dalle parole ai fatti*. (2015).ISBN 97888612 80038.
37. Eruopean Commission. *Circular Economy Action Plan*. Available online at: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en (accessed September 28, 2021).
38. Tseng M-L, Chiu ASF, Liu G, Jantaralolica T. Circular economy enables sustainable consumption and production in multi-level supply chain system. *Resour Conserv Recycl*. (2020) 154:104601. doi: 10.1016/j.resconrec.2019.104601
39. Velenturf APM, Purnell P. Principles for a sustainable circular economy. *Sustain Prod Consum*. (2021) 27:1437–1457. doi: 10.1016/j.spc.2021.02.018
40. Georganas A, Giamouri E, Pappas AC, Papadomichelakis G, Galliou F, Manios T, et al. Bioactive compounds in food waste: a review on the transformation of food waste to animal feed. *Foods*. (2020) 9:291. doi: 10.3390/foods9030291
41. Rajeh C, Saoud IP, Kharroubi S, Naalbandian S, Abiad MG. Food loss and food waste recovery as animal feed: a systematic review. *J Mater Cycles Waste Manag*. (2021) 23:1–17. doi: 10.1007/s10163-020-01102-6
42. Redlingshöfer B, Barles S, Weisz H. Are waste hierarchies effective in reducing environmental impacts from food waste? a systematic review for OECD countries. *Resour Conserv Recycl*. (2020) 156:104723. doi: 10.1016/j.resconrec.2020.104723
43. Azzurro P, GaianiS, Vittuari M. Italy-Country report on national food waste policy. *Food Policy*. (2016) 46:129–39. doi: 10.7208/chicago/9780226779386.001.0001
44. EU Platform on Food Losses and Food Waste. *Recommendations for Action in Food Waste Prevention*. (2019). Available online at: https://ec.europa.eu/food/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste_it (accessed September 30, 2021).
45. Antón-Peset A, Fernandez-Zamudio M-A, Pina T. Promoting food waste reduction at primary schools. a case study. *Sustainability*. (2021) 13:600. doi: 10.3390/su13020600
46. Derqui B, Fernandez V, Fayos T. Towards more sustainable food systems. addressing food waste at school canteens. *Appetite*. (2018) 129:1–11. doi: 10.1016/j.appet.2018.06.022

47. Derqui B, Grimaldi D, Fernandez V. Building and managing sustainable schools: The case of food waste. *J Clean Prod.* (2020) 243:118533. doi: 10.1016/j.jclepro.2019.118533

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Nutrition

TYPE Systematic Review
PUBLISHED 21 September 2022
DOI 10.3389/fnut.2022.983639

OPEN ACCESS

EDITED BY
João Miguel Rocha,
University of Porto, Portugal

REVIEWED BY
Daniela Spina,
University of Catania, Italy
Charles Odilichukwu R. Okpala,
Wroclaw University of Environmental and Life Sciences, Poland

*CORRESPONDENCE
Tarek Ben Hassen
thassen@qu.edu.qa

SPECIALTY SECTION
This article was submitted to Nutrition and Sustainable Diets, a section of the journal Frontiers in Nutrition

RECEIVED 01 July 2022
ACCEPTED 23 August 2022
PUBLISHED 21 September 2022

CITATION
El Bilali H, Berjan S, Ben Hassen T, Memon JA, Vaško Ž and Allahyari MS (2022) Research on food loss and waste in the Western Balkans: A systematic review.
Front. Nutr. 9:983639.
doi: 10.3389/fnut.2022.983639

Research on food loss and waste in the Western Balkans: A systematic review

Hamid El Bilali[1], Sinisa Berjan[2], Tarek Ben Hassen[3]*, Junaid Alam Memon[4], Željko Vaško[5] and Mohammad S. Allahyari[6,7]

[1]International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM-Bari), Bari, Italy, [2]Department of Agroeconomy and Rural Development, Faculty of Agriculture, University of East Sarajevo, East Sarajevo, Bosnia and Herzegovina, [3]Program of Policy, Planning, and Development, Department of International Affairs, College of Arts and Sciences, Qatar University, Doha, Qatar, [4]Department of Social Sciences and Liberal Arts, Institute of Business Administration, Karachi, Pakistan, [5]Faculty of Agriculture, University of Banja Luka, Banja Luka, Bosnia and Herzegovina, [6]Department of Agricultural Management, Rasht Branch, Islamic Azad University, Rasht, Iran, [7]Faculty of Economic and Management Sciences, North-West University, Mmabatho, South Africa

Food losses and waste (FLW) is considered a critical issue in the ongoing debate on the sustainability of agri-food systems. However, the scholarly literature on FLW is still geographically-biased, with more attention devoted to developed countries, even in Europe. In this context, this article analyses the state of research on FLW in the Western Balkan region (viz. Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, and Serbia). A search performed in October 2021 on the Web of Science database returned 34 documents, and 21 eligible ones were included in the systematic review. The topical analysis of the literature addressed causes of FLW, stages of the food supply chain, extent and magnitude of FLW, FLW and food security, economic and environmental impacts of FLW, and food waste (FW) management strategies. A central finding was the scarcity of data on FW in the Western Balkans. Moreover, the literature focused on FW at the consumer level, while food loss at other stages of the food chain was generally overlooked. There is a lack of comprehensive analyses of the economic and environmental impacts of FLW as well as its implications in terms of food and nutrition security. The quantification of FLW is generally inaccurate and based on estimates and self-reported data. The literature focuses on FW reuse and recycling (e.g., energy, compost) while other management strategies (e.g., reduction/prevention, redistribution) are rarely addressed. However, the results indicated that consumers in the Western Balkans pay attention to the FW issue, especially during the COVID-19 pandemic, which is an encouraging sign that can be exploited in awareness-raising campaigns and education activities. Meanwhile, research on FLW in the Western Balkans is highly needed to fill the identified knowledge gap and provide evidence to policies dealing with the transition to sustainable food systems in the region.

KEYWORDS

food loss, food waste, sustainable food system, environment, food security, waste management, Balkans

Introduction

Food loss and waste (FLW) refers to a decrease in food mass at all stages of the food chain (1). It occurs along the whole food chain from harvest to consumption; food loss occurs upstream of the food chain (e.g., production, transport, processing), while food waste takes place downstream of the chain (e.g., retail/distribution and consumption) (1–3). Food wastage is influenced by several behavioral, personal, product, and societal factors (4). FLW generates far-reaching environmental, economic and social impacts (1, 3, 5), is an ethical scandal (6), and represents a serious threat to food and nutrition security worldwide (1, 3, 7). Therefore, food waste management hierarchies present different options for managing waste to reduce its environmental footprints and impacts on food security; they prioritize prevention and redistribution with respect to its use as animal feed, for compost and/or energy production, or its landfill disposal (1, 8). The extent of FLW varies not only among countries but also from one commodity to another; food loss is high in the developing world, while food waste is predominant in developed countries (1–3).

Data on the extent and magnitude of FLW are generally scarce and inaccurate. This is particularly true in developing countries such as those of the Western Balkans. The countries of the Western Balkans generate high amounts of municipal waste (9) - Serbia, 2.46 million tons (0.33 t/capita/year) in 2019; Albania, 1.2 million tons (381 kg/capita/year) in 2019; Bosnia and Herzegovina, 3.25 million tons of waste per year (354 kg/capita); North Macedonia, 456 kg per capita in 2019; and Montenegro, 292.7 thousand tons in 2017. While it is assumed that food represents a significant share of solid municipal waste, accurate data on the share of food waste and its amount are missing.

In a recent systematic review of the literature on agri-food systems worldwide, El Bilali et al. (10) found that the research field is north-biased and dominated by researchers and organizations from developed countries in Europe and North America. It is not clear whether such a statement is true in the case of FLW in general and in the Western Balkans in particular. Nevertheless, as of October 2021, only two reviews indexed in the Web of Science database address FLW in the Western Balkans viz. Petravić-Tominac et al. (11) and Đurišić-Mladenović et al. (12). However, both reviews do not provide a comprehensive analysis of FLW in the Western Balkans neither geographically nor thematically. Indeed, geographically speaking, the two articles focus on Croatia (11) and Serbia (12). From the thematic viewpoint, they focus on biodiesel production from waste while overlooking many other issues relating to FLW, which is by far a multidisciplinary field. This makes the case and shows the need for a comprehensive review of the existing literature. In this context, the present systematic review analyses the state of research on FLW in the Western Balkans, focusing on Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, and Serbia. It addresses FLW causes, its extent, and magnitude along the food chain, its economic, environmental, and food security implications as well as FW management strategies.

Methodology

The article draws upon a systematic review of records indexed in the Web of Science (WoS) database and follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (13).

Search source and string

A search was performed on WS on October 16th, 2021, using the following search string*: ("food loss" OR "food wast*") AND (Bosnia OR Croatia OR Montenegro OR Macedonia OR Serbia OR Balkan OR "South*east* Europe").*

Inclusion and eligibility criteria

For the inclusion in the systematic review, a document had to meet simultaneously three eligibility criteria: (i) the thematic focus (viz. FLW is a central topic in the document); (ii) geographical coverage (viz. the document deals with one or more target countries), and (iii) document type (viz. the document is a journal article, book chapter or conference paper; letters to editors and/or notes were excluded).

Search strategy and selected documents

The initial search on WS returned 34 documents (Figure 1). Following the screening of the titles, one record was excluded as it does not deal with target countries. Additional 11 documents were not considered for further analysis based on scrutiny of abstracts. At this step, documents that address only recycling or reusing animal waste (manure) or "unavoidable food waste" were also excluded. Furthermore, one review was left out. Consequently, 21 documents were considered in the systematic review (Table 1).

Content and topical analyses

The content analysis of the selected literature was informed by the methodological approach El Bilali and Ben Hassen (34) adopted in their systematic review on FW in the Gulf

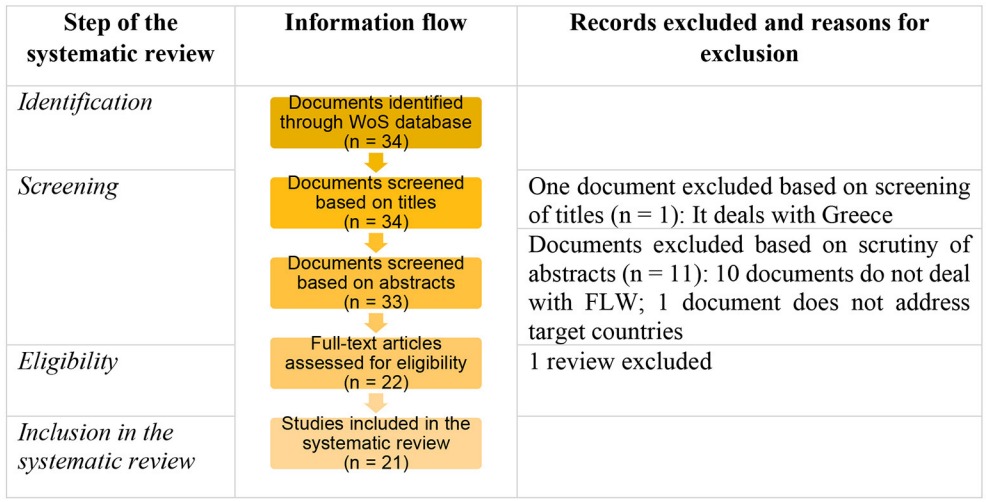


FIGURE 1
Process of the search and selection of documents.

TABLE 1 Documents considered in the systematic review.

Year	Number of documents	References
2021	4	Ben Hassen et al. (14), Berjan et al. (15), Guiné et al. (16), Knežević et al. (17)
2020	3	Ilakovac et al. (18), Matek Sarić et al. (19), Voca et al. (20)
2019	7	Berjan et al. (21), Djekic et al. (22), Djekic et al. (23), Djekic et al. (24), Janjic et al. (25), Jotanovic et al. (26), Knezevic et al. (27)
2018	2	Đurišić-Mladenović et al. (12), Ilakovac et al. (28)
2017	1	Knežević et al. (29), Rutz et al. (30)
2016	1	Rutz et al. (31)
2015	1	Dedinec et al. (32)
2010	1	Njezic et al. (33)

Cooperation Council (GCC) countries. Likewise, the limitations of this systematic review are similar to those mentioned by El Bilali and Ben Hassen (34). The topical analysis addressed causes of food wastage, stages of the food supply chain (viz. production, processing, distribution/trade/retail, consumption), extent and magnitude of FW, food wastage and food and nutrition security, economic impacts of food wastage, environmental implications of FW, FW management strategies (e.g., prevention, redistribution, recycling and reuse). The findings from the scholarly literature are analyzed to see whether or not it addresses each specific topic (and to what extent) as well as how the topic was addressed by comparing and discussing data from the different selected documents.

Results and discussion

Geography of the research on FLW in the Western Balkans

The systematic review suggests that research on FLW in the Western Balkan countries is relatively recent, with the first WoS-indexed article dating back to 2010 (33). One of the main results of this systematic review is the marginality of research on FLW in the target Western Balkan countries. It is, in fact, rather surprising that only 21 documents dealt with food wastage in the region. However, the analysis of the *research geography* shows that attention devoted by scholars to FLW issue differs across the Western Balkans. Indeed, most analyzed studies were performed in Serbia and Croatia (Table 2). It should be underlined that Croatia is the only country that is a member of the European Union (EU) among the target ones and that might suggest that it is better integrated into the research networks in the EU. Meanwhile, Serbia is the most populous country among the target ones. Nevertheless, there are some multi-country, regional and global studies.

FLW along the food supply chain

The selected articles generally focus on FW at the consumption stage, while little or no attention is paid to the

TABLE 2 Geography of the research on FLW in the Western Balkan countries.

Country or region (number of articles)	References
Bosnia and Herzegovina (2)	Ben Hassen et al. (14), Djekic et al. (23)
Croatia (5)	Ilakovac et al. (28), Ilakovac et al. (18), Knezevic et al. (27), Matek Sarić et al. (19), Voca et al. (20)
Montenegro (1)	Berjan et al. (21)
North Macedonia (1)	Dedinec et al. (32)
Serbia (6)	Berjan et al. (15), Djekic et al. (22), Djekic et al. (24), Đurišić-Mladenović et al. (12), Janjic et al. (25), Njezic et al. (33)
Western Balkans* (1)	Jotanovic et al. (26)[1]
Europe** (4)	Knežević et al. (29), Knežević et al. (17)[2], Rutz et al. (31)[3], Rutz et al. (30)[3]
Global*** (1)	Guiné et al. (16)[4]

*This category includes at least two Western Balkan countries.
**This category includes at least a European country outside the Western Balkans.
***This category includes at least one non-European country.
[1]Former Yugoslavian Republics (Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia, Slovenia).
[2]Croatia, Poland, Lithuania and Serbia.
[3]Croatia, France, Macedonia and Spain.
[4]Argentina, Brazil, Croatia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Serbia, Slovenia, Romania and United States.

remaining *stages of the food supply chain,* such as production, harvesting, storage, transport and/or processing. Indeed, most of the selected documents address food wastage at the consumer level (e.g., households, restaurants, etc.), while food losses are generally overlooked in the analyzed scholarly literature. Only documents dealing with the valorization, recycling, and reuse of FLW address food losses (12, 30, 31). This is rather surprising as food losses should be more important in the target developing and in-transition countries of the Western Balkans.

Causes of FLW

There is no article that analyses in a comprehensive way the *causes of FLW* along the whole food chain in the Western Balkan countries. However, some articles address the drivers of food wastage in specific stages of the food chain (mainly consumption) and/or in determined settings (e.g., university canteens, restaurants, households). Voca et al. (20) argue that plate waste in restaurants in Zagreb (Croatia) is affected not only by the portion size (leftover and waste increase with portion size) but also the type of meals (vegan meals are less wasted than dishes including food of animal origin). Meanwhile, Janjic et al. (25) enumerate too long storage, overconsumption, and improper preparation, among the reasons leading Serbian households to throw away significant amounts of food. Ilakovac et al. (28) report that the main culprits in household food wastage in Croatia are preparing excessive amounts of food for meals and purchasing an excessive quantity of food. Djekic et al. (23) found that the highest-ranked reason behind household FW in Bosnia and Herzegovina is linked to plate leftovers. In Serbia, Djekic et al. (22) found two main reasons for throwing away food: expiration dates and rotten smells and tastes. Meanwhile, Knezevic et al. (27) found that attitude toward food wastage among university students in Croatia is affected by the awareness of FW problem, concerns about environmental and economic impacts of FW, health concerns, and awareness and concerns about the expiration date.

Extent of FLW

The selected documents do not include any comprehensive *quantification of FLW* in the Western Balkan countries. Furthermore, most of the few presented figures on household FW quantities are based on estimates and self-reported data and do not make any distinction between edible (cf. avoidable FW) and inedible (cf. unavoidable FW) parts of food (Table 3). Some scholars also analyzed the *most wasted types of food*. Djekic et al. (22) argue that bread and bakery products are the most discarded types of food in Serbia. Likewise, Berjan et al. (21) found bakery products are the most wasted foods in Montenegro. Also, Njezic et al. (33) show a significant amount of leftover bread in Serbia.

Most studies report that food wastage is low in the Western Balkans, with respect to other more developed European countries, and highlight that consumers in the region have a positive attitude and are willing to reduce food wastage (14, 15, 19, 21–23, 25). However, Guiné et al. (16) explore motivations influencing people's eating habits toward sustainability in 13 countries (viz. Argentina, Brazil, Croatia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Serbia, Slovenia, Romania and the United States) and argue that "*Although people avoid food waste at home, the awareness for the waste at restaurants still needs to be improved*."

FLW during the COVID-19 pandemic

More recently, some studies analyzed the effects of the *COVID-19 pandemic*, and the related containment measures, on FLW in some Western Balkan countries such as Bosnia and Herzegovina (14) and Serbia (15). Both studies point out that the pandemic affected food-related practices and behaviors, including food wastage, but the findings are rather mixed; for instance, Ben Hassen et al. (14) report that the pandemic improved the awareness of Bosnians toward food with a decrease

TABLE 3 Quantification of FLW in the Western Balkan countries.

Document	Country	Type of FLW	FLW quantity
Ilakovac et al. (18)	Croatia	Household food waste	75 kg/person/year
Djekic et al. (23)	Bosnia and Herzegovina	Household food waste	2.8 kg/household/week
Djekic et al. (22)	Serbia	Household food waste	1.54 kg/household/week
Djekic et al. (24)	Serbia	Household food waste from animal origin	200 g/household/week (11.3 kg household/year)

in FW while Berjan et al. (15) found that household food wastage increased in Serbia during the COVID-19 pandemic.

Implications of FLW in terms of food security

The selected articles do not address the relationship between FLW and food security; this is probably because food security is not considered an issue in the Western Balkans but denotes, anyway, a gap in the research field. However, many authors refer to food security to justify reducing FLW in the Western Balkans. For instance, the purpose mission of social supermarkets, promoted in Europe during the 2008–2014 economic crisis, is to decrease FW to improve access to food by socially marginalized groups (17), thus combatting food poverty. Knežević et al. (29) point out that various social initiatives, based on cross-sector cooperation in food distribution, try to simultaneously address the problems of food poverty and FW in Croatia and other countries in the EU. Đurišić-Mladenović et al. (12) warn that the use of edible vegetable oils as a potential feedstock for biodiesel in Serbia cannot be considered as a long-term, sustainable choice due to the associated food vs. fuel debate i.e., trade-offs between biofuel production and food security.

Economic and environmental impacts of FLW

The literature included in the systematic review suggests that no article addresses the broad *economic impacts of FLW*. Furthermore, the 21 selected articles do not examine neither the impacts of FLW on the prices of agri-food products in the Western Balkan countries nor how such price changes affect consumers and producers, which are two recurring topics in the literature on the economic implications of FLW (35, 36). However, some articles estimate the financial value of food lost and/or wasted in different settings as well as the economic benefits of recycling or reusing FLW. Berjan et al. (21) argue that the monthly economic value of FW among Montenegrin households is 5–25 Euro. Ilakovac et al. (28) report that about two-thirds of the interviewed Croatian households consider FW a financial loss. Likewise, Knezevic et al. (27) argue that concerns about the economic aspects of FW affect the awareness of university students toward food wastage in Croatia. Interestingly, Djekic et al. (24) study shows that Serbian consumers are more aware of FW's negative social and environmental impacts than of its associated negative economic dimensions.

Further, no article among the selected ones comprehensively analyses the *environmental footprints of FLW* in the Western Balkan countries. Furthermore, no article dealt with neither the externalities of FLW (e.g., water pollution, ecosystem disturbance, biodiversity loss, deforestation) nor the relationship between FLW and climate change. Nevertheless, Djekic et al. (23) report that food wastage contributes to global warming (cf. climate change), acidification, and eutrophication. Likewise, Djekic et al. (22) suggest that "*The global warming impact of food waste and food packaging waste was quantified around 3.46 kg CO_2e/household a week and 0.16 kg CO_2e/household a week, respectively*" (p. 44). Djekic et al. (24) argue that animal origin FW contributes significantly to CO_2 emissions in Serbia. A study carried out by Guiné et al. (16) shows that environmental motivations that affect people's food habits in many countries (including Croatia and Serbia) relate, among others, to biodiversity preservation, natural resources and energy saving, and industrial pollution reduction.

Meanwhile, Ilakovac et al. (28) found that about two-thirds of the Croatian households consider FW bad for the environment. Matek Sarić et al. (19) found that many different socio-demographic factors influence environmentally-concerned food choices in Croatia, such as age, gender, education level, and marital status. Knezevic et al. (27) point out that concern about the environmental impacts is one factor affecting the attitude of Croatian university students toward FW. *Environmental awareness* about FW changes from a country to another even within the Western Balkan region. In this regard, in their analysis of consumers' environmental management of FW of the former Yugoslavian Republics, Jotanovic et al. (26) found that there are significant differences between countries; respondents from Slovenia (that is a member of EU since 2004) show a significantly higher level of ecological disposal of FW, while respondents from Macedonia are less prone to dispose of FW in an ecological manner in comparison to Bosnian and Croatian ones.

FLW management

The considered articles mention different *food waste recovery strategies* ranging from FLW prevention and/or reduction to FLW recycling and reuse (e.g., animal feed, composting, industrial uses such as the production of biogas/biofuel) through food surplus redistribution (donation to food banks, social supermarkets, etc.), which are strategies contemplated in the food waste management hierarchy (37, 38). Ilakovac et al. (28) found that only a small share of the Croatian households feed food leftovers to dogs or cats while many still simply discard leftovers in the bin. Njezic et al. (33) suggest that leftover bread represents an environmental problem in Serbia (especially when landfilled), but also a potentially valuable raw material as animal feed. Đurišić-Mladenović et al. (12) analyze the biodiesel production potential of Serbia and highlight that besides conventional biodiesel sources (e.g., oilseed crops) many other sources can be used, including waste cooking oils as well as oils from non-edible agro-food wastes. Rutz et al. (30, 31) show the potential of biomethane production and its use in transport by using segregated FW (cf. catering sector, households, food, and beverage industry) as feedstock in four European cities [Zagreb (Croatia), Skopje (Macedonia), Malaga (Spain), and Paris (France)] and highlight the multiple environmental benefits of source-separated waste collection and conversion into biomethane in comparison to other waste treatment methods (e.g., landfilling, incineration, composting). Dedinec et al. (32) use the Greenhouse Gas Costing Model (GACMO) and highlight that sustainable management of waste (including FW) can contribute to climate change mitigation measures in developing countries such as North Macedonia. Indeed, the use of the appropriate waste treatment methods (e.g., mechanical biological treatment–MBT–with composting, MBT with anaerobic digesters for energy production) can reduce both GHG emissions and waste management costs (32). Different socio-demographic factors affect the quantities of FW produced and food wastage prevention potential. Ilakovac et al. (18) report that in Croatia the respondent age positively affected FW prevention, while the household income level and size (especially the number of children and teens under 18) had an adverse effect. Knežević et al. (17) analyse the perception of consumers in Central Eastern Europe (viz. Croatia, Poland, Lithuania, and Serbia) toward social supermarkets and put that there is a positive attitude regarding the role of social supermarkets FW reduction.

Conclusion

To the best of our knowledge, this is the first systematic review on FLW in the Western Balkans. The relevance of the present systematic review lies not only in informing the actors of the food supply chain (e.g., policymakers, scientists, etc.) on the landscape of research on FLW in the region but also in synthesizing available data and findings, highlighting the existing knowledge gaps, and identifying research needs in the field. The literature review clearly shows that research on FLW is still marginal in the Western Balkans. Furthermore, the analysis of the available literature shows that the research focuses on FW at the consumer level, while food losses are often overlooked. The existing research gaps also include causes and drivers of FLW, extent, and quantification of FLW along the whole food supply chain, implications of food wastage for food security, and economic impacts and environmental footprints of FLW. Future research should also pay more attention to the type of wasted food (cf. avoidable vs. unavoidable FW) as it determines not only environmental and economic impacts but also appropriate FW management strategies (viz. prevention, redistribution, recycling, and reuse). While FLW prevention and reduction should be given priority, it is also vital to emphasize strategies relating to the reuse and recycling of FW (cf. composting, energy production, industrial use). As the causes of FLW are different, also solutions depend on the food supply chain stage and differ among countries and regions. In this respect, the integration of FW reduction into policy is crucial. Moreover, the efficiency of FW reduction solutions depends on the participation and inclusiveness of a wide range of food supply chain stakeholders. The review highlights the lack of accurate statistics and data about food wastage in the countries of the Western Balkans, and research should help provide data on the magnitude and extent of FW in the region. Given the magnitude of FLW in Western Balkan countries and the obvious knowledge gaps, further research is needed to inform future policy and action. The generation of new data through research is indispensable for designing effective and efficient policies and strategies toward addressing FLW issues in the region. The results indicate that consumers in the Western Balkans pay increasing attention to the FW issue, which is an encouraging sign that can be exploited in other awareness-raising campaigns and education activities. In order to be effective in reducing and/or preventing food wastage, these activities should consider their FW habits, starting from procurement planning through food storage and meals preparation. The reduction of FLW is paramount for food and nutrition security, climate change mitigation, and sustainable management of natural resources in the broader context of sustainable food systems. Therefore, curbing FLW is crucial to achieving the Sustainable Development Goals (SDGs) in the Western Balkans.

Author contributions

HE, SB, and TB: conceptualization, methodology, and writing—review and editing. HE and SB: formal analysis and project administration. MA: data curation. HE, SB, TB, JM, ŽV,

and MA: writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

Funding

The publication of this article was funded by the Qatar National Library.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. HLPE. Food Losses and Waste in the Context of Sustainable Food Systems. *A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. A Report by the High Level Panel of Experts on Food Security and Nutrition (HLPE) of the Committee on World Food Security*. Rome. (2014). Available online at: http://www.fao.org/3/a-i3901e.pdf (accessed October 10, 2021).

2. FAO. *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome. (2011). Available online at: https://www.fao.org/3/i2697e/i2697e.pdf (accessed October 10, 2021).

3. FAO. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome; 2019.

4. Roodhuyzen DMA, Luning PA, Fogliano V, Steenbekkers LPA. Putting together the puzzle of consumer food waste: towards an integral perspective. *Trends Food Sci Technol.* (2017) 68:37–50. doi: 10.1016/j.tifs.2017.07.009

5. WRAP. *Food Waste Trends Survey 2019: Citizen Behaviours, Attitudes and Awareness Around Food Waste*. Waste & Resources Action Programme (WRAP), Banbury (UK). (2020). Available online at: https://wrap.org.uk/resources/report/food-waste-trends-survey-2019 (accessed October 10, 2021).

6. Stuart T. *Waste: Uncovering the Global Food Scandal*. London, UK: WW Norton Co. (2009).

7. FAO. *The Future of Food and Agriculture: Trends and Challenges*. Rome. (2017). Available online at: www.fao.org/3/a-i6583e.pdf (accessed October 10, 2021).

8. Mourad M. Recycling, recovering and preventing "food waste": competing solutions for food systems sustainability in the United States and France. *J Clean Prod.* (2016) 126:461–77. doi: 10.1016/j.jclepro.2016.03.084

9. Maleš I. *Guidelines on Circular Economy for the Countries of the Western Balkans and Turkey*. Brussels: European Environmental Bureau (EEB) and Institute for the Circular Economy (INCIEN). (2020).

10. El Bilali H, Strassner C, Ben Hassen T. Sustainable agri-food systems: environment, economy, society, and policy. *Sustainability*. (2021) 13:6260. doi: 10.3390/su13116260

11. Petravić-Tominac V, Nastav N, Buljubašić M, Šantek B. Current state of biogas production in Croatia. *Energy Sustain Soc.* (2020) 10:8. doi: 10.1186/s13705-020-0243-y

12. Đurišić-Mladenović N, Kiss F, Škrbić B, Tomić M, Mićić R, Predojević Z. Current state of the biodiesel production and the indigenous feedstock potential in Serbia. *Renew Sustain Energy Rev.* (2018) 81:280–91. doi: 10.1016/j.rser.2017.07.059

13. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* (2009) 6:e1000097. doi: 10.1371/journal.pmed.1000097

14. Ben Hassen T, El Bilali H, Allahyari MS, Karabašević D, Radosavac A, Berjan S, et al. Food behavior changes during the COVID-19 pandemic: statistical analysis of consumer survey data from bosnia and herzegovina. *Sustainability*. (2021) 13:8617. doi: 10.3390/su13158617

15. Berjan S, Vaško Ž, Ben Hassen T, El Bilali H, Allahyari MS, Tomić V, et al. Assessment of household food waste management during the COVID-19 pandemic in Serbia: a cross-sectional online survey. *Environ Sci Pollut Res.* (2021) 9:11130–41. doi: 10.1007/s11356-021-16485-8

16. Guiné RPF, Bartkiene E, Florença SG, Djekić I, Bizjak MC, Tarcea M, et al. Environmental issues as drivers for food choice: study from a multinational framework. *Sustainability*. (2021) 13:2869. doi: 10.3390/su13052869

17. Knežević B, Škrobot P, Žmuk B. Position and role of social supermarkets in food supply chains. *Bus Syst Res J*. (2021) 12:179–96. doi: 10.2478/bsrj-2021-0012

18. Ilakovac B, Voca N, Pezo L, Cerjak M. Quantification and determination of household food waste and its relation to sociodemographic characteristics in Croatia. *Waste Manag.* (2020) 102:231–40. doi: 10.1016/j.wasman.2019.10.042

19. Matek Sarić M, Jakšić K, Culin J, Guiné RPF. environmental and political determinants of food choices: a preliminary study in a croatian sample. *Environments*. (2020) 7:103. doi: 10.3390/environments7110103

20. Voca N, Puntaric E, Suric J, Kunjko D. Vegan vs. meat: Categorization of plate waste in restaurants. *Fresenius Environ Bull.* (2020) 29:3048–55.

21. Berjan S, Mrdalj V, El Bilali H, Velimirovic A, Blagojevic Z, Bottalico F, et al. Household food waste in Montenegro. *Ital J Food Sci.* (2019) 31:274–87. doi: 10.14674/IJFS-1276

22. Djekic I, Miloradovic Z, Djekic S, Tomasevic I. Household food waste in Serbia – Attitudes, quantities and global warming potential. *J Clean Prod.* (2019) 229:44–52. doi: 10.1016/j.jclepro.2019.04.400

23. Djekic I, Operta S, Djulancic N, Lorenzo JM, Barba FJ, Djordjević V, et al. Quantities, environmental footprints and beliefs associated with household food waste in Bosnia and Herzegovina. *Waste Manag Res.* (2019) 37:1250–60. doi: 10.1177/0734242X19873709

24. Djekic S, Tomasevic I, Miloradovic Z, Subić J, Roljević S, Djekic I. Sustainability of animal origin food waste in Serbia. *IOP Conf Ser Earth Environ Sci.* (2019) 333:012055. doi: 10.1088/1755-1315/333/1/012055

25. Janjic J, Popovic M, Radosavac A, Sarcevic D, Grbic S, Starcevic M, et al. Household food waste in Belgrade - sin and unconcern. *IOP Conf Ser Earth Environ Sci.* (2019) 333:012039. doi: 10.1088/1755-1315/333/1/012039

26. Jotanovic RS, Sudarevic T, Grubor A, Katic A, Vuksanovic N. Consumers' environmental management of waste analysis of the former yugoslavian republics. *Appl Ecol Environ Res.* (2019) 17:7229–48. doi: 10.15666/aeer/1704_72297248

27. Knezevic B, Kurnoga N, Anic ID. Typology of university students regarding attitudes towards food waste. *Br Food J.* (2019) 121:2578–91. doi: 10.1108/BFJ-05-2018-0316

28. Ilakovac B, Iličković M, Voća N. Food waste drivers in croatian households. *J Cent Eur Agric.* (2018) 19:678–709. doi: 10.5513/JCEA01/19.3.1994

29. Knežević B, Marić I, Šućur Z. Cross-sector cooperation in the field of food distribution as a response to problems of poverty and material deprivation. *Rev za Soc Polit.* (2017) 24:143–67. doi: 10.3935/rsp.v24i2.1410

30. Rutz D, Mergner R, Janssen R, Ribic B, Kostic R, Hadzic A, et al. Benchmarking different treatment methods for organic municipal solid waste. In: Ek L, Ehrnrooth H, Scarlat N, Grassi A, Helm P, editors. *25th European Biomass International Conference*. Stockholm. (2017). p. 204–9.

31. Rutz D, Ribic B, Mergner R, Ugalde J-M, Janssen R, Hadzic A, et al. Turning unexploited food waste into biomethane distributed through local filling stations networks. In: Faaij A, Baxter D, Grassi A, Helm P, editors. *24th International European Biomass Conference on Setting the Course for a Biobased Economy*. Amsterdam. (2016). p. 283–9.

32. Dedinec A, Markovska N, Ristovski I, Velevski G, Gjorgjievska VT, Grncarovska TO, et al. Economic and environmental evaluation of climate change mitigation measures in the waste sector of developing countries. *J Clean Prod.* (2015) 88:234–41. doi: 10.1016/j.jclepro.2014.05.048

33. Njezic Z, Zivkovic J, Cvetkovic B. Possibilities of utilization of the leftover bread. *Chem Ind Chem Eng Q.* (2010) 16:399–403. doi: 10.2298/CICEQ100325039N

34. El Bilali H, Ben Hassen T. Food waste in the countries of the gulf cooperation council: a systematic review. *Foods.* (2020) 9:463. doi: 10.3390/foods9040463

35. Friman A, Hyytiä N. The economic and welfare effects of food waste reduction on a food-production-driven rural region. *Sustainability.* (2022) 14:3632. doi: 10.3390/su14063632

36. Rutten MM. What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agric Food Secur.* (2013) 2:13. doi: 10.1186/2048-7010-2-13

37. Papargyropoulou E, Lozano R, Steinberger JK, Wright N, Ujang ZB. The food waste hierarchy as a framework for the management of food surplus and food waste. *J Clean Prod.* (2014) 76:106–15. doi: 10.1016/j.jclepro.2014.04.020

38. Lombardi M, Costantino M. A hierarchical pyramid for food waste based on a social innovation perspective. *Sustainability.* (2021) 13:4661. doi: 10.3390/su13094661

frontiers | Frontiers in Nutrition

TYPE Original Research
PUBLISHED 01 December 2022
DOI 10.3389/fnut.2022.1062619

OPEN ACCESS

EDITED BY
Muhammad Bilal Sadiq,
Forman Christian College, Pakistan

REVIEWED BY
Manisha Singh,
RMIT University, Australia
Dao Nguyen,
RMIT University, Australia

*CORRESPONDENCE
Jorja Collins
jorja.collins@monash.edu

SPECIALTY SECTION
This article was submitted to Nutrition and Food Science Technology, a section of the journal Frontiers in Nutrition

RECEIVED 06 October 2022
ACCEPTED 10 November 2022
PUBLISHED 01 December 2022

CITATION
Cook N, Collins J, Goodwin D and Porter J (2022) Factors influencing implementation of food and food-related waste audits in hospital foodservices. *Front. Nutr.* 9:1062619. doi: 10.3389/fnut.2022.1062619

Factors influencing implementation of food and food-related waste audits in hospital foodservices

Nathan Cook[1], Jorja Collins[1,2]*, Denise Goodwin[3] and Judi Porter[4]

[1]Department of Nutrition, Dietetics and Food, Monash University, Notting Hill, VIC, Australia, [2]Eastern Health, Box Hill, VIC, Australia, [3]BehaviourWorks Australia Health Programs, Monash University, Clayton, VIC, Australia, [4]School of Exercise and Nutrition Sciences, Institute for Physical Activity and Nutrition, Deakin University, Geelong, VIC, Australia

Background: Designing a food waste audit tool for novel hospital foodservice practice does not guarantee uptake. Intended users must be consulted to understand the tool's feasibility and face validity. This study aimed to identify the perspectives of staff involved in the operation of hospital foodservices on (1) how an evidenced based consensus pathway food waste audit tool is perceived to translate into practice, and (2) to determine the factors that influence the completion of food and food-related waste audits within this setting.

Materials and methods: Purposeful sampling was used to recruit staff with knowledge on the operation/governance of foodservices within hospitals in Victoria, Australia. Semi-structured interviews (n = 20) were conducted *via* Zoom to explore barriers and enablers to completing food and food-related waste audits and a previously published food waste audit tool. NVivo was used for inductive thematic analysis.

Results: Three factors determined the completion of food and food-related waste audits in hospital foodservices, and each factor could be a barrier or an enabler; (1) capacity: the availability of time, labour and materials to complete an audit (2) change: staff resistance to audit procedures and how to gain their buy-in (3) processes, governance, and leadership: the opportunity for high level support, policy and structure to encourage waste audits if present. The consensus tool appeared to have face validity. Planning audit operations, conducting stakeholder meetings, providing education/training to foodservice team members, and facilitating communication between managers and staff were described to support consensus tool use and audit completion.

Conclusion: The consensus tool can be used to support hospital foodservices to complete food and food-related waste audits, although it may need to be customised to be fit for purpose. Optimising the capacity, change

management and processes, governance and leadership of the foodservice department may improve the experience and success of a food and food-related waste audit.

KEYWORDS

foodservice, hospital, food waste, audit, sustainability

Introduction

An estimated 40% of all food produced is lost or wasted globally (1). This has economic, environmental, and social consequences for society, including contributing nearly 10% of total carbon emissions, driving food insecurity and food scarcity, spawning community conflict, and costing the global economy around USD one-trillion annually (2). In response to the UN Sustainable Development Goals (SDGs) countries around the world have adopted their recommendation to halve global food waste by 2030 (SDG goal 12.3) (3). Measuring food waste through food waste audits and waste analytics is critical to achieving this goal as it allows industries to monitor their waste and confidently demonstrate progress over time (4). For example, the "*Target, Measure, Act*" campaign from the UK Waste and Resource Action Programme (WRAP) (5) asks food and drink businesses to set a food waste *target*, consistently *measure* their waste, and *act* to reduce this food waste. Measuring food waste also facilitates changes to practice to reduce the amount of waste generated and/or sent to landfill. The Australian National Food Waste Roadmap which lists 47 interventions predicts that measuring food waste is the intervention that has the second largest capacity to reduce food waste (2.69 million tonnes over 10 years) (6).

With these benefits in mind, measuring food waste could be transformative in the healthcare industry where there are high amounts of food waste; estimated as half of total hospital waste in some institutions (7). It arises due to a variety of reasons such as patients' poor appetite, meal interruptions on the ward, food quality, portion sizes, and rigid ordering systems (8, 9). Aggregate food waste audits (which measure preparation waste, excess food, and plate waste) are important to quantify baseline waste, highlight problem areas or products within the foodservice, and monitor waste over time (10). A recent systematic review (10) consolidated 17 different food waste audit methods into a consensus pathway food waste audit tool that describes how to plan, conduct and analyse an audit in healthcare (**Figure 1**). The tool recommends that foodservices complete regular food waste audits for a duration of 2-weeks (14 days), collecting food and food-related waste (e.g., food packaging, plastic cutlery), before (preparation waste) and after (plate waste) meal times, including the waste from the plating line, and to measure waste using electronic scales.

However, there continues to be an evidence-practice gap when implementing evidence based practice change into healthcare settings (11, 12). Guidelines for complex settings such as hospitals are often developed and assumed to be adopted in practice without considering site readiness, local significance, or organisational goals (12). Previous research has reported that staff involved in hospital foodservice operations are aware of the food waste problem and want to implement strategies for measuring and reducing waste (13–15). However, limitations to measuring food and food-related waste exist and include minimal staff training, problems with data collection (e.g., faulty equipment and missing data) and audit method feasibility (10). Furthermore, kitchen staff completing a 1 day hospital food and food-related waste audit reported difficulty sorting their dish room waste because of staffing resources, safety, and space considerations (16). Other research suggests the challenges faced by foodservice staff are not unique to measuring food and food-related waste. For example, a study which explored the perspectives of hospital foodservice staff on their experiences of delivering a nutrition intervention, identified challenges with completing their existing work tasks due to strict time schedules, specific work role allocations, and the rigid foodservice structure (17).

The aims of this study were to identify the perspectives of staff involved in the operation of hospital foodservices on (1) how an evidenced based consensus pathway food waste audit tool is perceived to translate into practice, and (2) to determine the factors that influence the completion of food and food-related waste audits within this setting.

Materials and methods

A qualitative description approach (18) was used where the authors approached the research from an interpretivist position (19). Interpretivism views knowledge as subjective and based on individual's previous experiences. Realities are multiple and perceived to be socially constructed from the interactions between researchers and participants, to make meaning of the questions under investigation. Participants were hospital foodservice workers who were purposefully selected based on their wealth of knowledge and experience from their work role to describe and explain in depth the phenomenon under study

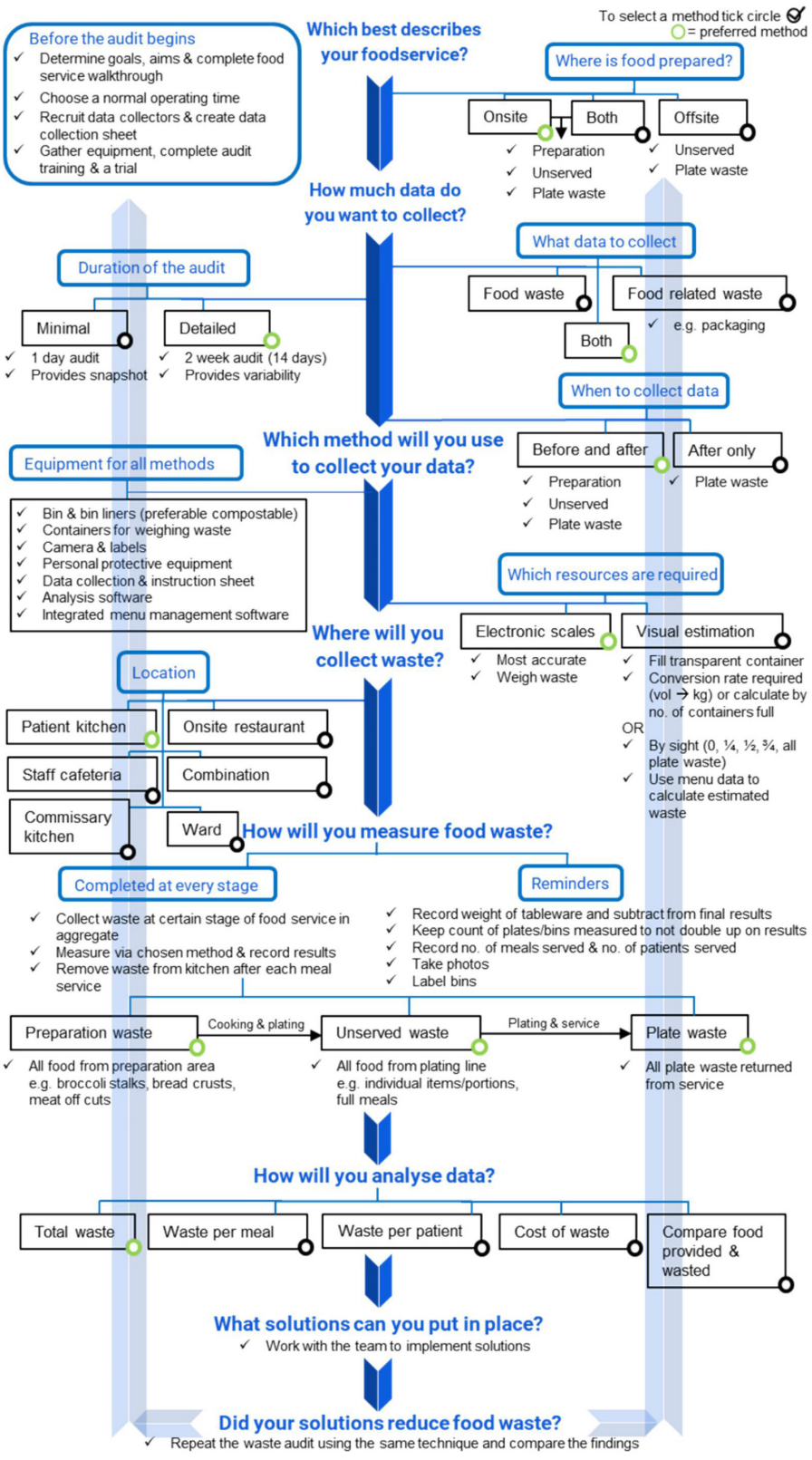


FIGURE 1
Hospital food waste audit consensus tool developed from the most common food waste audit methods identified in the systematic review of food waste audit methods in hospital foodservices originally presented in Cook et al. (10).

(18). Inquiry through the use of semi-structured interviews allowed the opportunity for the researcher to interact with participants and obtain insightful information about what they perceived were barriers and enablers to completing food and food-related waste audits within their individual context. The study was approved by the Monash University Research Ethics Committee (Project ID: 28908) and was developed and reported following the Consolidated criteria for reporting qualitative research (COREQ) guidelines (20).

Setting, participants, and recruitment

Participants sought to form the sample were staff with knowledge on the operation or governance of hospital foodservices. These key informants included foodservice workers and managers, foodservice dietitians, project coordinators, waste management staff, and sustainability officers. They were recruited from public hospitals in Victoria, Australia, using a maximum variation sample approach to include a varied selection of hospitals that may have different realities and experience or perceive the phenomena under study uniquely (21).

Using a random number generator (22) public hospitals in Victoria, Australia (23) were assigned a number 1–140, and clusters of 10 hospitals were invited fortnightly to participate in the study. To recruit the desired key informants for interviews, hospital administrators were contacted by phone to ask for operations managers email addresses. Operations managers were then contacted to identify and request contact details of possible participants, which were shared (with consent) to the research team. A consent form, organisational permission letter and explanatory statement were provided to contacted participants. When these were returned a one on one interview was scheduled. At the end of interviews a snowballing sampling strategy was utilised, whereby participants were asked to identify (if possible), another participant with knowledge on the research topic, and were requested to ask this person to contact the research team if they were interested in participating (24).

Recruitment, data collection and analysis were completed concurrently. During data analysis a combination of information power (considering this study's broad aim, sparse specificity, use of theory, lower dialogue quality, and cross-case analysis strategy) (25) and evidentiary adequacy (ensuring an adequate amount, variety, interpretative, disconfirming, and discrepant evidence is collected) (26) were utilised to determine when a sufficient sample size of hospitals had been reached. The appropriate sample size was deemed satisfactory by the research team through the assistance of the maximum variation sampling technique (21) as it facilitated sampling a wide range of multiple realities (different hospitals) and diverse experiences (different participant roles) helping to reach information power (25). Therefore, a larger sample of hospitals was sought compared to other qualitative studies (9, 13, 27, 28) in this area of research as there is a finite number of potential participants within each hospital (as hospitals usually only contain one foodservice dietitian and foodservice manager). Recruitment of hospitals and therefore identification of important key informants was difficult due to the interruptions of COVID-19 with low response rates from invited participants.

Data collection

The semi-structured interview schedule (**Table 1**) developed by the researchers for this study consisted of open-ended questions to explore barriers and enablers toward completing food and food-related waste audits. Prior to data collection, pilot interviews were completed with nine individuals (four dietitians, four foodservice dietitians, and one food safety and quality coordinator) to test the interview protocol, gauge participant understanding and refine the protocol if required. The major alteration for the interview protocol was providing participants the consensus pathway food waste audit tool (**Figure 1**) (10) and an explanation of how it was designed for use, in advance of their interview.

All interviews were conducted and audio recorded *via* zoom (Version 5.5, Zoom video communications, California) during the period August to November 2021 by one researcher, a Ph.D. candidate and Accredited Practising Dietitian who has previously worked in foodservices and had prior research experience on the topic of food waste audits. Before interviews began, this researcher explained their position and relationship to the project, and confirmed the participant's understanding of the interview topic, data confidentiality and consent. Demographic information (e.g., name, age, gender, job title, and time in position) were collected for descriptive purposes and to verify data sources during analysis. This research was completed during Victoria's 6th COVID-19 lockdown period, thus to reduce participant burden interviews were not repeated and transcripts were not member checked. However, clarification of participant responses or contribution of additional information by participants occurred by email exchange. Additionally, to ensure the researcher provided their full attention to the participant field notes were not taken. Therefore to demonstrate researcher reflexivity during data collection, the interviewer and two other research team members met fortnightly to discuss the concurrent findings (peer debriefing) (29).

Data analysis

Demographic information were analysed and reported using descriptive statistics in Microsoft Excel (Version 16.0). Audio recorded interviews were auto-transcribed using Otter.ai

(Version 2.1.52, California),[1] and transcripts were checked for accuracy by the primary researcher by concurrently listening to recorded audio and manually editing the transcripts. Inductive thematic analysis using a semantic approach proposed by Braun and Clarke (30) was completed by the primary researcher using NVivo (NVivo, QSR International, Victoria). One researcher (NC) conducted initial coding and assigned codes as either "barriers" or "enablers." Next codes with similar meanings or ideas were categorised into broader factors underneath the "barriers" or "enablers" headings. This thematic analysis technique was guided by the approach of previous qualitative studies exploring barriers and enablers to different guidelines and interventions (31–34).

Results

Twelve hospitals participated out of the 70 contacted (17% response rate) where a majority of hospitals were unable to be recruited due to unavailable operations managers email addresses, lack of response, and eligible participants declining the invitation due to time commitments. From the 12 hospitals, 21 participants were interviewed with five of these recruited through snowball sampling. One of the 21 participants withdrew their data post-interview, leaving 20 participants from 11 hospitals for data analysis.

Of the participants, the average (±standard deviation) age was 44 ± 11 years, with a majority (n = 6, 30%) between the ages of 31–40 years. Sixty percent of the participants were female. Participants had worked in their current role between 2-months and 25 years, mostly (n = 15, 75%) for less than 5 years. The most prominent role reported was foodservice dietitian (n = 4), followed by hotel services coordinator. The other 14 positions reported had varying responsibilities, including: cooking food, stock management, allergy control, recipe development, management of sustainability projects, and training of staff. The hospital size represented ranged between 18 and 600 beds, with most hospitals ranging from 100 to 300 beds. The most common foodservice production method was cook chill (n = 5), consistent with the practices of Victorian public hospitals, followed by cook fresh (n = 2), cook freeze (n = 1) and the remaining kitchens using combinations of cook chill, cook fresh and cook freeze (n = 3) (35). Five health services reported completing a food waste audit previously, measuring either unserved or plate waste. Interview length ranged from 50 to 94 min.

The following results discuss participants' perspectives of the consensus pathway food waste audit tool including their general reflections and preliminary thoughts, suggested recommendations for change in design and how they perceive the tool would be used in practice.

1 https://otter.ai/

Strategies to implement the consensus tool

Preparing for an audit and introducing the concepts to staff were described by participants when asked how they would support the execution of a food waste audit within their hospital. Participants suggested that understanding the goals of the audit, assessing their current practice before auditing, planning audit logistics, conducting meetings, providing education to the foodservice team, and facilitating communication between managers and staff about the audit process were all important to ensure a food waste audit was completed.

> *"it's just figuring out what we actually want to get out of it, for starters, figuring out what we want to do, what goals, and what we want to get out of the audit."* (Participant 8, Hotel services coordinator)

Two participants (Participant 2, Foodservice project officer and Participant 4, Food safety supervisor) suggested that creating a data entry sheet to record waste volumes would be helpful in addition to the consensus tool, as it would avoid them needing to create this themselves. Moreover, one participant (Participant 11, Group management support services) suggested that introducing an audit at the same time as another foodservice system change (such as a new menu or the integration of a new electronic menu system which supported data entry) would enhance the implementation of a food waste audit compared to having multiple different system changes occurring over time. This point was not raised by others.

Perceptions of the consensus pathway food waste audit tool

The majority of the participants were supportive of the tool and believed it was detailed, supported understanding of concepts, encouraged different thinking and would facilitate decision making for the completion of a food waste audit.

> *"I mean, I love your food waste audit tool. And it gets to the real nuts and bolts of where we're wasting and allows us to then look at it and then just see where we're wasting food and perhaps then drill down as to why."* (Participant 12, Foodservice dietitian)

Some participants perceived the tool as busy and confusing, while others commented that its use would be individual and specific, with a higher level of knowledge needed to use it in practice. Recommendations to change the structure and content of the tool were provided by 14 participants. Several respondents advised that they would alter the tool to suit their individual needs; for example, one participant focused their

recommendations around providing more explanation on how to complete the audit, and to include detailed information why certain areas of food waste needed to be considered.

> *"I just need more info [Information] because all this info is good to know, this is what I need to do, but it doesn't show me how to do it, you get what I mean?. so probably just mention a little bit more like preparation waste is for this, and why are you looking at that? And why are you looking at unserved waste? And why are you looking at plate wastage? I guess, a little bit more detail. I think you have to think about who is the audience. . ."* (Participant 10, Foodservice dietitian)

When asked how the tool would support participants to complete a food waste audit, the most common response was that the tool supported appropriate decision-making processes to be able to complete a food waste audit successfully. Several participants reported that the tool was ready to use and explained how they would use it in practice.

> *"I think it's great, because it gives a tool for people that don't have that prior knowledge to use, so I can give this to the foodservice supervisor, and say, I think if you're doing an audit, this is what you need to consider before you just jump in and do an audit. . .. And they can use this to actually ask themselves what do I need to do? What do I need to consider?"* (Participant 17, Foodservice dietitian)

TABLE 1 Semi-structured interview protocol to explore staff involved in the operation of hospital foodservices perspectives on how an evidenced based consensus pathway food waste audit tool is perceived to translate into practice, and to determine the factors that influence the completion of food and food-related waste audits within this setting.

Main semi-structured interview questions

1. Can you please tell me about your role, how long you have been in this role and how it is involved in the operation of the hospital foodservice?
2. What do you see as current and anticipated barriers toward regular food waste audits in hospital foodservices?
3. What can you see as current and anticipated enablers toward regular food waste audits?
4. Reflecting on our discussion of barriers and enablers to hospital foodservice food waste audits, what strategies do you think could be used to best roll out a food waste audit in your hospital?
5. What do you think of the decision tree pathway (referring to pathway included within previous publication, which was shared with participants) (10)? Would you change anything?
6. How, or in what way, could the decision tree pathway support food waste audits in your foodservice?
7. When you think back to what we have discussed today is there anything you would like to add before we conclude the interview?

Example prompt questions

- Why do you think these barriers are in place?
- How do they effect the completion of food waste audits?

Other comments were focussed toward using the tool for education purposes, with one participant (Participant 12, Foodservice dietitian) suggesting the tool could act as a starting point and training guide to prepare students for a food waste audit project.

> *"I think it's just a really neat way of preparing for a food waste (audit). So I could imagine showing this to a student and saying, what are we going to measure? Are we going to measure everything? Or are we just going to measure plate waste? Are we just going to measure preparation waste? and then following it down I think would work really well. So it could be very useful as a training tool."*

The subsequent results describe the findings for the second aim of this study. There were three factors which determined the completion of food and food-related waste audits in hospital foodservices; (1) capacity: the availability of time, labour and materials required to complete an audit (2) change: staff resistance to audit procedures and how to gain their buy-in (3) processes, governance and leadership: the opportunity for high level support, policy and structure to encourage waste audits if present. The barriers and enablers for each of these factors are presented below and are connected whereby one suggested barrier can be solved by a recommended enabler and vice versa (**Figure 2**).

1. Capacity

Time was identified as the largest barrier to conducting food waste audits in hospitals and was mentioned by all participants, in part attributable to the study being conducted during the COVID-19 Delta outbreak. Several participants explained how foodservices run on a strict time schedule and the inclusion of additional tasks required time to be allocated within rostered hours. Participants perceived that there was no time left in their scheduled work day to consider completing a food waste audit due to the large nature and detail of the task, day to day interruptions, and time constraints of usual practice. Moreover, participants reported that it is hard to justify a food waste audit when other tasks such as allergen management and meeting government food standards take priority. Participants also commented on the expected regularity (more than once a year) of audits (10) and that repeating the audit regularly would also not be feasible. One participant (Participant 13, Sustainable food systems dietitian) who had previously completed an audit, described that it took 6-months to plan the audit, complete it, and analyse the data.

Labour was also recognised as a one of the largest barriers to completing food waste audits. A food waste audit was labelled as labour intensive, needing a lot of staff resources to collect, sort and measure waste. Foodservices were

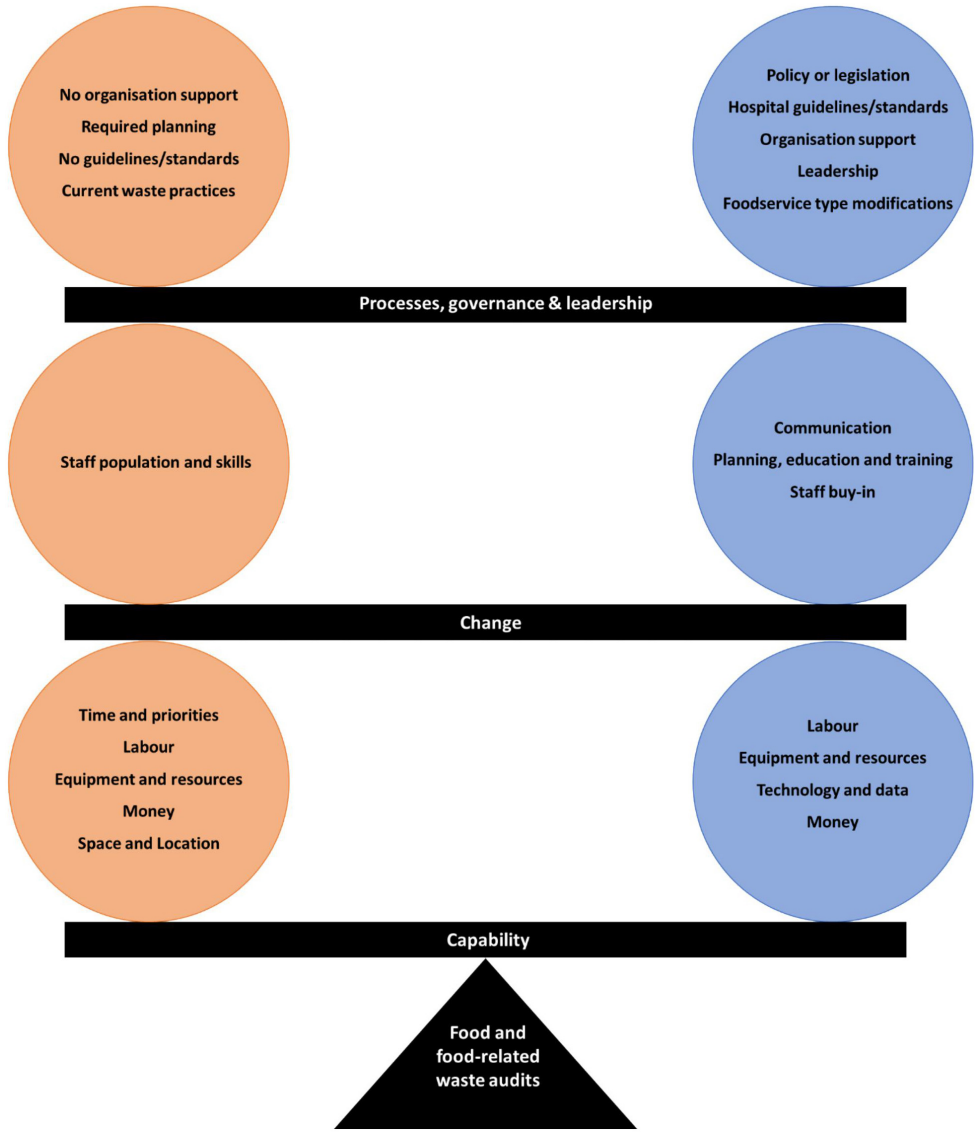


FIGURE 2
Participant reported barriers and enablers to the completion of food and food-related waste audits. Orange circles represent barriers and blue circles represent enablers. White text are the major factors and the black text are individually generated codes.

perceived as *"an understaffed department"* that experiences considerable unplanned leave, with staffing numbers sometimes barely meeting requirements to run day to day operations. For example, one participant (Participant 1, Support service manager) advised that her department has minimal full time staff and are reliant on part-time or casual staff. In addition, time pressures were frequently reported by participants. This resulted in the question of *"who are we going to get to do it?"* being stated often by participants. They described that they would need to hire extra staff to complete audit tasks, find extra labour hours (time) or re-allocate their current workforce to meet audit requirements. The associated funding needed to pay staff was also a related issue.

> *"And the labour, so if I was going to do this at lunchtime, I'd actually need another two people assisting, like checking as the trolleys come in because there's time limits on the strip down of the trolleys to get everything ready for the next meal period. So, there would be me, let's say the supervisor and then we'd need another body to assist. And so that would be the same if we're going to do it for breakfast, lunch and dinner."* (Participant 20, Facilities services manager)

Participants felt staff needed a deep knowledge and understanding of the process to execute the audit correctly. One participant (Participant 6, Foodservice manager) suggested her

staff did not have the necessary skills or knowledge to complete the audit but others felt their staff were capable.

The belief of participants was that the lack of foodservice specific equipment and materials were also a hindrance to food waste audit completion. These included practical tools for data collection such as technology (spreadsheets, artificial intelligence, electronic foodservice systems), forms and templates, as well as training materials to support this process. Other items required for completing industrial-scale food waste audits, such as weighing scales and bins, were not readily available within the organisations who were represented. These items were important because those interviewed, as well as their staff, did not have the knowledge to design their own or procure these resources.

> *"What, I was trying to say is, that is it something we can just adopt, and use? Rather than trying to create something new again, for example, you mentioned here in the decision tree tool the resources required are electronic scales. But it did not mention what kind of electronic scales? What are you referring to? How big or small? Are you talking about mini ones where we just weigh? Or are you talking about the big one? So from my experience, I know that we are talking about the huge one. In terms of, where can we get it from? So be as detailed as possible. . ."* (Participant 10, Foodservice dietitian)

Additionally, some participants from rural sites suggested that the location of the hospital and the position of the kitchen reduced the practicality of completing an audit due to the design of the kitchen providing little space to collect waste.

An increase in labour was the most prominent enabler described by interview participants. To aid audit completion, participants suggested multiple solutions including creating a new role solely focussed on completing food waste audits *via* increasing full time equivalent hours, using casual employees, or splitting tasks up between current staff. However, this would require alterations to current staff scheduling practices. Participants also placed value in having tertiary level healthcare students complete food waste audits. Other suggestions included collaborating with other departments or hiring an external person to undertake the audits.

> *"or maybe getting someone who's qualified to do it, a bit like an external food safety auditor. . .. maybe the same thing, maybe you have a food waste auditor, that comes out periodically and does the audits for you and presents the results and says these are the issues, and this is what you have to address."* (Participant 4, Foodservice dietitian)

Resources were also perceived as enablers toward completing food waste audits. Equipment to facilitate the audit process, including scales, bins and software, as well as an implementation tool such as the consensus pathway (10), were recommended resources to help support audit execution. Technology that could assist in the reporting and collation of data was seen as a worthwhile investment to track changes in waste overtime. Participants were enthusiastic toward having the capability to input food waste data into an electronic system that would allow them to immediately, or retrospectively, access information to support decision making regarding patient care or foodservice improvements. Some foodservices were already achieving this through the use of an online portable patient intake application (visually estimating food waste on the ward when plates are collected by kitchen staff) (36) or sharing data with other foodservices and food rescue organisations. An electronic version of the consensus pathway food waste audit tool was recommended which would allow portability, accuracy, reduce paper waste and decrease time needed for manual data entry and analysis.

> *"to my knowledge I haven't found an easier way, and that's where you've got systems like an electronic foodservice system such as mobile intake where you can just plug stuff in and then it gets extrapolated really easily, that obviously makes it a lot easier. . . so probably another enabler is if you've got an electronic food system, is there some way that that electronic food system can support the data entry for food waste? then that's obviously an enabler that you can just pull data from."* (Participant 17, Foodservice dietitian)

Many participants mentioned the conceivable financial incentives from reducing food waste as a result of actioning improvements to foodservice operations following audit data analysis. For example, potential cost savings could be generated through less waste hauling and reduction in resources such as time and labour for food preparation if there is a stronger understanding of portion requirements for service.

2. Change

Participants described that foodservice staff themselves were a barrier to food waste audit completion. Participants perceived that the magnitude of the change, and the time it required, would disrupt the daily routines of staff who are already resistant to the introduction of new initiatives. Some participants in manager roles alluded to the fact that some foodservice staff had been working in the same role and completing the same tasks for up to 40 years, emphasising why practice change may be difficult in this staff group. Managers also reported that foodservice staff perceived the extra work required for food waste audits being too difficult or not their responsibility. It was further reported that lower level of skills in data collection and limited knowledge of the importance of audits were barriers to accurate audit completion. Foodservice staff, although highly valued, were

believed to be habitual in their tasks and impacted by any small or large variation in practice, which led to foodservice managers not wanting to involve them in planned food waste audits.

> *"I just think that anything that disrupts the routine in the kitchen is burdensome for the staff and is seen as a burden for the staff. I don't know what it is within the culture of the staff, but I think they don't like anything that's out of the ordinary to happen. They like to know their trolleys are going to be ready to go to the ward at a certain time, they take that up, when they've taken that up, they've got their break, then they come back. I just think in some ways, that becomes much more burdensome. . ."* (Participant 5, Foodservice dietitian)

Communicating to staff what the method is to complete food waste audits as well as ensuring the method was performed correctly were described as enablers. Many participants explained that improving the accuracy of audits could be achieved through planning, education and training. Participants provided unique examples of how staff are currently trained, and described they would use these strategies again. These included completing a trial audit, practicing audit methods, training manuals, paid training, and using materials provided by an in-house training advisor.

The most reiterated point in regards to education was to confirm that staff understand how to complete the task properly, so data are trustworthy. Checking with staff to confirm their awareness of the audit steps in the lead up to and during an audit as well as receiving their feedback on the process afterward was suggested by a number of participants. Conducting meetings with all foodservice staff completing the audit, and discussing the audit regularly, in as much detail as possible, was another strategy to ensure that *"everyone is on the same page."* One participant (Participant 13, Sustainable food systems dietitian) highlighted that when communicating to specific staff groups with different levels of education, framing information with the appropriate lens was essential to ensuring the message was understood.

> *"I think it all just generally falls back to training. And it needs to be robust training so that everyone knows exactly what needs to be done."* (Participant 1, Support services manager)

Additionally, gaining foodservice staff buy-in to the idea of an audit before introducing it to their workload was viewed as a critical enabler. To reinforce staff interest one participant (Participant 17, Foodservice dietitian) suggested explaining to the staff group how the audit may benefit them in the future through possible additional funds being generated from less food waste, and that these funds could lead to the purchase of equipment which would make their job easier such as a new dishwasher. Gamification of the data collection process was another strategy said to possibly encourage staff participation whereby setting an achievable target or challenge for staff to work toward may make things fun. Participants also shared that they have staff members in their teams who are concerned about food waste and who would be intrinsically motivated to partake in an audit.

> *"So I think definitely start at grassroots and talk to the staff about what they would think would be a benefit of a plate waste audit, or food waste audit, get their thoughts and ideas back, get an understanding of how they think they would like it to operate, and then obviously work with the managers on the other side of things."* (Participant 2, Foodservice project officer)

Moreover, asking for staff to contribute to the audit design was a major recommendation from participants who believed that, *"foodservice staff have so much knowledge of the kitchen and how it works."* (Participant 13, Sustainable food systems dietitian)

3. Processes, governance, and leadership

The hospital, as an organisation, was also perceived as a barrier toward conducting food waste audits. Participants described the initiation of food waste audits requiring planning and organisational support, however, staff hierarchy and task prioritisation reduced the endorsement of audits as a quality improvement project when compared to other clinically important tasks. Current waste management practices and the absence of guidelines or standards that mandated hospitals to measure food waste were identified as barriers to audit completion.

> *"So to put on potentially other tasks, such as doing plate waste audits regularly, or fairly regularly, I think would be something difficult to get on board when we're not even meeting accreditation standards, like choices with meals and things like that, which I think people would see and consider more of a priority than looking at food waste."* (Participant 4, Food safety supervisor)

Several participants explained how different internal and external influences would help support the implementation of a food waste audit. One strategy described was the use of a top down approach from government to mandate food waste audits through policy or legislation and mandatory reporting. Similarly, participants mentioned that hospital level guidelines or standards are essential to follow for other tasks in the foodservice, such as nutrition standards for meals and menus, and having these for food waste audits would increase their regularity and support workflow.

> *"And so if they make it in a way that every hospital mandates it, which I say if you can put it in a standard it will be perfect, because it makes it very clear that this has to be done."* (Participant 10, Foodservice dietitian)

Executive level support from the organisation was said to be an enabler to implementing food waste audits. Some hospitals already had established environmental sustainability working groups and food waste audits were a "project" participants believed could be of future focus. Influencing change through identifying an individual in a leadership role (such as a supervisor, manager, or champion) was also discussed. Modifying other foodservice practices such as the foodservice type from cook chill to room service and when or how waste was collected were expected to facilitate the implementation of food waste audits and help achieve the overall goal of reducing food waste.

> *"But there are other ways around meeting that waste management I guess. With a new food project that we're going to introduce it will be designed so we can do plate waste audits, which is beneficial for a number of reasons. One of those reasons is obviously food waste data. The other reason is malnutrition of our patients and residents. So that gives dietitians sort of an insight or data to look into as far as how nutrition balances go for our patients. From our point of view, it gives us an insight of food waste."* (Participant 11, Group management support services)

Discussion

This study sought to identify the perspectives of staff involved in the operation of hospital foodservices on how an evidenced based consensus pathway food waste audit tool is perceived to translate into practice, and to determine the factors that influence the completion of food and food-related waste audits within this setting. With positive reflections toward the consensus tool presented by a majority of participants, hospital foodservices are encouraged to use the tool to plan, conduct and analyse a food and food related waste audit. Additionally, the findings indicate a number of reported barriers that are perceived to deter from prioritising and completing a food waste audit, including time, labour, resources, the staff population, hospital logistics, and change. However, various enabling factors were described by participants which present a solution to these barriers, such as outsourcing labour, training staff, organisational support, increased resources, and an uncomplicated audit procedure. For hospital foodservices to successfully trial or implement this tool in their practice the perspectives presented in this study should be reviewed. Appropriately applying the consensus pathway food waste audit tool may then promote possible outcomes such as decreases in waste, monetary savings and workflow enhancements. Moreover, if the use of the consensus tool is magnified to other food providing institutions experiencing high amounts of food waste such as aged care, prisons and childcare (37), this could have large influences on the economic, social and environmental impacts associated with food waste (38). This may promote reputational sustainability within these organisations or industries and (39) will contribute to the actions required to meet UN SDG 12.3 (3).

The consensus pathway food waste audit tool (10) may act as a guideline and reference point for hospital foodservices to recognise the essential decisions required before completing a food waste audit. The tool provides users with different choices to design an audit to best suit their foodservice operations. It appeared that the tool had face validity and was accepted by those working in the foodservice setting who are the intended users. Participants described the need to customise the tool to their needs and their contexts, and this is appropriate and recommended. A systematic review has found that providing flexibility in intervention design to different hospital sites that are incorporating the same intervention caters for unique site specific barriers and enablers (40). Additionally, transferring the current manual version of the tool to an online format which is interactive, similar to other foodservice innovations that can calculate food waste (36, 41–43), may be the next step to accelerate the tool's accessibility and support its usage at scale. Refinements recommended in this study for the tool's detail, design, and content could be integrated at that time. Furthermore, evidence based strategies to reduce food waste (8, 9) or waste management strategies aligned with the food recovery hierarchy (44) to divert waste from landfill could be built into the tool to provide direction on what actions can be taken after a waste audit is completed (45).

Within the three categories of (1) capacity, (2) change, and (3) processes, governance and leadership identified in this study the reported barriers and enablers were inter-linked, whereby collectively across all interviews the barriers to practice change were combatted by suggested enablers from the same or different participants (**Figure 2**). This pattern of clear associations between reported barriers and enablers occurred in a similar systematic review (40) exploring the barriers and enablers to implementing hospital interventions, which also found comparable themes to those derived from our data; system, staff, and the intervention itself. Participants in the present study suggested that for foodservices to support a food and food-related waste audit at their site they need to: increase overall staff resources; obtain necessary equipment; gain key stakeholder buy-in and executive support; develop an audit plan; and lead, communicate, and educate those expected to complete the audit. These could possibly be achieved

through the involvement of hospital nutrition and dietetics departments in the audit process. Dietitians are equipped with communication, leadership and management skills, have experience with project development, implementation and evaluation (46), regularly have work-based placement students who could assist with data collection, and also collaborate with other professionals such as speech pathology (47) who have a vested interest in the foodservice. Furthermore there is a role for other staff groups, including members from the organisational environmental/sustainability committees, and nursing and medical staff who are committed to sustainability in healthcare (48).

Limitations

This study was completed during the height of the delta-strain COVID-19 outbreak in Melbourne, Victoria (49). Consequently, recruitment of participants was challenging as the healthcare system prioritised its resources to combat the pandemic. There were considerably more participants in management roles rather than general foodservice roles, potentially due to their greater availability to participate in an online interview. However, although these staff were not front line workers they were still able to contribute valuable opinions regarding waste audit implementation within their teams. Completing interviews *via* Zoom (Version 5.5, Zoom video communications, California) rather than face to face may be viewed as a limitation, however, research has demonstrated interview participants perceive this method as time and cost-effective, convenient and practical (50). Furthermore, this method allowed the researchers to access previously out of reach participants as a result of the COVID-19 pandemic. This research has been designed in a way to support internal coherence, increasing its quality, trustworthiness and rigour (19). Philosophical alignment was established through the interpretivist paradigm whereby the authors' relativist ontology, subjectivist epistemology, value bound axiology, use of qualitative description methodology and semi-structured interview data collection method supported research design (19, 51, 52). Additionally, reflexivity was demonstrated during data collection and analysis through explaining to participants the researcher's connection to the project, and the research team conducting fortnightly peer-debriefing sessions where collective group discussion of themes occurred (29).

Conclusion

This research uncovered perceptions of the factors that may influence implementation of food and food-related waste audits and an evidenced based consensus pathway food waste audit tool which could facilitate decision making among staff involved in hospital foodservices. The consensus tool appears to have face validity according to the participants interviewed in this study and could be used to design a food and food-related waste audit in a hospital foodservice. However, before integrating this tool into practice, hospital foodservices must consider the findings highlighted in this study to identify possible barriers and or enablers that may impact their site-specific style of food and food-related waste audit. Customisation of an audit best suited to a hospital's environment, resources, workforce and perhaps behaviours will then support appropriate audit execution and outcomes.

Data availability statement

Raw data is not available for sharing as ethics approval and participant consent does not allow for this.

Ethics statement

The studies involving human participants were reviewed and approved by the Monash University Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

NC conducted the interviews, collated, analysed and interpreted the data, and wrote the manuscript. DG, JC, and JP supervised this process and critically reviewed the manuscript. All authors contributed to the conceptualisation and design of the study and have read and approved the final publication.

Funding

NC received a departmental scholarship for his Ph.D. from Monash University's Department of Nutrition, Dietetics and Food, and a King and Amy O'Malley Trust Scholarship during this study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. World Wide Fund for Nature [WWF]. *Driven to Waste*. Gland: World Wide Fund for Nature (2021).

2. Food and Agriculture Organization of the United Nations [FAO]. *Food Wastage Footprint Full-Cost Accounting Final Report*. Rome: Food and Agriculture Organization of the United Nations (2014).

3. Food and Agriculture Organization of the United Nations [FAO]. *Sustainable Development Goals*. Rome: Food and Agriculture Organization of the United Nations (2020).

4. Champions 12.3. *Call to Global Action on Food Loss and Waste*. (2020). Available online at: https://champions123.org/publication/call-global-action-food-loss-and-waste (accessed September 16, 2022).

5. Waste and Resource Action Programme [WRAP]. *Food Waste Reduction Roadmap*. Banbury: Waste and resource action programme (2021).

6. Food Innovation Australia Limited [FIAL]. *National Food Waste Strategy Feasibility Study - Can We Halve Australia's Food Waste by 2030?* Macquarie Park, NSW: Food Innovation Australia Limited (2021).

7. Carino S, Porter J, Malekpour S, Collins J. Environmental sustainability of hospital foodservices across the food supply chain: a systematic review. *J Acad Nutr Diet.* (2020) 120:825–73. doi: 10.1016/j.jand.2020.01.001

8. Williams P, Walton K. Plate waste in hospitals and strategies for change. *e-SPEN Eur J Clin Nutr Metab.* (2011) 6:e235–41. doi: 10.1016/j.eclnm.2011.09.006

9. Porter J, Collins JA. Qualitative study exploring hospital food waste from the patient perspective. *J Nutr Educ Behav.* (2021) 53:410–7. doi: 10.1016/j.jneb.2020.10.008

10. Cook N, Collins J, Goodwin D, Porter J. A Systematic review of food waste audit methods in hospital foodservices. *J Hum Nutr Diet*. (2021) 35:68–80. doi: 10.1111/jhn.12928

11. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci.* (2009) 4:50. doi: 10.1186/1748-5908-4-50

12. Lyon AR, Comtois KA, Kerns SE, Landes SJ, Lewis CC. Closing the science–practice gap in implementation before it widens. In: Albers B, Shlonsky A, Mildon R, editors. *Implementation Science 3.0*. Berlin: Springer (2020). p. 295–313. doi: 10.1007/978-3-030-03874-8_12

13. Carino S, Collins J, Malekpour S, Porter J. Environmentally sustainable hospital foodservices: drawing on staff perspectives to guide change. *Sustain Prod Consum*. (2021) 25:152–61. doi: 10.1016/j.spc.2020.08.003

14. Ofei KT, Holst M, Rasmussen HH, Mikkelsen BE. How practice contributes to trolley food waste. a qualitative study among staff involved in serving meals to hospital patients. *Appetite.* (2014) 83:49–56. doi: 10.1016/j.appet.2014.08.001

15. Ofei KT, Werther M, Thomsen JD, Holst M, Rasmussen HH, Mikkelsen BE. Reducing food waste in large-scale institutions and hospitals: insights from interviews with danish foodservice professionals. *J Foodserv Bus Res.* (2015) 18:502–19. doi: 10.1080/15378020.2015.1093457

16. Thiel CL, Park S, Musicus AA, Agins J, Gan J, Held J, et al. Waste generation and emissions of a hospital kitchen in the Us: potential for waste diversion and carbon reductions. *PLoS One.* (2021) 16:e0247616. doi: 10.1371/journal.pone.0247616

17. Collins J, Huggins CE, Porter J, Palermo C. Factors influencing hospital foodservice staff's capacity to deliver a nutrition intervention. *Nutr Diet.* (2017) 74:129–37. doi: 10.1111/1747-0080.12344

18. Moisey LL, Campbell K, Whitmore C, Jack SM. Advancing qualitative health research approaches in applied nutrition research. *J Hum Nutr Diet.* (2022) 35:376–87. doi: 10.1111/jhn.12989

19. Palermo C, Reidlinger DP, Rees CE. Internal coherence matters: lessons for nutrition and dietetics research. *Nutr Diet.* (2021) 78:252–67. doi: 10.1111/1747-0080.12680

20. Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (Coreq): a 32-item checklist for interviews and focus groups. *Int J Qual Health Care.* (2007) 19:349–57. doi: 10.1093/intqhc/mzm042

21. Suri H. Purposeful sampling in qualitative research synthesis. *Qual Res J.* (2011) 11:63–75. doi: 10.3316/QRJ1102063

22. Haahr M. *Random.Org*. Dublin: Ireland Randomness and Integrity Services Ltd (1998).

23. Victoria State Government. *Public Hospitals in Victoria*. Washington, DC: Department of Health & Human Services (2015).

24. Vehovar V, Toepoel V, Steinmetz S. Non-probability sampling. In: Wolf C, Joye D, Smith TW, Fu YC, editors. *The Sage Handbook of Survey Methods*. Thousand Oaks, CA: Sage (2016). p. 329–45. doi: 10.4135/9781473957893.n22

25. Malterud K, Siersma VD, Guassora AD. Sample size in qualitative interview studies: guided by information power. *Qual Health Res.* (2016) 26:1753–60. doi: 10.1177/1049732315617444

26. Vasileiou K, Barnett J, Thorpe S, Young T. Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-Year period. *BMC Med Res Methodol.* (2018) 18:148. doi: 10.1186/s12874-018-0594-7

27. Goonan S, Mirosa M, Spence H. Getting a taste for food waste: a mixed methods ethnographic study into hospital food waste before patient consumption conducted at three New Zealand foodservice facilities. *J Acad Nutr Diet.* (2014) 114:63–71. doi: 10.1016/j.jand.2013.09.022

28. Sonnino R, McWilliam S. food waste, catering practices and public procurement: a case study of hospital food systems in Wales. *Food Policy.* (2011) 36:823–9. doi: 10.1016/j.foodpol.2011.09.003

29. Lodico MG, Spaulding DT, Voegtle KH. *Methods in Educational Research: From Theory to Practice*. New York, NY: John Wiley and Sons (2010).

30. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol.* (2006) 3:77–101. doi: 10.1191/1478088706qp063oa

31. Tauqeer F, Myhr K, Gopinathan U. Institutional barriers and enablers to implementing and complying with internationally accepted quality standards in the local pharmaceutical industry of Pakistan: a qualitative study. *Health Policy Plan.* (2019) 34:440–9. doi: 10.1093/heapol/czz054

32. Ruuskanen E, Leitch S, Sciberras E, Evans S. "Eat, pray, love. ritalin": a qualitative investigation into the perceived barriers and enablers to parents of children with adhd undertaking a mindful parenting intervention. *Complement Ther Med.* (2019) 37:39–46. doi: 10.1016/j.ctcp.2019.08.005

33. Barnard E, Brown CR, Weiland TJ, Jelinek GA, Marck CH. Understanding barriers, enablers, and long-term adherence to a health behavior intervention in people with multiple sclerosis. *Disabil Rehabil.* (2020) 42:822–32. doi: 10.1080/09638288.2018.1510550

34. Mc Goldrick E, Crawford T, Brown J, Groom K, Crowther C. Identifying the barriers and enablers in the implementation of the New Zealand and Australian antenatal corticosteroid clinical practice guidelines. *BMC Health Serv Res.* (2016) 16:617. doi: 10.1186/s12913-016-1858-8

35. Victorian State Government Department of Health. *Review of Food Standards in Victorian Public Hospitals and Residential Aged Care Services: Summary Report*. (2021). Available online at: https://www.health.vic.gov.au/quality-safety-service/healthy-and-high-quality-food-in-public-hospitals-and-aged-care-facilities (accessed February 16, 2022).

36. Maunder K, Marshall K, Syed K, Smilevska S, Beck E, Mak M, et al. Validation of an electronic food intake tool and its usability and efficacy in the healthcare setting. *J Hum Nutr Diet.* (2021) 35:613–20. doi: 10.1111/jhn.12969

37. Meier T, von Borstel T, Welte B, Hogan B, Finn SM, Bonaventura M, et al. Food waste in healthcare, business and hospitality catering: composition,

environmental impacts and reduction potential on company and national levels. *Sustain.* (2021) 13:3288. doi: 10.3390/su13063288

38. Lins M, Puppin Zandonadi R, Raposo A, Ginani VC. Food waste on foodservice: an overview through the perspective of sustainable dimensions. *Foods.* (2021) 10:1175. doi: 10.3390/foods10061175

39. Nobanee H, Alhajjar M, Abushairah G, Al Harbi S. Reputational risk and sustainability: a bibliometric analysis of relevant literature. *Risks.* (2021) 9:134. doi: 10.3390/risks9070134

40. Geerligs L, Rankin NM, Shepherd HL, Butow P. Hospital-based interventions: a systematic review of staff-reported barriers and facilitators to implementation processes. *Implement Sci.* (2018) 13:36. doi: 10.1186/s13012-018-0726-9

41. Roberts S, Chaboyer W, Hopper Z, Marshall AP. Using technology to promote patient engagement in nutrition care: a feasibility study. *Nutrients.* (2021) 13:314. doi: 10.3390/nu13020314

42. Neaves B, Bell JJ, McCray S. Impact of room service on nutritional intake, plate and production waste, meal quality and patient satisfaction and meal costs: a single site pre-post evaluation. *Nutr Diet.* (2021) 79:187–96. doi: 10.1111/1747-0080.12705

43. MacKenzie-Shalders K, Maunder K, So D, Norris R, McCray S. Impact of electronic bedside meal ordering systems on dietary intake, patient satisfaction, plate waste and costs: a systematic literature review. *Nutr Diet.* (2020) 77:103–11. doi: 10.1111/1747-0080.12600

44. United States Environmental Protection Agency [USEPA]. *Sustainable Management of Food, Food Recovery Hierarchy*. Washington, DC: United States Environmental Protection Agency (2020).

45. Cook N, Goodwin D, Porter J, Collins J. Food and food-related waste management strategies in hospital food services: a systematic review. *Nutr Diet.* (2022). [Epub ahead of print]. doi: 10.1111/1747-0080.12768

46. Dietitians Australia. *National Competency Standards for Dietitians in Australia*. (2021). Available online at: https://dietitiansaustralia.org.au/sites/default/files/2022-03/DA_NationalCompetencyStandards_WithGuide_2021%20%28PDF%2C%20376KB%29.pdf (accessed September 16, 2022).

47. Croker A, Brown L, Little A, Squires K, Crowley E. Developing and maintaining collaborative practice: exploring perspectives from dietetics and speech pathology about 'what works well'. *Nutr Diet.* (2019) 76:28–37. doi: 10.1111/1747-0080.12506

48. Australian Medical Association [AMA]. *Environmental Sustainability in Health Care - 2019*. (2019). Available online at: https://www.ama.com.au/position-statement/environmental-sustainability-health-care-2019 (accessed October 2, 2022).

49. Garside V. *Timeline of Every Victoria Lockdown (Dates and Restrictions)*. (2021). Available online at: https://bigaustraliabucketlist.com/victoria-lockdowns-dates-restrictions/ (accessed January 13, 2022).

50. Archibald MM, Ambagtsheer RC, Casey MG, Lawless M. Using zoom videoconferencing for qualitative data collection: perceptions and experiences of researchers and participants. *Int J Qual Methods.* (2019) 18:1–8. doi: 10.1177/1609406919874596

51. Kivunja C, Kuyini AB. Understanding and applying research paradigms in educational contexts. *Int J High Educ.* (2017) 6:26–41. doi: 10.5430/ijhe.v6n5p26

52. Wahyuni D. The research design maze: understanding paradigms, cases, methods and methodologies. *J Appl Manag Account Res.* (2012) 10:69–80.

frontiers | Frontiers in Nutrition

TYPE Original Research
PUBLISHED 14 December 2022
DOI 10.3389/fnut.2022.1026829

OPEN ACCESS

EDITED BY
Lei Chen,
Guangdong Ocean University, China

REVIEWED BY
Mohammad Sadegh Allahyari,
Islamic Azad University, Rasht Branch, Iran
Francesca Scazzina,
University of Parma, Italy

*CORRESPONDENCE
Federica Grant
federica.grant@crea.gov.it

SPECIALTY SECTION
This article was submitted to Nutrition and Food Science Technology, a section of the journal Frontiers in Nutrition

RECEIVED 24 August 2022
ACCEPTED 30 November 2022
PUBLISHED 14 December 2022

CITATION
Grant F and Rossi L (2022) Sustainable choices: The relationship between adherence to the dietary guidelines and food waste behaviors in Italian families.
Front. Nutr. 9:1026829.
doi: 10.3389/fnut.2022.1026829

Sustainable choices: The relationship between adherence to the dietary guidelines and food waste behaviors in Italian families

Federica Grant* and Laura Rossi

Council for Agricultural Research and Economics-Research Centre for Food and Nutrition (CREA Food and Nutrition), Rome, Italy

Introduction: Food loss and waste are urgent problems to address. Recent estimates highlighted that the highest quantities of waste are generated at the household level and for this reason, the interest in this sector has increased over years.

Methods: To investigate if there is a connection between consumers' behaviors aiming at reducing food waste and consumers' choices in adopting healthy eating habits, a survey among a sample (n = 2,869) representative of the Italian population was carried out with the use of validated questionnaires.

Results: Results demonstrated that the higher the adherence to the Italian dietary guidelines indicator (AIDGI) the higher the score measuring household food waste behaviors (HFWB). In particular, the highest AIDGI corresponds to a preponderance of respondents that was more able to plan the shopping and the use of food (38.9%, $p < 0.001$), to better evaluate the quantities to cook (40.4%, $p < 0.001$), to avoid impulsive buying (35.2%, $p < 0.01$), to have a high knowledge of the food stored (38.4%, $p < 0.001$), to reuse leftovers (35.4%, $p < 0.001$), to assess food safety (34.7%, $p < 0.001$), to plan accurately (34.9%, $p < 0.01$), to know how to prolong the shelf life of a product (34%, $p < 0.05$), and to cook creatively (32%, $p < 0.01$). In addition to that, half of the respondents with the lowest AIDGI score did not receive any education regarding food waste (51.1%, $p < 0.001$). HFWB indicators globally resulted in scores ranging from 40 to 80% revealing the attention of Italians to food waste issues. Regarding eating habits, in half of the sample (50.4%) a consumption pattern with low adherence to nutritional recommendations was found, in particular among men (34.4%), younger age groups (40%), and people living in large families (42.3%).

Discussion: The overall results provided interesting information that could give input for planning nutrition education actions and identifying targets and topics to be addressed.

KEYWORDS

food waste behaviors, dietary recommendations, eating habits, sustainability, household, Italy

1 Introduction

Food loss and waste (FLW) is a problem that needs to be addressed urgently due to its social, economic, and environmental implications. The main sector responsible for generating waste along the food supply chain is the household consumption level. According to recent estimates, 17% of available food is wasted globally, with 61% of which consisting of household food waste (1). Various studies have highlighted that household food waste is influenced by specific causes and determinants (2–6). In 2018, a research model was developed to categorize the reasons for household food waste (7, 8), identifying Motivations, Opportunities, and Abilities (MOA) as the main drivers of food waste. The motivations include awareness of food waste and the social norms related to throwing away food. The opportunities consist of the access to grocery shops either as typology and variety of products, or shop organization, e.g., the opening times and the geographical proximity. The abilities concern all the factors related to the organizational aspects of eating, such as planning, storing, and cooking the food. Although not included in the classical MOA models, the researchers also looked at other potential drivers of FLW, including whether education received from parents on food waste had an impact on the amount of food thrown away (9, 10). All these factors can influence household food waste prevention practices, which can be identified as planning the shopping and the use of the food, avoiding impulsive buying, checking for food already stored, cooking the right quantities of food for the family, and storing or using leftovers (7).

The MOA theoretical framework on household food waste was used in Italy in a national survey carried out in 2018 (11), to investigate the food waste behavioral profile of Italian consumers to obtain data to address the causes and to design FLW prevention strategies. In Italy, throwing away food is associated with a widespread negative emotional experience, with the majority of respondents stating that they considered food waste a deplorable practice. For Italian consumers, the ethical aspects of food waste are more important than the ecological consequences. At the household level, time availability and unexpected events were reported as key aspects of difficult food management in the kitchen, even though respondents declared abilities in the use of the leftovers.

The 12th goal of the sustainable development goals (SDGs) of the 2030 agenda established by the United Nations (12, 13) regarding sustainable production and consumption patterns includes target 12.3 which focuses on halving per capita food waste at the retail and household level by 2030 (14). Adopting a sustainable diet could be a strategy to limit the environmental impact of the food system and to make consumers more sensitive to the FLW problem (15, 16). Several studies have stated that the Mediterranean diet, which has been largely recommended for many years for its health-protective aspects, is also sustainable (17). The Mediterranean diet pattern has a low impact on soil, water, and energy resources (18). The Mediterranean diet principles were followed to establish the Italian food-based dietary guidelines, which were updated in 2018 with a focus on the sustainability of the dietary pattern. In particular, directive no. 13 of the Italian dietary guidelines brings together recommendations on how to adopt a sustainable lifestyle that can improve the quality of the diet and that can reduce food waste (19).

The rationale of this work is based on the recommendations of the Europe sustainable development report 2021 (20) that underlies the need for European union member states, including Italy, to adopt significant actions to achieve the 12th goal of SDGs to fulfill what the 2030 agenda established. In this sense, the analysis and knowledge of food waste behaviors and their relationship with healthy eating habits may be considered determinant elements to pursue the sustainability goal. However, data on these topics are limited and with non-univocal findings. Helander et al. (21) reported that a shift toward a healthy and sustainable diet can lead to an increased amount of food waste considering that a healthy diet is characterized by the consumption of products that largely contribute to food waste, such as fruit, vegetables, and milk. To the best of our knowledge, the relationship between the determinants of a healthy diet and food waste is a new area of interest investigated only in a few studies. Conrad et al. (22) found that high-quality diets were associated with greater food waste and Carroll et al. (23) reported a correlation between diet quality and fruit and vegetable waste. Similar results were reported in the study of Mijares et al. (24), which observed that the quantity of waste of fresh vegetables, cereals, and dairy products was related to a higher quality of the diet even though the high quality of diet was associated with low total food waste. On the same topic, another study pointed out that consumers who pay particular attention to food consumption and nutrition have also attitudes to prevent and limit food waste generation confirming the idea that healthy eating habits are associated with a sustainable lifestyle (25). In consideration of this scenario, we would demonstrate that attention to sustainability issues can affect both eating habits and food waste behaviors.

The main purpose of this study is to evaluate the consumers' food waste behaviors and their food habits investigating whether there is a connection between these two aspects. The hypothesis underlying this research is that adherence to dietary recommendations is linked to a good food management capacity and consequently to the prevention of food waste at the household level. This work would address the following research questions: (i) to what extent the adherence to dietary recommendations is related to food waste attitudes? (ii) To what extent do sociodemographic aspects influence consumers' behaviors in terms of dietary patterns? (iii) Nutrition educational activities could be the place to promote food waste prevention practices?

This work is part of the activities of the Italian Observatory on food surplus, recovery, and waste, a technical entity with a pivotal role in the production of research, methodologies, and reliable data that can be used as drivers for policy actions. One of the priorities recognized by the Observatory was to assess and monitor household food waste at the national level to support the development of actions aimed at reducing the amount of food waste (26). In light of this commitment, the behavioral assessment presented in this paper will provide inputs to allow for a better understanding of the causes of household food waste, as well as information to develop potential targets and intervention strategies to help reduce waste in the framework of the promotion of healthy diet.

2 Materials and methods

2.1 The survey methodology

A cross-sectional survey including 2,869 respondents, representative of the Italian adult population (age > 18 years), was carried out.

The data collection was performed by SWG S.p.A., a specialized market research agency, through interviews carried out among a panel group, including more than 60,000 individuals profiled according to the main sociodemographic variables and purchasing habits. The online procedure through the computer assisted web interviewing (CAWI) method was self-completed by 2,619 participants. The remaining sample (n = 250) consisted of people who were unfamiliar with the online system and therefore used the computer assisted personal interviewing (CAPI) method, with direct contact with the operators. The sampling plan was carried out to provide a stratification for area of residence and using simultaneously fixed quotas for age classes and gender. During the survey, the number of key component parameters such as the family size and the level of education were kept under control. The sample size of 2,500 was calculated in order to cover 11 territorial areas with a probability proportional to size methodology and with a statistical margin of error of 1.82% at 95% of confidence interval. The reported sampling permitted to cover Italian macro-regions and some high-density population areas in order to assess the territorial variability related to socioeconomic and cultural diversity between the Italian regions. The sample size was increased of 10% to cover the population that do not use internet. All indicators were aligned with the data provided by istituto nazionale di statistica (ISTAT) related to 2020 (27). The data were weighted to ensure the representativeness with respect to the parameters of area, gender, age, and level of education.

To participate in the SWG panel consumer surveys, respondents were required to sign a privacy agreement and consent form to collect and process their personal data in advance, following the Italian data protection law (Legislative Decree 101/2018) in line with European commission general data protection regulation (679/2016). Before starting the data collection, participants were informed about the objective of the research and the consequent statistical analysis. Participation in the study was fully voluntary and anonymous and subjects could withdraw from the survey at any time and for any reason. This study was conducted according to the guidelines of the declaration of Helsinki (28) and all procedures involving research study participants were approved and are in line with the SWG code of conduct (29). The assessment did not involve any invasive procedures nor induce any changes in dietary patterns. Therefore, the study did not require approval from the ethics committee.

The data collection was performed between the 26th of June and the 20th of July 2020. This period was selected in consideration of the fact that the social restrictions related to the Coronavirus disease-2019 (COVID-19) pandemic in Italy were attenuated from the 18th of May 2020 and further reduced after the 3rd of June 2020 when all the social activities started again and free movement between regions was allowed.

2.2 The survey structure and the questionnaire

The measurements carried out in the present study were shaped according to the objective of the survey. An articulated questionnaire was administrated with the first part covering sociodemographic information (gender, age, region of residence, education, job, income, and family size). Two main modules constitute the core of the assessment tool: (i) the household food waste behaviors (HFWB) questionnaire; (ii) a food frequency questionnaire that permitted the evaluation of adherence to the Italian dietary guidelines indicator (AIDGI). These two modules represented the capitalization of the work carried out in previous studies (11, 30) in which the methodologies of data collection were tested, validated, and adapted to the Italian context. The full questionnaire used for this paper is reported in the **Supplementary material** (**Supplementary Table 1**).

Household food waste behaviors were measured with the validated questionnaire developed by van Herpen et al. (31) and further adapted to the Italian context (11) assessing determinants and behaviors of consumers toward food waste. The HFWB module included 39 questions that assessed (i) prevention practices (planning the shopping and using the food, avoiding impulsive buying, the overview of stored food, cooking the right quantities of food, and storing and using leftovers), (ii) abilities (the perceived difficulty with assessing food safety, the perceived difficulty with cooking creatively, the perceived difficulty with accurate planning, and the knowledge of prolonging the shelf-life), and (iii) education received from parents (parents' attention to prevent food waste). A 7-point scale was used with answers ranging from "strongly disagree" to

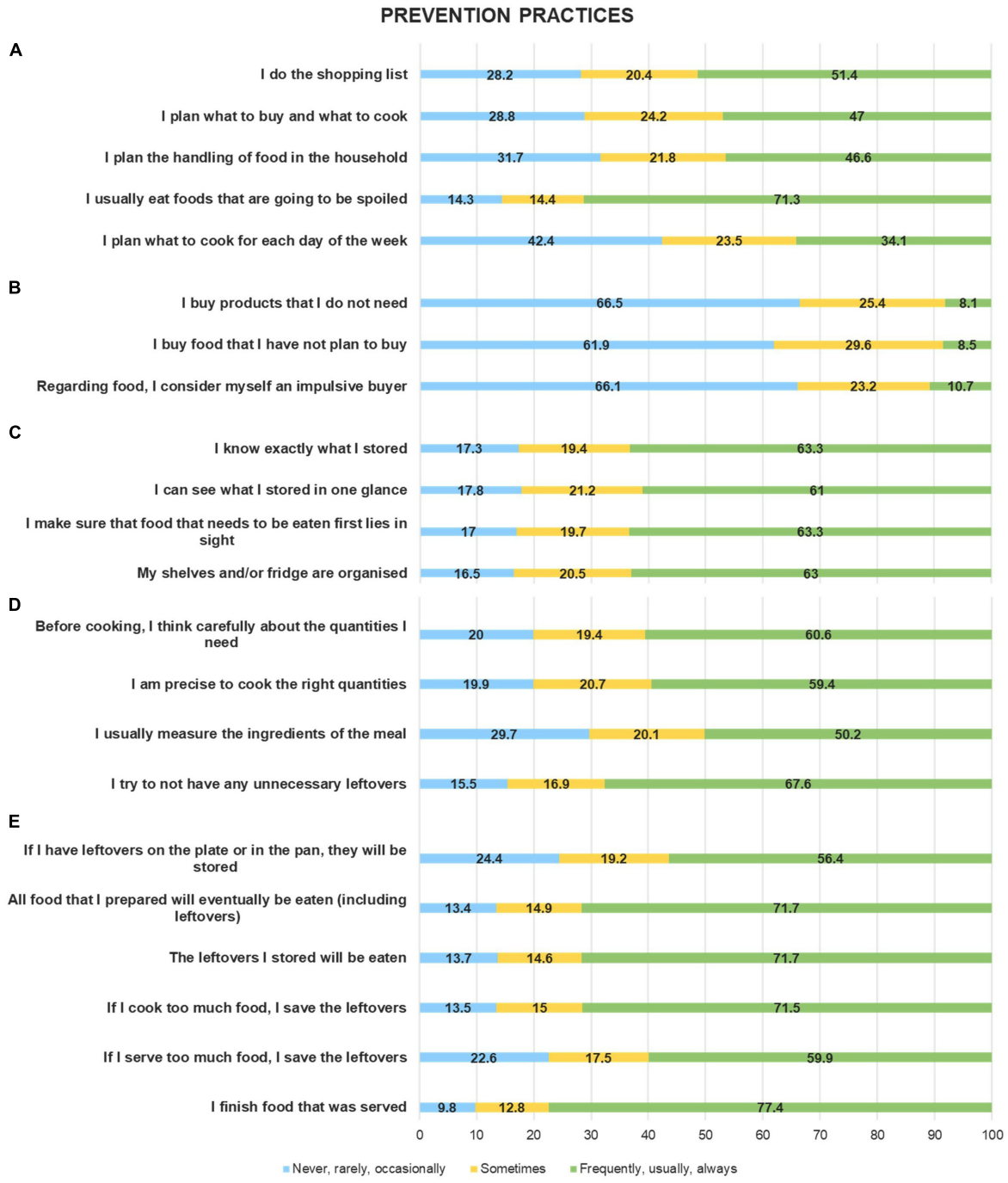


FIGURE 1
Food waste prevention practices among the sample: planning the shopping and using the food **(A)**; avoiding impulsive buying **(B)**; the overview of stored food **(C)**; cooking the right quantities of food **(D)**; storing and using leftovers **(E)**. Percentage values (%).

"strongly agree" or from "never" to "always." The answer scales were further grouped into four categories following the quartile distributions that varied for each behavior related to food waste: low, low–medium, medium–high, high.

Eating habits were evaluated by adapting the food frequency questionnaire used by the Italian national institute of statistics (27). The module consists of 18 food category items. For each category respondents were asked to quantify the frequency of consumption on a scale of five possible answers: more than once a day, once a day, few times a week, less than once a week, never. Hence, the AIDGI was created with a procedure similar to Benedetti et al. (32). AIDGI was based on a qualitative frequency

scale and provided a synthetic evaluation of the adherence to a healthy diet defined in the dietary guidelines. For each food group, the following scores were assigned: +2 points in case of frequency of consumption in line with recommendations, 0 points in case of frequency of consumption very far from recommendations, and +1 points for answers close to the recommendations, but not exactly in line with them. AIDGI was calculated as the sum of 18 group scores. For example, for the groups "fresh fruit" and "vegetables," the maximum score (2 points) was set for "more than once a day," a score of 1 was assigned to the option "once a day," and 0 scores were assigned to the other reported intakes. The scores obtained from each category were summed up and four AIDGI levels were identified: low (0–18), medium–low (19–20), medium–high (21–23), and high (> 23).

2.3 Data analysis

Descriptive statistics to illustrate the most important characteristics of the data collected were performed, such as food waste behaviors, the food habits of Italian consumers, and the adherence to nutritional recommendations. AIDGI and HFWB ordinal measures were calculated based on quartiles of the quantitative scores. A contingency analysis was performed to check associations between variables such as AIDGI and sociodemographic, and AIDGI and HFWB. Specifically, double-entry tables were processed, and the Chi-squared test of independence was applied along with *post-hoc* tests to check pairwise comparisons with Bonferroni corrections of the *p*-values. A *p*-value less than 0.05 was fixed for statistical significance. The statistical analysis was performed using IBM SPSS Statistics, version 25.

3 Results

3.1 Sociodemographic characteristics of the sample

The study sample resulted aligned to the Italian socio-demographic composition (27) for the effect of the sampling procedure and the subsequent weighting of the data. In particular, variables such as gender, age, and region of living have the same distribution of the Italian population. Small differences were observed amongst the level of education and the family size. In the present sample, the medium and high level of education are more represented (respectively +6 and +4%) than in the Italian population while the low level of education is less common (−9%) respect to the percentages measured at the national level. For the family size, single-member families are lower represented (−18%) and two-members families are more represented (+7%) respect to Italian population. Nevertheless, the overall distribution of smaller (one and two members) and larger (more than three members) families is similar to the national data. The results are therefore representative of the population in Italy, distributed in macro-regions corresponding to the local population density (**Supplementary Table 2**).

3.2 Household food waste behaviors in Italy

3.2.1 Prevention practices

Figure 1 reports the results obtained from the survey on household food waste prevention practices that included five subsets of questions (panels A, E). Planning food shopping and handling food in the household were common practices. More than two–thirds (71.3%) of the Italian families in the sample paid attention to eat purchased foods before throwing them away. Around half of the respondents, declared they made a food shopping list, planned what to buy and what to cook, and organized the management of food in the family. Planning what to cook for the week was less frequently reported (34.1%) (**Figure 1**, panel A). The majority of Italian families (66.1%) did not consider themselves impulsive buyers, avoiding buying no-needed or no-planned products. However, around 25% of the sample declared having bought "sometimes" unnecessary products (**Figure 1**, panel B). Having a good overview of the food inventory in the kitchen, as well as knowing what was in the fridge or stored in the pantry, were practices commonly adopted by Italian families, with approximately 60% of respondents having reported the habit of checking the quality and the quantity of stored food (**Figure 1**, panel C). Regarding the precision in cooking (**Figure 1**, panel D), avoiding producing leftovers was reported by around 70% of respondents, alongside the ability to be precise in measuring ingredients, preparing, and cooking the correct amount of food for the families. Italian families were also careful to eat all food that was prepared, including leftovers (**Figure 1**, panel E). The majority of respondents (77.4%) finished all the food on their plates. If there were leftovers (either due to having cooked or served more than what was necessary) they were stored and further reused.

3.2.2 Abilities

In **Figure 2**, the results of the subset of questions related to the influence of the consumers' abilities on food waste generation are reported.

Around 70% of Italian families had no difficulties with understanding whether the food was still edible and safe to eat, using smell or taste, or evaluating the external aspect (**Figure 2**, panel A).

More than 60% of the respondents reported having cooked creatively, using the food that was in the fridge and leftovers, and experiencing new recipes to cook (**Figure 2**, panel B).

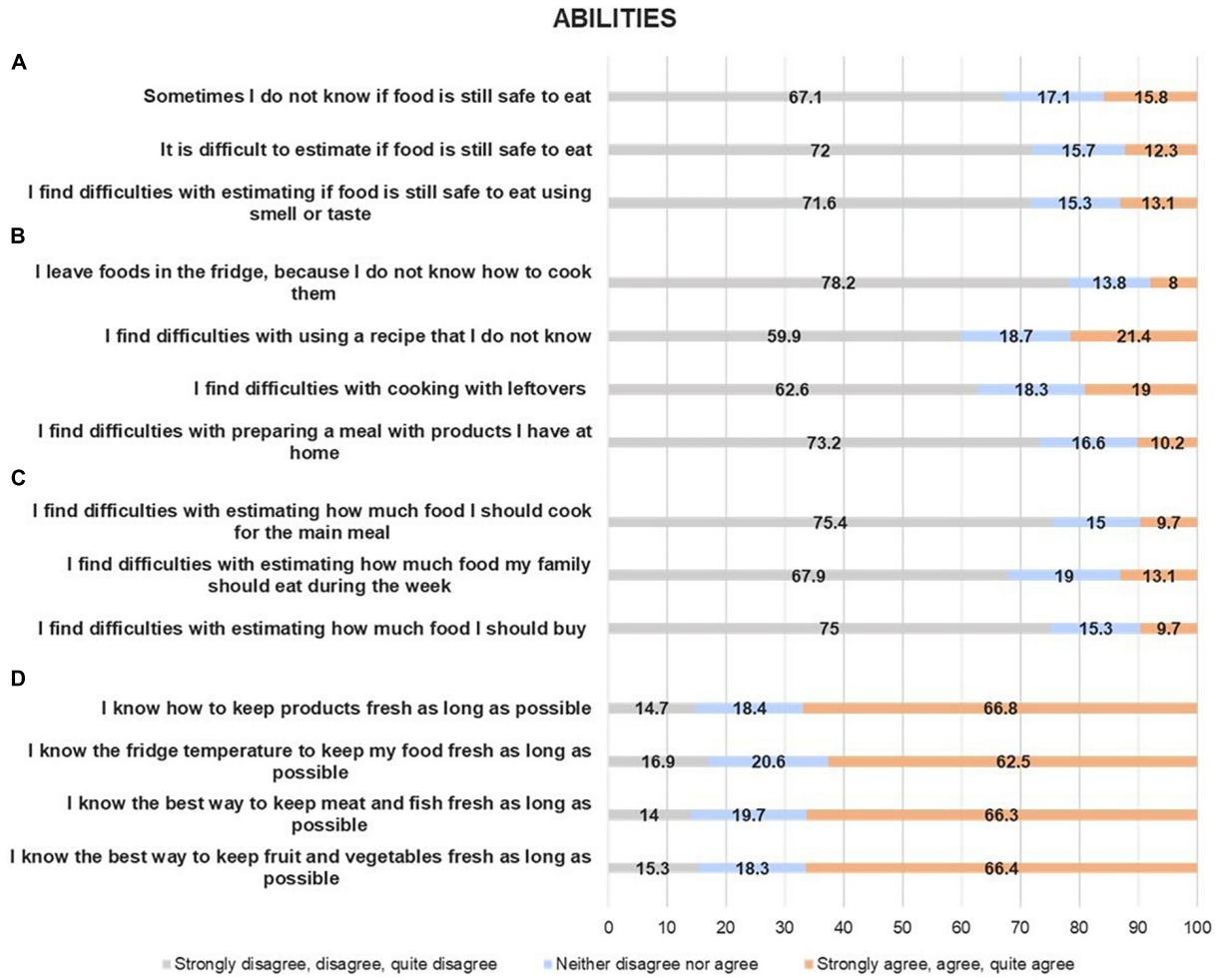


FIGURE 2
Food waste abilities among the sample: the perceived difficulty with assessing food safety **(A)**; the perceived difficulty with cooking creatively **(B)**; the perceived difficulty with accurate planning **(C)**; the knowledge of prolonging the shelf-life **(D)**. Percentage values (%).

Concerning food purchase planning, around 70% of respondents declared they were able to estimate the quantities of foods to buy and cook, to satisfy the needs of the family (Figure 2, panel C).

Panel D of Figure 2 reports the answers to the questions related to the knowledge of prolonging the shelf-life of foods. Around 60% of respondents considered themselves to know the best way and the optimal temperature to store fresh foods (fruit, vegetables, meat, and fish) and preserve them longer.

3.2.3 Education received from parents

Education received from parents was reported as a factor impacting on food waste behavior for almost 80% of Italian families (Figure 3). The attention of the parents to food waste and being taught not to throw away food were reported as having influenced the respondents' attitudes to food waste early in their childhood.

3.3 Adherence to the Italian dietary guidelines

Italian consumers did not follow the dietary guidelines as far as concerning the intakes of processed meat, (69.9%), sugary drinks (74.7%), and alcoholic beverages (80.4% beer and wine, 63.9% other alcoholic drinks) which resulted higher than recommended. In addition, most of the respondents (90%) reported a frequency of consumption of milk and yogurt lower than the recommendations. Bread, pasta, and rice were consumed in the adequate quantities only in 20% of cases, although around 50% of families declared a consumption frequency near the recommendations. However, most of the respondents reported to follow the guidelines in terms of the occasional consumption of cakes and sweets (80.5%) and savory snacks (57.2%). Almost half of the families reported an appropriate consumption of legumes (55.9%), nuts (51.9%),

dairy products (57.8%), fish and fisheries products (55.4%), and white meat (68.3%). In line with dietary guidelines, a low intake of red meat was declared by 52.4% of respondents while a high percentage of them reported an appropriate level of consumption of fruit (40.7%) and vegetables (29.8%).

These results are reported in **Supplementary Table 3**.

3.4 The AIDGI and Italian sociodemographic variables

The AIDGI was conceived to identify four levels of adherence to nutritional recommendations that in our sample were homogeneously distributed: 28.9% low; 21.5% low–medium; 25.5% medium–high; 24.1% high. The relationship between the AIDGI and sociodemographic variables (**Supplementary Table 4**) showed that among those who obtained the lowest AIDGI score, a preponderance of men ($p < 0.001$), younger groups (18–44 years old, $p < 0.01$), and families with five or more members ($p < 0.05$) was found. On the other hand, in the highest AIDGI level group, a preponderance of women ($p < 0.05$), older groups ($\geq$ 55 years old, $p < 0.001$), and families with two members ($p < 0.05$) was observed. No significant differences were observed concerning education level and income groups (data not shown).

3.5 The relationship between AIDGI and the adoption of household food waste behaviors

The results of the contingency analysis with the Chi-square test between AIDGI and HFWB are shown in **Table 1**. In the group of participants with the highest adherence to dietary guidelines there was a significant preponderance of respondents that was more able to plan the purchasing and the use of food (38.9%, $p < 0.001$), to better evaluate the quantities to cook (40.4%, $p < 0.001$) and to avoid impulsive buying (35.2%, $p < 0.01$). In addition, in this group a medium–high and high knowledge of the food stored (respectively 31.2 and 38.4%, $p < 0.001$) and a tendency to reuse leftovers (respectively 30.5 and 35.4%, $p < 0.001$) were observed. On the other hand, more than one–third of Italian families who obtained the lowest AIDGI scores reported a less frequent adoption of food waste prevention practices ($p < 0.001$).

As reported in **Table 1**, consumers with the highest AIDGI reported a medium–high and high capacity in assessing food safety (28.8 and 34.7%, $p < 0.001$), in planning accurately (29.4 and 34.9%, $p < 0.01$), in knowing how to prolong the shelf life of a product (32.4 and 34%, $p < 0.05$), and in cooking creatively (29 and 32%, $p < 0.01$). On the other hand, more than one-third of the respondents who obtained the lowest AIDGI level less frequently adopted these practices ($p < 0.001$), especially as far as concerning the knowledge of the shelf-life of a product (49.1%).

Finally, half of the respondents with low AIDGI scores did not receive any education regarding food waste (51.1%, $p < 0.001$) while those who achieved the highest AIDGI had a family in which the parents paid attention to avoid food waste (medium–high 30.8% and high 33.7%, $p < 0.01$).

4 Discussion

Food waste, eating habits, and nutritional education are intrinsically linked in terms of public health, environmental protection, and sustainability goals. The main purpose of this paper was to evaluate consumer food waste behaviors and food habits to demonstrate if and how these aspects are correlated. To the best of our knowledge, this is the first study that investigated the relationship between consumers' food waste habits and the quality of their diet in a representative sample of the Italian population. The added value of this work is the interdisciplinary approach combining nutrition and sustainability aspects focusing on an emerging topic as food waste. In fact, according to Conrad et al. (22), it is necessary to collect more data concerning the relationship between the quality of the diet and food waste, since at the moment this is a critical research gap in the field of the sustainability of the food system.

The most significant result of this assessment is the strong statistically significant association between food waste attitudes and adherence to nutrition recommendations. The results of the contingency analysis confirmed that in the Italian consumers it is possible to demonstrate a polarization. In particular, among the group of population with higher AIDGI levels, higher HFWB indicators' scores corresponding to behaviors aimed at preventing and limiting food waste were observed. On the other hand, in the lower AIDGI classes was reported a tendency to have lower HFWB scores that correspond to habits that may produce most waste. In other words, consumers with better food consumption patterns were also consumers with increased attention toward food waste in terms of prevention, knowledge of the problem, and abilities in the kitchen to limit the food that is thrown away. This is an important point in terms of policy and intervention strategies. In fact, according to our results, adherence to dietary recommendations is a driver of food waste prevention. These results represent an important answer to the prefixed research questions, hence demonstrating the importance of including food waste prevention practices in the framework of educational nutritional activities.

The correlation between food habits, through the AIDGI, and food waste behavior in Italy strengthens the concept that sustainability is a goal that can be achieved by combining different aspects. Although it was conducted in the UK and included participants aged only between 18 and 35 years old,

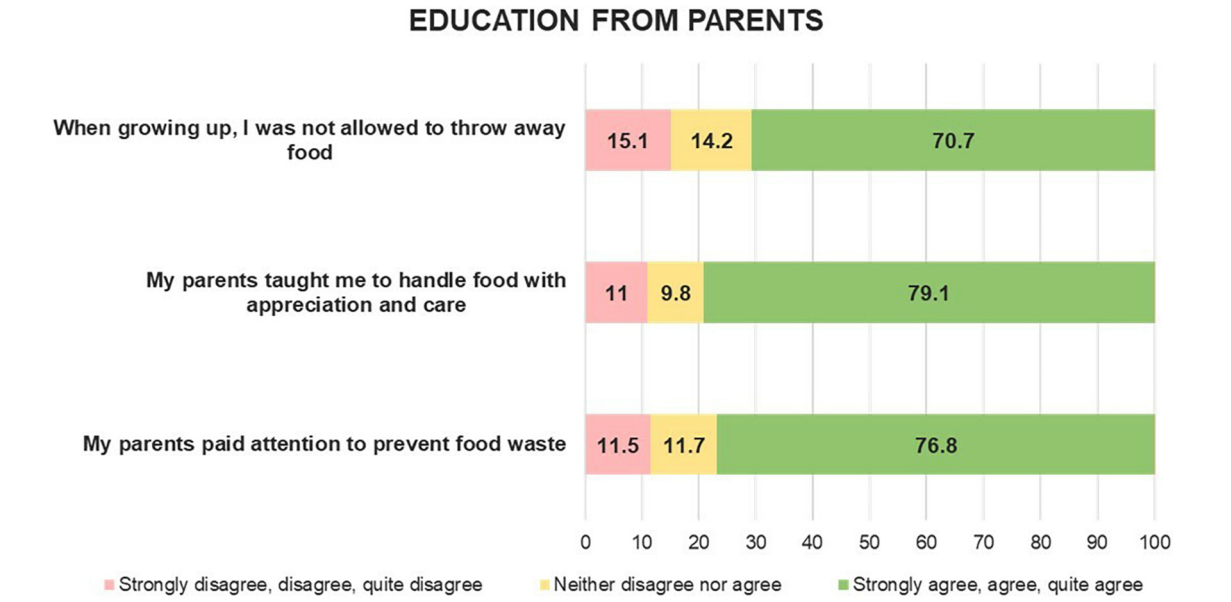


FIGURE 3
Education received from parents among the sample. Percentage values (%).

the study developed by Savelli et al. (25) supports our findings and conclusions. The promotion of a healthy diet together with campaigns for food waste reduction could be public health actions that efficiently reach different population targets. It should be considered that in recent years, consumers have become more sensitive toward the issue of the sustainability of dietary choices (33, 34). Considering the HFWB indicators, the education received from parents on preventing food waste was particularly correlated to a high AIDGI. This finding could be interpreted considering that the acquisition of healthy eating habits, since childhood, could influence other aspects of sustainability including the attention to the limitation of food waste. It is a consolidated concept that educational strategies are most efficient if applied among the youngest. In various studies, educational activities targeting students resulted in positive behaviors changes, such as an increase in the consumption of fruit and vegetables and a decrease in the amount of food waste (35), or the adoption of a healthier lifestyle that includes sustainable food choices (locally grown or organic foods) (36, 37).

In addition to that, it is important that educational actions would reach the most in need. According to our data, the segment of the population with low AIDGI is also the group of people with a low level of indicators of food waste prevention and reduction behaviors. This population group should be identified as a target for educational campaigns combining nutrition and food waste topics.

The relationships between diet and food waste are complex. Conrad et al. and Carroll et al. (22, 23) found a correlation between higher levels of a certain type of food wasted (vegetables, fruit, dairy products) and a higher-quality diet. This could be expected considering quantitative aspects, since healthy eating means, among other aspects, a high level of consumption of fresh and perishable products impacting the quantity of discarded food. In addition to that Garnett et al. (38) described a scenario in which consumers reported knowledge, attention, and consideration in terms of sustainability even with difficulties in adopting behaviors in line with the intentions. This could be related either to the fact that consumers are resistant in changing their habits or to the ineffectiveness of current educational programs that probably should be more incisive.

Half of the sample reported a consumption pattern with low adherence to nutritional recommendations in particular among men, the youngest, and people living in large families. The homogenous distribution of the four levels of AIDGI found in Italy in this study was the same that was found in the previous study that used AIDGI in a selected sample of the population. As shown by Scalvedi et al. (30), categorizing AIDGI at three levels, the results were 32% low, 40% medium, and 28% high with a quite homogeneous third-party distribution. Even though improving the adherence to the Italian dietary guidelines, especially among the above-mentioned subgroups, is a necessary public health action, overall Italian eating habits showed interesting results in terms of the consumption of foods impacting the environment and influencing the sustainability of the dietary patterns. The quota of consumers that declared a low intake of red meat and adequate frequencies of consumption of white meat, fish, and plant-based products should be taken into account. The overtime changes in these consumption patterns need to be confirmed by an update of Italian food consumption

TABLE 1 The relationship between adherence to the Italian dietary guidelines indicator (AIDGI) and household food waste behaviors (HFWBs) (prevention practices, abilities, education received from parents).

		AIDGI levels			
Overall sample		**Low (%) 28.9**	**Low–medium (%) 21.5**	**Medium–high (%) 25.5**	**High (%) 24.1**
Prevention practices					
Planning and using	Low (0–3.6)	44.8*	20.4	19.2	15.7
	Low–medium (3.7–4.4)	28.3	28.4	25.5	17.7
	Medium–high (4.5–5.4)	21.2	20.6	31.5	26.7
	High (>5.4)	16.6	16.9	27.6	38.9*
No impulsive buying	Low (1–4.3)	36.5*	22.4	24.8	16.4
	Low–medium (4.4–5.0)	29	22	25.2	23.7
	Medium–high (5.1–6)	27.5	21	25.5	25.9
	High (>6.0)	17.5	19.9	27.4	35.2*
Overview of stored food	Low (1–4.0)	50.2*	22	17.2	10.6
	Low–medium (4.1–5.0)	22.8	23.7	32.5	21
	Medium–high (5.1–5.75)	19.3	21.5	28	31.2*
	High (>5.75)	18.4	18.1	25	38.4*
Cooking the right quantities	Low (1–4.0)	45.6*	25	18.2	11.3
	Low–medium (4.1–5.75)	24	23.9	29.1	23
	Medium–high (4.75–5.75)	21.9	19.7	32	26.3
	High (>5.75)	17.1	16.8	25.7	40.4*
Using leftovers	Low (1–4.17)	50.5*	21.5	16.6	11.5
	Low–medium (4.18–5.33)	27.9	26.1	26.3	19.7
	Medium–high (5.34–6.35)	19.2	20.3	30	30.5*
	High (>6.35)	16.9	18.1	29.6	35.4*
Abilities					
No difficulty with assessing food safety	Low (1–4.34)	38.5*	25.9	20.1	15.6
	Low–medium (4.35–5.67)	35.4*	18.7	26.4	19.5
	Medium–high (5.68–6.67)	23.3	18.8	29.1	28.8*
	High (>6.67)	15.8	21.8	27.7	34.7*
No difficulty with cooking creatively	Low (1–4.34)	40.8*	26.7	20.3	12.2
	Medium–low (4.35–5.67)	37.9*	20.2	21.3	20.6
	Medium–high (5.68–6.34)	19.7	20.2	30.7	29.4*
	High (>6.34)	16	18.6	30.5	34.9*
No difficulty with accurate planning	Low (1–4.34)	40.8*	26.7	20.3	12.2
	Medium–low (4.35–5.67)	37.9*	20.2	21.3	20.6
	Medium–high (5.68–6.34)	19.7	20.2	30.7	29.4*
	High (>6.34)	16	18.6	30.5	34.9*
Knowledge of prolonging shelf life	Low (1–4.0)	49.1*	20.1	19	11.8
	Medium–low (4.1–5.0)	22.7	24.8	28.4	24
	Medium–high (5.1–6.0)	18.2	22	27.4	32.4*
	High (>6.0)	19.9	16.2	29.8	34*
Education received from parents					
Parents' attention to preventing food waste	Low (1–4.67)	51.1*	21.3	17.2	10.3
	Medium–low (4.7–5.67)	25.9	28.1	24.5	21.5
	Medium–high (5.68–6.9)	19.4	19.9	29.9	30.8*
	High (7.0)	16.9	18.7	30.7	33.7*

*$p < 0.05$ calculated performing the Chi-square test with Bonferroni correction.

data that presently are available for the period 2005–2006 (39). It is also true that these food habits combine health-promoting aspects with environmental issues. The recommendation of a consumption pattern that includes foods that preserve human health and natural resources was one of the main objectives of the last updated revision of the Italian dietary guidelines (19). These guidelines provide recommendations aligned with the most recent evidence not only on healthy eating but also on the wider social and environmental implications of dietary choices with the idea of promoting a food environment that contributes to good public and personal health, as well as to local and global environmental sustainability (40).

In addition, our results highlighted that most the Italian consumers tried to adopt behaviors aimed at preventing and reducing food waste during their daily life. Attention was paid to avoiding generating food surplus, or otherwise storing them, and then consuming the leftovers. This result was confirmed in the assessment of Scalvedi and Rossi (11) in which the attention of Italian consumers toward food waste, the habits of consuming all foods that are cooked and using the leftovers was already reported. Furthermore, similar data were reported by Annunziata et al. (41) in an assessment of food waste behaviors in Southern Italy in which the sub-sample that wasted less reported reusing leftovers more than the group that wasted higher quantities of food. Another aspect largely reported by Italian consumers is the influence of education from parents as a determinant of food waste preventive attitude. According to van Geffen et al. (7) awareness of parents for food waste prevention during the upbringing did not affect food waste levels directly. However, a higher awareness during the upbringing led to a better overview of the stored food, to cook precisely and to use leftovers, confirming the results of the present assessment.

The results of this study need to be interpreted also in consideration of the period of data collection. Even though it was realized after the lockdown period–that in Italy was gradually reduced from the 18th of May 2020–the pandemic could have influenced dietary habits and food waste behaviors. The effect of the COVID-19 pandemic had an impact on dietary practices both negatively and positively throughout Europe. Several studies reported an increase in the quality of the diet with increased consumption of healthy foods that were, however, associated with poor lifestyle outcomes such as weight gain and limited physical activity (42, 43). In terms of food waste, in a survey carried out during the most restrictive phase of the containment measures against COVID-19 in Italy, the awareness of food surplus and waste was reported by nearly 80% of participants who claimed to have consumed all the food they cooked and reported to have had the capacity to store surplus and consume the leftovers (44). The consumers' awareness toward food waste during the pandemic period was confirmed by other European studies (45–47). According to Principato et al. (48), in Italy, the unexpected positive effect of the lockdown caused by the pandemic was that most consumers threw away less food in comparison to the pre-pandemic situation with a better implementation of food management practices (shopping list, meal planning, etc.). In addition, the logistical difficulties of grocery shopping experienced by consumers resulted in an increased capacity for handling household food consumption, with a reduction in the amount of food wasted. In light of these points, our results on the avoidance of impulse buying together with the reported cooking creativity could be the carryover effect of the lockdown period, after which this data collection was realized. Further assessments are needed to monitor the trends to detect changes in food waste behavior.

This study has strengths and limitations. The strength of this work is represented by the sampling methodology that provided the national representativeness of the Italian adult population in terms of gender, age, income, and education. Another important added value of this assessment is the use of a questionnaire that had already been tested in Italy. The questionnaires were specifically designed to collect information on HFWB and AIDGI as the main outcomes of the study, in line with the pre-determined objectives. However, this kind of study has a general limitation related to self-reported answers that could affect the reliability of the responses. The food waste behavior and the eating habits assessed were based on the participants' perceptions that may not reflect reality and the answers could be influenced by the willingness of declaring behaviors corresponding to socially desirable norms or healthy food consumption practices. However, the large sample size, the robustness of the methodology, and the confirmation of our results with other similar surveys support the reliability of the data collected.

In conclusion, the achievement of SDGs includes the improvement of human health guaranteeing access to healthy foods for all, and the reduction of food waste at the consumer level. With this study, we demonstrated that in Italy these aspects are correlated. Food waste is associated with nutrient wastage and food waste reduction interventions can successfully address food sustainability and nutrition quality. According to the present paper, Italians that follow nutritional recommendations are also consumers with higher attention toward the limitation of food waste. This is a point to take into consideration while planning nutrition education actions.

Food waste prevention and reduction are key aspects of sustainability and a responsible food consumption attitude. According to Springmann et al. (49), the inclusion of sustainability of food choices into the nutritional recommendations could be not only beneficial from a health perspective but also necessary to meet global sustainability goals and to stay within the environmental limits of the food system. The results of the present study are in line with these points.

Considering the scarcity of data collected concerning AIDGI and HFWB at the national level, this study could be considered a benchmark for future monitoring assessments despite the exceptional events that took place in 2020 due to the COVID-19

pandemic. This data confirmed the importance of targeting the younger age groups who are most in need of nutrition education actions. The recent increase in young people's awareness of climate and environmental issues could be exploited to transmit the message regarding the importance of combining healthy food behavior and food waste issues as key elements to improve the sustainability of their dietary choices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

FG and LR contributed to the conceiving, writing, and reviewing the manuscript. LR was responsible for the overall supervision, project administration, and funding acquisition. Both authors read and agreed with the published version of the manuscript.

Funding

This research was funded by the project FAOWASTE: "Food waste in Italy: International policies and measurements" (Nos. 23278-27 and 12.2019) granted by the Italian Ministry of Ecological Transition (MITE).

Acknowledgments

We thank Rado Fonda, Elisa Boran, and Riccardo Benetti (SWG S.p.A.) for support in data collection and for granting access to the comprehensive datasets and allowing their elaboration for the present manuscript. We also thank Dr. Maria Luisa Scalvedi and Dr. Daniele Peluso that performed the statistical analysis.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1026829/full#supplementary-material

References

1. United Nations Environment Programme [UNEP]. *United Nations Environment Programme-Food Waste Index Report. ISBN 978-92-807-3851-3.* (2021). Available online at: https://www.unep.org/resources/report/unep-food-waste-index-report-2021 (accessed January 20, 2022).

2. Fami HS, Aramyan LH, Sijtsema SJ, Alambaigi A. Determinants of household food waste behavior in Tehran city: a structural model. *Resour Conserv Recycl.* (2019) 143:154–66. doi: 10.1016/j.resconrec.2018.12.033

3. Fanelli R. Using causal maps to analyse the major root causes of household food waste: results of a survey among people from central and Southern Italy. *Sustainability.* (2019) 11:1183. doi: 10.3390/su11041183

4. Neff RA, Spiker ML, Truant PL. Wasted food: US consumers' reported awareness, attitudes, and behaviors. *PLoS One.* (2015) 10:e0127881. doi: 10.1371/journal.pone.0127881

5. Stancu V, Haugaard P, Lähteenmäki L. Determinants of consumer food waste behaviour: two routes to food waste. *Appetite.* (2016) 96:7–17. doi: 10.1016/j.appet.2015.08.025

6. Visschers VHM, Wickli N, Siegrist M. Sorting out food waste behaviour: a survey on the motivators and barriers of self-reported amounts of food waste in households. *J Environ Psychol.* (2016) 45:66–78. doi: 10.1016/j.jenvp.2015.11.007

7. van Geffen L, van Herpen E, van Trijp H. *Quantified Consumer Insights on Food Waste-Pan-European Research for Quantified Consumer Food Waste Understanding.* (2017). Available online at: https://eu-refresh.org/quantified-consumer-insights-food-waste.html#:~{}:text=Results%20show%20that%2C%20in%20line,the%20amount%20of%20food%20waste (accessed January 20, 2022).

8. van Geffen L, van Herpen E, van Trijp H. *Causes and Determinants of Consumers Food Waste- A theoretical framework.* (2016). Available online at: https://eu-refresh.org/causes-determinants-consumers-food-waste.html (accessed January 20, 2022).

9. Pocol CB, Pinoteau M, Amuza A, Burlea-Schiopoiu A, Glogoveţan A-I. Food waste behavior among Romanian consumers: a cluster analysis. *Sustainability.* (2020) 12:9708. doi: 10.3390/su12229708

10. van Geffen L, Sijtsema S, Díaz-Ruiz R, Diedrich A-C, López-i-Gelats F, Brumbauer T, et al. *National, Qualitative Insight on Household and Catering Food Waste*. (2016). Available online at: https://eu-refresh.org/national-qualitative-insight-household-catering-food-waste.html (accessed January 8, 2022).

11. Scalvedi ML, Rossi L. Comprehensive measurement of Italian domestic food waste in a European framework. *Sustainability.* (2021) 13:1492. doi: 10.3390/su13031492

12. United Nations [UN]. *Transforming our World: the 2030 Agenda for Sustainable Development*. (2015). Available online at: https://sdgs.un.org/2030agenda (accessed January 22, 2022).

13. United Nations [UN]. *The 17 Goals*. (2015). Available online at: https://sdgs.un.org/goals (accessed January 20, 2022).

14. United Nations [UN]. *Sustainable Development Goals. Goal 12: Ensure Sustainable Consumption and Production Patterns*. (2015). Available online at: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/ (accessed January 16, 2022).

15. Hallström E, Carlsson-Kanyama A, Börjesson P. Environmental impact of dietary change: a systematic review. *J Clean Prod.* (2015) 91:1–11. doi: 10.1016/j.jclepro.2014.12.008

16. Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A, et al. Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? *Am J Clin Nutr.* (2012) 96:632–9. doi: 10.3945/ajcn.112.038729

17. Dernini S, Berry E, Serra-Majem L, La Vecchia C, Capone R, Medina F, et al. Med Diet 4.0: the Mediterranean diet with four sustainable benefits. *Public Health Nutr.* (2017) 20:1322–30. doi: 10.1017/S1368980016003177

18. Sáez-Almendros S, Obrador B, Bach-Faig A, Serra-Majem L. Environmental footprints of Mediterranean versus Western dietary patterns: beyond the health benefits of the Mediterranean diet. *Environ Health.* (2013) 12:118. doi: 10.1186/1476-069X-12-118

19. CREA. *Centro di Ricerca Alimenti e la Nutrizione. Linee Guida per una Sana Alimentazione*. (2018). Available online at: https://www.crea.gov.it/en/web/alimenti-e-nutrizione/-/linee-guida-per-una-sana-alimentazione-2018 (accessed January 20, 2022).

20. Sustainable Development Solutions Network [SDSN]. *Europe Sustainable Development Report 2021*. (2021). Available online at: https://eu-dashboards.sdgindex.org/ (accessed January 20, 2022).

21. Helander H, Bruckner M, Leipold S, Petit-Boix A, Bringezu S. Eating healthy or wasting less? Reducing resource footprints of food consumption. *Environ Res Lett.* (2021) 16:054033. doi: 10.1088/1748-9326/abe673

22. Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, Jahns L. Relationship between food waste, diet quality, and environmental sustainability. *PLoS One.* (2018) 13:e0195405. doi: 10.1371/journal.pone.0195405

23. Carroll N, Wallace A, Jewell K, Darlington G, Ma DWL, Duncan AM, et al. Association between diet quality and food waste in Canadian families: a cross-sectional study. *Nutr J.* (2020) 19:54. doi: 10.1186/s12937-020-00571-7

24. Mijares V, Alcivar J, Palacios C. Food waste and its association with diet quality of foods purchased in South Florida. *Nutrients.* (2021) 13:2535. doi: 10.3390/nu13082535

25. Savelli E, Francioni B, Curina I. Healthy lifestyle and food waste behavior. *J Consum Mark.* (2019) 37:148–59. doi: 10.1108/JCM-10-2018-2890

26. Grant F, Rossi L. The Italian observatory on food surplus, recovery, and waste: the development process and future achievements. *Front Nutr.* (2022) 8:787982. doi: 10.3389/fnut.2021.787982

27. ISTAT. *Indagine Multiscopo Sulle Famiglie: Aspetti Della Vita Quotidiana*. (2020). Available online at: https://www.istat.it/it/archivio/91926 (accessed January 21, 2022).

28. World Medical Association [WMA]. *Wma Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects*. (2018). Available online at: https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/ (accessed January 19, 2022).

29. SWG. *Modello di Organizzazione Gestione e Controllo*. (2021). Available online at: https://www.swg.it/download/MOGCSWG.pdf (accessed January 17, 2022).

30. Scalvedi ML, Gennaro L, Saba A, Rossi L. Relationship between nutrition knowledge and dietary intake: an assessment among a sample of Italian adults. *Front Nutr.* (2021) 8:714493. doi: 10.3389/fnut.2021.714493

31. van Herpen E, van Geffen L, Nijenhuis-de Vries M, Holthuysen N, van der Lans I, Quested T. A validated survey to measure household food waste. *MethodsX.* (2019) 6:2767–75. doi: 10.1016/j.mex.2019.10.029

32. Benedetti I, Biggeri L, Laureti T, Secondi L. Exploring the Italians' food habits and tendency towards a sustainable diet: the mediterranean eating pattern. *Agric Agric Sci Procedia.* (2016) 8:433–40. doi: 10.1016/j.aaspro.2016.02.040

33. Borrello M, Caracciolo F, Lombardi A, Pascucci S, Cembalo L. Consumers' perspective on circular economy strategy for reducing food waste. *Sustainability.* (2017) 9:141. doi: 10.3390/su9010141

34. Lubowiecki-Vikuk A, Dąbrowska A, Machnik A. Responsible consumer and lifestyle: sustainability insights. *Sustain Prod Consum.* (2021) 25:91–101. doi: 10.1016/j.spc.2020.08.007

35. Prescott MP, Burg X, Metcalfe JJ, Lipka AE, Herritt C, Cunningham-Sabo L. Healthy planet, healthy youth: a food systems education and promotion intervention to improve adolescent diet quality and reduce food waste. *Nutrients.* (2019) 11:1869. doi: 10.3390/nu11081869

36. Pelletier JE, Laska MN, Neumark-Sztainer D, Story M. Positive attitudes toward organic, local, and sustainable foods are associated with higher dietary quality among young adults. *J Acad Nutr Diet.* (2013) 113:127–32. doi: 10.1016/j.jand.2012.08.021

37. Robinson-O'Brien R, Larson N, Neumark-Sztainer D, Hannan P, Story M. Characteristics and dietary patterns of adolescents who value eating locally grown, organic, nongenetically engineered, and nonprocessed food. *J Nutr Educ Behav.* (2009) 41:11–8. doi: 10.1016/j.jneb.2008.03.007

38. Garnett T. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy.* (2011) 36:S23–32. doi: 10.1016/j.foodpol.2010.10.010

39. Leclercq C, Arcella D, Piccinelli R, Sette S, Le Donne C. Aida Turrini on behalf of the INRAN-SCAI 2005–06 study group. The Italian national food consumption survey INRAN-SCAI 2005–06: main results in terms of food consumption. *Public Health Nutr.* (2009) 12:2504–32. doi: 10.1017/S1368980009005035

40. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet Health.* (2018) 2:e451–61. doi: 10.1016/S2542-5196(18)30206-7

41. Annunziata A, Agovino M, Ferraro A, Mariani A. Household food waste: a case study in Southern Italy. *Sustainability.* (2020) 12:1495. doi: 10.3390/su12041495

42. Bennett G, Young E, Butler I, Coe S. The impact of lockdown during the COVID-19 outbreak on dietary habits in various population groups: a scoping review. *Front Nutr.* (2021) 8:626432. doi: 10.3389/fnut.2021.626432

43. Catucci A, Scognamiglio U, Rossi L. Lifestyle changes related to eating habits, physical activity, and weight status during COVID-19 quarantine in italy and some European countries. *Front Nutr.* (2021) 8:718877. doi: 10.3389/fnut.2021.718877

44. Grant F, Scalvedi ML, Scognamiglio U, Turrini A, Rossi L. Eating habits during the COVID-19 lockdown in Italy: the nutritional and lifestyle side effects of the pandemic. *Nutrients.* (2021) 13:2279. doi: 10.3390/nu13072279

45. Berjan S, Vaško Ž, Ben Hassen T, El Bilali H, Allahyari MS, Tomiæ V, et al. Assessment of household food waste management during the COVID-19 pandemic in Serbia: a cross-sectional online survey. *Environ Sci Pollut Res.* (2022) 29:11130–41. doi: 10.1007/s11356-021-16485-8

46. Bogevska Z, Berjan S, El Bilali H, Sadegh Allahyari M, Radosavac A, Davitkovska M. Exploring food shopping, consumption and waste habits in North Macedonia during the COVID-19 pandemic. *Socioecon Plann Sci.* (2022) 82:101150. doi: 10.1016/j.seps.2021.101150

47. Vasko Z, Berjan S, El Bilali H, Allahyari MS, Despotovic A, Vukojeviæ D, et al. Household food wastage in Montenegro: exploring consumer food behaviour and attitude under COVID-19 pandemic circumstances. *Br Food J.* (2022): doi: 10.1108/BFJ-01-2022-0019 [Epub ahead of print].

48. Principato L, Secondi L, Cicatiello C, Mattia G. Caring more about food: the unexpected positive effect of the COVID-19 lockdown on household food management and waste. *Socioecon Plann Sci.* (2020) 82:100953. doi: 10.1016/j.seps.2020.100953

49. Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P, et al. The healthiness and sustainability of national and global food based dietary guidelines: modelling study. *BMJ.* (2020) 370:m2322. doi: 10.1136/bmj.m2322

frontiers | Frontiers in Sustainability

TYPE Opinion
PUBLISHED 16 January 2023
DOI 10.3389/frsus.2023.1112950

OPEN ACCESS

EDITED BY
Muhammad Bilal Sadiq,
Forman Christian College, Pakistan

REVIEWED BY
Muhammad Saleem Kalhoro,
Sindh Agriculture University, Pakistan
Manisha Singh,
RMIT University, Australia
Dao Nguyen,
RMIT University, Australia
Khurram Muaz,
Forman Christian College, Pakistan

*CORRESPONDENCE
Klaus W. Lange
✉ klaus.lange@ur.de

SPECIALTY SECTION
This article was submitted to Sustainable Consumption, a section of the journal Frontiers in Sustainability

RECEIVED 30 November 2022
ACCEPTED 03 January 2023
PUBLISHED 16 January 2023

CITATION
Lange KW and Nakamura Y (2023) Potential contribution of edible insects to sustainable consumption and production. *Front. Sustain.* 4:1112950. doi: 10.3389/frsus.2023.1112950

Potential contribution of edible insects to sustainable consumption and production

Klaus W. Lange* and Yukiko Nakamura

Faculty of Human Sciences, University of Regensburg, Regensburg, Bavaria, Germany

KEYWORDS

edible insects for food, food production and consumption, responsible consumption and production, sustainability, food security

Introduction

The world population has been estimated to increase to over nine billion people by 2050 (United Nations, 2019), with the demand for animal-derived protein expected to rise at an even higher rate (Godfray et al., 2010). Population growth in China has been associated with a significant increase in meat consumption (Al-Ali et al., 2018). The required rise in global meat production predicted in 2014 over the following 35 years was 72% (Wu et al., 2014). However, animal-derived food, including beef, pork and poultry, is becoming increasingly expensive, in both economic and environmental terms, and has increasingly been associated with depletion of resources, emission of greenhouse gases, pollution and health issues. In the everyday life of the future, meat cannot be consumed on the scale it is today.

The constant growth of the world's population, food insecurity in some world regions as well as an increasing demand for and rising cost of animal protein will require a significant increase of food production and will place an unprecedentedly heavy burden on limited natural resources. This will pose a major challenge for the agricultural food industry, which needs to account for not only demographic and economic factors, but also issues related to a range of natural resources, such as energy, land and water (Calicioglu et al., 2019). Environmental sustainability will become a key issue, since unsustainable patterns of consumption and production are causally related to the current planetary crises of biodiversity loss, pollution and climate change. The United Nations Sustainable Development Goal #12 of ensuring sustainable consumption and production patterns entails the transformation of energy and materials to maintain or even improve human wellbeing without negatively impacting environmental resources (United Nations, 2022). In the context of achieving environmentally sustainable food security worldwide, edible insects as a future food for humans have become an issue of increasing interest (Lange and Nakamura, 2021b). While insect consumption may provide various benefits, the narrative of edible insects as a solution to resource challenges and hunger may be misleading. Thus, the present opinion piece argues that the presence of high-quality protein and various micronutrients as well as potential environmental and economic benefits may render edible insects globally a food for the future and an environmentally sustainable solution to malnutrition and food insecurity. However, scaling up the farming of insects, including more efficient breeding and ecologically friendly rearing methods, may not necessarily result in sustainability or more food resources for all. Edible insect products in a global market may become novel ingredients used to provide new snacks for overfed consumers.

Insects as food source

Insects are one of numerous food sources that have been consumed throughout the history of human development (Pager, 1976; Backwell and d'Errico, 2001). Edible insects have been an

important source of protein, fat and micronutrients in otherwise plant-based diets (Rothman et al., 2014), and insect eating is, to various degrees, common in all primates (McGrew, 2014). Today, the eating of insects remains popular in many regions worldwide (mainly Central and South America, sub-Saharan Africa and Southeast Asia), with regular consumption of edible insects estimated to form part of traditional diets of more than two billion people (van Huis et al., 2013).

Edible insects are a promising source of macronutrients and micronutrients. The available evidence suggests a high nutritional value of insects, since they are rich in protein, fat, vitamins, minerals and fibre (Lange and Nakamura, 2021a). The amount of protein and various types of lipids in insects depends primarily on species, type of diet and stage of metamorphosis (van Huis et al., 2013). The protein content of insects is in the same range as that of beef and pork (40–75 g/100 g dry weight) (Istituto Nazionale della Nutrizione, 1989). Insect consumption can contribute to the total intake of protein and various amino acids and may therefore enhance nutritional quality in the human diet (Bukkens, 1997). Most species of edible insects, such as yellow mealworm beetle, black soldier fly, housefly and house cricket, meet the amino acid content (e.g., phenylalanine, tyrosine, tryptophan, threonine and lysine) recommended by the World Health Organisation (World Health Organization, 2007). The total fat content of insects has been found to range from 2 to 62% (Williams et al., 2016). The fatty acid profile of insects is similar to that of animal fats and vegetable oils (Tzompa-Sosa and Fogliano, 2017). Compared to beef and pork, however, insects are particularly rich in unsaturated fatty acids, with some insect species containing up to 75% of total fatty acid content (Rumpold and Schlüter, 2013; Tzompa-Sosa et al., 2014). The composition of omega-3 polyunsaturated and some other fatty acids in mealworms is comparable to that found in fish and higher than that in pig and cattle. The omega-6/omega-3 fatty acid ratio can be influenced by diet (Lange and Nakamura, 2021b). Edible insects are also an important dietary source of fibre, since the exoskeleton of many insects consists of chitin. Edible insects appear to be a promising source of food bioactives, such as minerals, polyunsaturated fatty acids and fibre, and may be able to provide a wide range of food supplements and functional food ingredients for specific purposes. However, in view of the very large number of edible insect species and the many factors affecting their nutrient and bioactive content, generalisable conclusions concerning their nutritional value and potential health-promoting properties cannot be drawn.

Environmental benefits of edible insects

Major environmental benefits of edible insect production are related to the relatively high feed-to-meat conversion rate, with insects converting plant proteins to insect proteins far more efficiently than other animals (Deroy et al., 2015). While crickets require <2 kg of feed for every 1 kg of bodyweight gain (Collavo et al., 2005), the average amount of feed required to produce an increase in bodyweight by 1 kg is 2.5 kg for chicken, 5 kg for pork and up to 10 kg for beef (Smil, 2002). A further advantage of insects as a food source is the high percentage of the animal that can be consumed. Up to 80% of a cricket is edible for humans, compared to 55% for pigs and chickens and 40% for cattle (Nakagaki and de Foliart, 1991).

With respect to sustainability, a major advantage of edible insects is the viability of farming them using organic food waste, such as compost, manure or vegetable waste not suitable for human consumption, which may decrease environmentally damaging contamination. The food waste used for rearing insects provides an attractive approach to closing the loop of the food value chain in a sustainable circular economy (Ojha et al., 2020). Using organic side streams as insect feed can also increase the profitability of insect farming (Offenberg, 2011). However, the use of this form of waste may result in a reduction in growth and nutrient efficiency (Smetana et al., 2016). Moreover, mortality rates of crickets may increase when organic waste is used as feed (Lundy and Parrella, 2015).

Edible insects appear to be more climate-friendly than cattle, pigs or chickens, since they require less space and water to grow and develop and cause fewer greenhouse gas emissions. Food production in its present form can be expected to result increasingly in deforestation, environmental degradation and greenhouse gas emissions. The large-scale facilities producing livestock and fish incur huge environmental costs (Tilman et al., 2002; Fiala, 2008). Land use, in particular, will become a critical factor. The raising of livestock, accounting for over 70% of agricultural land use worldwide (Food Agriculture Organization of the United Nations, 2009), will increasingly contribute to the environmental problems, since the decrease in land available for agriculture as a consequence of climate change is likely to exacerbate food insecurity (Lloyd et al., 2011; Premalatha et al., 2011).

The ever-increasing demands on water supply will threaten global biodiversity as well as agricultural output and food production. Up to 70% of freshwater is used worldwide for agriculture (Pimentel et al., 2004), with meat production requiring particularly large quantities of water. The volume of water required for producing 1 kg of meat has been estimated to be 2,300 L for chicken, 3,500 L for pork and 22,000–43,000 L for beef (Chapagain and Hoekstra, 2003; Pimentel et al., 2004). The amount of water needed to produce 1 kg of edible insects is thought to be considerably lower (van Huis et al., 2013).

Livestock rearing has been estimated to produce 18% of greenhouse gas emissions, which is higher than emissions produced by the transport sector (Steinfeld et al., 2006). Insects appear to emit substantially smaller amounts of greenhouse gases and ammonia than cattle or pigs. The emissions of carbon dioxide, methane and nitrous oxide resulting from the farming of edible insects have been found to be lower by a factor of 100 per kg of weight in comparison with cattle (Oonincx et al., 2010). Manure and urine (ammonia) also contribute to environmental pollution and cause nitrification and soil acidification (Aarnink et al., 1995). Ammonia emissions of edible insects compare favourably to pigs, with a tenfold difference (Oonincx et al., 2010).

Possible problems of sustainable edible insect production

Despite the wide range of potential benefits of insect consumption, the narrative of edible insects as the solution to malnutrition and hunger as well as to resource and climate challenges or even as "the last great hope to save the planet" (Martin, 2014) is misleading. While insects can provide nutritious and sustainable food for a growing population, they are not a panacea.

Various problems may be associated with the sustainable production of edible insects. While they were believed to be an inexhaustible natural resource in the past (Schabel, 2006), some populations of insects are currently under threat of extinction due to their collection by humans (Ramos-Elorduy, 2006). Since several edible insect species are predated on by other insects and animals, a decrease in their numbers may have adverse effects on other insect populations and a wide range of ecosystem functions. For example, collecting edible insects may threaten essential ecosystem services, such as pollination, composting and pest control (Losey and Vaughan, 2006). In order to preserve wild insect populations and to avoid overexploitation, with the number of collected insects exceeding the capacity for regeneration capacity (Cerritos, 2009), the use of edible insects as a sustainable food source requires large-scale insect farming (van Huis et al., 2013). Whether scaling up the production of edible insects, with associated requirements including feed, energy, processing and transportation will involve unforeseen environmental costs and will, in fact, prove to be more sustainable than traditional livestock rearing remains to be seen. Sustainability in this context may be a property of mass production rather than of organisms. The current destructive food production methods should not be replaced by equally harmful new production systems for insect-based foods. Future research is therefore required to compare the sustainability and environmental impacts of large-scale farming of edible insects with those of existing farming practices.

Questions regarding insects as sustainable food source

Many questions regarding the use of edible insects as a sustainable food source remain to be answered. The future sustainability and environmental impact of large-scale rearing, harvesting and producing of edible insects is largely unknown and needs to be investigated in more detail in order to allow comparisons with traditional livestock raising and farming practices. In particular, suitable insect species and their requirements (feeding, housing, animal health and welfare) (Berggren et al., 2019) as well as processing, transport and storage conditions of insect-based foods need to be studied. Our knowledge of food safety in relation to insects for human consumption and of potential hazards of the intake of insects is limited. In common with other animal and plant-based foods, edible insects could be associated with various health risk factors, such as allergens, anti-nutritional compounds, food contaminants (e.g., mycotoxins, pathogenic microorganisms) and chemical residues (e.g., pesticides, heavy metals) (Lange and Nakamura, 2021b). This requires further consideration and research.

The potential socio-economic benefits of insect farming on improving food security in low-income countries requires further study. Once edible insects become a commodity in global markets, they may, like soy, serve as feed for livestock rather than food for humans and may therefore not benefit vulnerable populations. Cricket powder has become an ingredient of novel snacks for higher-income consumers, while low income individuals collecting and selling insects do not eat this nutritious food themselves. For example, increasing demand for insects from city-dwellers in Thailand led to the import of insects from bordering low-income countries with higher rates of malnourishment. Thus, the major source of protein of rural peasants in Cambodia, Laos and Myanmar is consumed mainly as snacks by well-fed urban people in Thailand (Müller et al., 2016).

A major obstacle to the inclusion of insects in human diets is consumer acceptance in western societies. The advantages of edible insects cannot be realised if people do not choose to eat them. In Europe and North America, insect consumption is viewed with feelings of disgust and is associated with a precarious and primitive lifestyle (Rozin and Fallon, 1987; Vane-Wright, 1991). Food disgust and aversion to insect consumption is mainly rooted in culturally determined food habits and can be attributed to prejudice (Mela, 1999). The question of whether people in western countries are willing to incorporate insects into their daily diet therefore depends on learning to tackle negative attitudes towards them by making edible insects available and educating the general public. Various approaches have been used to convince people that insects are palatable and thus influence consumer choices towards a favourable outlook on insects as a food source (Lange and Nakamura, 2021b). These include educational exhibitions in museums and zoos, combinations of educational talks and experience of insect eating, gastronomic activities, such as insect snacks and menus in bars and restaurants, as well as edible insect cookbooks. Experimental experience has confirmed the effectiveness of "bug banquets" in overcoming disgust towards edible insects (Lange and Nakamura, 2021b).

Furthermore, environmental sustainability appears not to be the main factor influencing acceptance and consumption of insect-based foods, but taste, price and availability (Berger et al., 2018; House, 2018). In consequence, the edible insect industry may forego sustainability measures, and the potential of insects as a sustainable food alternative might be diminished. In addition, the very high cost of cricket products, reflecting high demand and low supply, renders them currently an unlikely alternative to conventional protein sources.

In addition, the limited knowledge of food safety in relation to the use of insects in food production is likely to be a barrier to the introduction and promotion of edible insects as human food in western countries (Lange and Nakamura, 2021b). Risk factors to human health associated with the intake of edible insects include allergens as well as biological and chemical hazards. Both prevalence and concentration of contaminants in edible insects are influenced by species, stage of harvest, feed substrate and production methods. The use of hazard-free feed substrate is essential in improving the food safety of edible insects.

Conclusion

In summary, while food production will need to grow substantially in the future in order to meet the need for global food security, the environmental footprint of agricultural production systems has to be reduced dramatically. Amending diets by including edible insects in human consumption can markedly halt agricultural expansion for livestock production and may solve the dilemma of increasing population and consumption. Furthermore, edible insects could provide an eco-friendly and sustainable production approach and a nutritional profile beneficial to consumer health. The nutritional quality of edible insects appears to be equivalent or even superior to that of common animal-derived foods. Compared

to cattle and pigs, insects have a faster growth rate, a higher feed-to-food conversion efficiency, lower requirements for space and water as well as lower emissions of greenhouse gas and ammonia. It seems ironic that we invest energy, land and water in growing lower-quality protein, which requires more input than insects. Money is spent worldwide to save crops containing only 14% plant protein by killing another food source (insects) whose protein content in dry insect matter can be as high as over 70% (Premalatha et al., 2011; Rumpold and Schlüter, 2013). Large-scale production of insect-based foods may help solve the looming global food insecurity problem and contribute to accomplishing the sustainable development goals set by the United Nations.

Author contributions

KL and YN made substantial contributions to the conception of the work, provide approval for publication of the content, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. KL drafted the work. YN revised it critically for important intellectual content. Both authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Aarnink, A., Keen, A., Metz, J., Speelman, L., and Verstegen, M. (1995). Ammonia emission patterns during the growing periods of pigs housed on partially slatted floors. *J. Agric. Eng. Res.* 62, 105–116. doi: 10.1006/jaer.1995.1069

Al-Ali, E., Shingler, A., Huston, A., and Leung, E. (2018). *Meat: The Past, Present, and Future of Meat in China's Diet*. Waterloo: University of Waterloo.

Backwell, L. R., and d'Errico, F. (2001). Evidence of termite foraging by Swartkrans early hominids. *Proc. Natl. Acad. Sci.* 98, 1358–1363. doi: 10.1073/pnas.98.4.1358

Berger, S., Bärtsch, C., Schmidt, C., Christandl, F., and Wyss, A. M. (2018). When utilitarian claims backfire: advertising content and the uptake of insects as food. *Front. Nutr.* 5, 88. doi: 10.3389/fnut.2018.00088

Berggren, Å., Jansson, A., and Low, M. (2019). Approaching ecological sustainability in the emerging insects-as-food industry. *Trends Ecol. Evol.* 34, 132–138. doi: 10.1016/j.tree.2018.11.005

Bukkens, S. G. (1997). The nutritional value of edible insects. *Ecol. Food Nutr.* 36, 287–319. doi: 10.1080/03670244.1997.9991521

Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., and Sims, R. (2019). The future challenges of food and agriculture: an integrated analysis of trends and solutions. *Sustainability* 11, 222. doi: 10.3390/su11010222

Cerritos, R. (2009). Insects as food: an ecological, social and economical approach. *CAB Rev: Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* 4, 1–10. doi: 10.1079/PAVSNNR20094027

Chapagain, A. K., and Hoekstra, A. Y. (2003). "Virtual water flows between nations in relation to trade in livestock and livestock products," in *Value of Water Research Report Series No. 13*. Paris: UNESCO.

Collavo, A., Glew, R. H., Huang, Y. S., Chuang, L. T., Bosse, R., and Paoletti, M. G. (2005). "House cricket small-scale farming," in *Ecological Implications of Minilivestock*, ed M. G. Paoletti (New Hampshire: CRC Press), 519–44. Available online at: https://woven-network.co.uk/wp-content/uploads/2015/08/Paoletti-2005-BOOK-Ecological-Implications-of-Minilivestock-Potential-of-Insects-Rodents-Frogs-and-Snails-1.pdf (accessed August 25, 2021).

Deroy, O., Reade, B., and Spence, C. (2015). The insectivore's dilemma, and how to take the west out of it. *Food Qual. Prefer.* 44, 44–55. doi: 10.1016/j.foodqual.2015.02.007

Fiala, N. (2008). Meeting the demand: an estimation of potential future greenhouse gas emissions from meat production. *Ecol. Econ.* 67, 412–419. doi: 10.1016/j.ecolecon.2007.12.021

Food and Agriculture Organization of the United Nations (2009). *How to Feed the World in 2050: Food and Agriculture Organization of the United Nations*. Available online at: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf (accessed November 23, 2022).

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. (2010). Food security: the challenge of feeding 9 billion people. *Science* 327, 812–818. doi: 10.1126/science.1185383

House, J. (2018). Insects as food in the Netherlands: production networks and the geographies of edibility. *Geoforum* 94, 82–93. doi: 10.1016/j.geoforum.2018.05.011

Istituto Nazionale della Nutrizione (1989). *Tabelle di Composizione degli Alimenti*. Rome: INN.

Lange, K. W., and Nakamura, Y. (2021a). Edible insects as a source of food bioactives and their potential health effects. *J. Food Bioact.* 14, 4–9. doi: 10.31665/JFB.2021.14264

Lange, K. W., and Nakamura, Y. (2021b). Edible insects as future food: chances and challenges. *J. Future Foods* 1, 38–46. doi: 10.1016/j.jfutfo.2021.10.001

Lloyd, S. J., Kovats, R. S., and Chalabi, Z. (2011). Climate change, crop yields, and undernutrition: development of a model to quantify the impact of climate scenarios on child undernutrition. *Environ. Health Perspect.* 119, 1817–1823. doi: 10.1289/ehp.1003311

Losey, J. E., and Vaughan, M. (2006). The economic value of ecological services provided by insects. *BioScience* 56, 311–323. doi: 10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2

Lundy, M. E., and Parrella, M. P. (2015). Crickets are not a free lunch: protein capture from scalable organic side-streams via high-density populations of Acheta domesticus. *PLoS ONE* 10, e0118785. doi: 10.1371/journal.pone.0118785

Martin, D. (2014). *Edible: An Adventure into the World of Eating Insects and the Last Great Hope to Save the planet*. Boston, NY: New Harvest Houghton Mifflin Harcourt.

McGrew, W. C. (2014). The 'other faunivory' revisited: insectivory in human and non-human primates and the evolution of human diet. *J. Hum. Evol.* 71, 4–11. doi: 10.1016/j.jhevol.2013.07.016

Mela, D. J. (1999). Food choice and intake: the human factor. *Proc. Nutr. Soc.* 58, 513–521. doi: 10.1017/S0029665199000683

Müller, A., Evans, J., Payne, C., and Roberts, R. (2016). Entomophagy and power. *J. Insects Food Feed* 2, 121–136. doi: 10.3920/JIFF2016.0010

Nakagaki, B. J., and de Foliart, G. R. (1991). Comparison of diets for mass-rearing acheta domesticus (orthoptera: gryllidae) as a novelty food, and comparison of food conversion efficiency with values reported for livestock. *J. Econ. Entomol.* 84, 891–896. doi: 10.1093/jee/84.3.891

Offenberg, J. (2011). Oecophylla smaragdina food conversion efficiency: prospects for ant farming. *J. Appl. Entomol.* 135, 575–581. doi: 10.1111/j.1439-0418.2010.01588.x

Ojha, S., Bußler, S., and Schlüter, O. K. (2020). Food waste valorisation and circular economy concepts in insect production and processing. *Waste Manag.* 118, 600–609. doi: 10.1016/j.wasman.2020.09.010

Oonincx, D. G. A. B., van Itterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. J. A., and van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PLoS ONE*5, e14445. doi: 10.1371/journal.pone.0014445

Pager, H. (1976). Cave paintings suggest honey hunting activities in ice age times. *Bee World* 57, 9–14. doi: 10.1080/0005772X.1976.11097580

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., et al. (2004). Water resources: agricultural and environmental issues. *Bioscience* 54, 909–918. doi: 10.1641/0006-3568(2004)054[0909:WRAAEI]2.0.CO;2

Premalatha, M., Abbasi, T., Abbasi, T., and Abbasi, S. A. (2011). Energy-efficient food production to reduce global warming and ecodegradation: the use of edible insects. *Renew. Sust. Energ Rev*. 15, 4357–4360. doi: 10.1016/j.rser.2011.07.115

Ramos-Elorduy, J. (2006). Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. *J. Ethnobiol. Ethnomed*. 2, 51. doi: 10.1186/1746-4269-2-51

Rothman, J. M., Raubenheimer, D., Bryer, M. A. H., Takahashi, M., and Gilbert, C. C. (2014). Nutritional contributions of insects to primate diets: implications for primate evolution. *J. Hum. Evol.* 71, 59–69. doi: 10.1016/j.jhevol.2014.02.016

Rozin, P., and Fallon, A. E. (1987). A perspective on disgust. *Psychol. Rev.* 94, 23–41. doi: 10.1037/0033-295X.94.1.23

Rumpold, B. A., and Schlüter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Mol. Nutr. Food Res.* 57, 802–823. doi: 10.1002/mnfr.201200735

Schabel, H. G. (2006). *Forest Entomology in East Africa: Forest Insects of Tanzania*. Dordrecht: Springer. Available online at: http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10145149 (accessed November 27, 2022).

Smetana, S., Palanisamy, M., Mathys, A., and Heinz, V. (2016). Sustainability of insect use for feed and food: life cycle assessment perspective. *J. Clean. Prod.* 137, 741–751. doi: 10.1016/j.jclepro.2016.07.148

Smil, V. (2002). Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. *Enzyme Microb. Technol.* 30, 305–311. doi: 10.1016/S0141-0229(01)00504-X

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C. (2006). *Livestock's Long Shadow: Environmental Issues and Options: Food and Agriculture Organization*. Available online at: https://www.europarl.europa.eu/climatechange/doc/FAO%20report%20executive%20summary.pdf (accessed November 23, 2022).

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature* 418, 671–677. doi: 10.1038/nature01014

Tzompa-Sosa, D. A., and Fogliano, V. (2017). "Potential of insect-derived ingredients for food applications," in *Insect Physiology and Ecology*, ed V. D. Shields (San Luis Potosí: InTech), 215–231.

Tzompa-Sosa, D. A., Yi, L., van Valenberg, H. J., van Boekel, M. A., and Lakemond, C. M. (2014). Insect lipid profile: aqueous versus organic solvent-based extraction methods. *Food Res. Int.* 62, 1087–1094. doi: 10.1016/j.foodres.2014.05.052

United Nations (2022). *Ensure Sustainable Consumption and Production Patterns*. Available online at: https://sdgs.un.org/goals/goal12 (accessed November 22, 2022).

United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019*. New York, NY: United Nations, Department of Economic and Social Affairs, Population Division.

van Huis, A., van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., et al. (2013). *Edible Insects: Future Prospects for Food and Feed Security*. Rome: FAO. (FAO forestry paper; Vol. 171). Available online at: https://www.fao.org/3/i3253e/i3253e.pdf (accessed November 27, 2022).

Vane-Wright, R. I. (1991). Why not eat insects? *Bull. Entomol. Res.* 81, 1–4. doi: 10.1017/S0007485300053165

Williams, J. P., Williams, J. R., Kirabo, A., Chester, D., and Peterson, M. (2016). "Nutrient content and health benefits of insects," in *Insects as Sustainable Food Ingredients*, eds A. T. Dossey, J. Morales-Ramos, and M. Guadalupe Rojas (Amsterdam: Elsevier), 61–84. doi: 10.1016/B978-0-12-802856-8.00003-X

World Health Organization (2007). *Protein and Amino Acid Requirements in Human Nutrition: Report of a Joint WHO/FAO/UNU Expert Consultation*. Geneva: World Health Organization. (WHO technical report series; Vol. 935). Available online at: https://apps.who.int/iris/handle/10665/43411 (accessed November 22, 2022).

Wu, G., Bazer, F. W., and Cross, H. R. (2014). Land-based production of animal protein: impacts, efficiency, and sustainability. *Ann. N. Y. Acad. Sci.* 1328, 18–28. doi: 10.1111/nyas.12566

frontiers | Frontiers in Nutrition

TYPE Original Research
PUBLISHED 28 March 2023
DOI 10.3389/fnut.2023.1145068

OPEN ACCESS

EDITED BY
Muhammad Bilal Sadiq,
Forman Christian College,
Pakistan

REVIEWED BY
Sabreen Ezzat Fadl,
Matrouh University,
Egypt
Meleksen Akin,
Iğdır Üniversitesi,
Türkiye
Mo Peng,
Jiangxi Agricultural University,
China

*CORRESPONDENCE
Md Reaz Chaklader
✉ mrreaz.chaklader@postgrad.curtin.edu.au;
✉ reaz.chaklader@dpird.wa.gov.au

SPECIALTY SECTION
This article was submitted to Nutrition and Sustainable Diets, a section of the journal Frontiers in Nutrition

RECEIVED 15 January 2023
ACCEPTED 02 March 2023
PUBLISHED 28 March 2023

CITATION
Chaklader MR, Howieson J, Foysal MJ, Hanif MA, Abdel-Latif HMR and Fotedar R (2023) Fish waste to sustainable additives: Fish protein hydrolysates alleviate intestinal dysbiosis and muscle atrophy induced by poultry by-product meal in *Lates calcarifer* juvenile.
Front. Nutr. 10:1145068.
doi: 10.3389/fnut.2023.1145068

Fish waste to sustainable additives: Fish protein hydrolysates alleviate intestinal dysbiosis and muscle atrophy induced by poultry by-product meal in *Lates calcarifer* juvenile

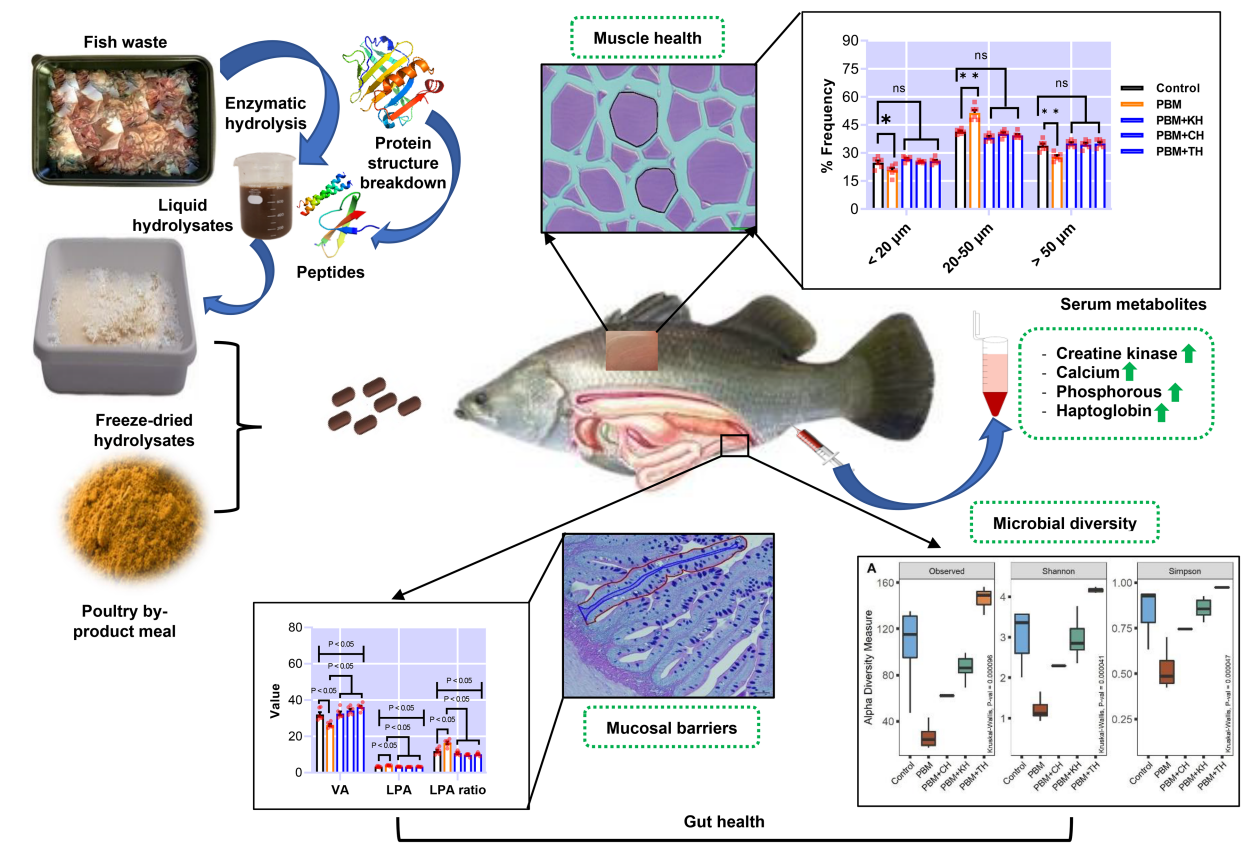
Md Reaz Chaklader[1,2]*, Janet Howieson[1], Md Javed Foysal[1,3], Md Abu Hanif[4], Hany M.R. Abdel-Latif[5] and Ravi Fotedar[1]

[1]School of Molecular and Life Sciences, Curtin University, Bentley, WA, Australia, [2]Department of Primary Industries and Regional Development, Fremantle, WA, Australia, [3]Department of Genetic Engineering and Biotechnology, Shahjalal University of Science and Technology, Sylhet, Bangladesh, [4]Department of Fisheries Science, Chonnam National University, Yeosu, Republic of Korea, [5]Department of Poultry and Fish Diseases, Faculty of Veterinary Medicine, Alexandria University, Alexandria, Egypt

Valorising waste from the processing of fishery and aquaculture products into functional additives, and subsequent use in aquafeed as supplements could be a novel approach to promoting sustainability in the aquaculture industry. The present study supplemented 10% of various fish protein hydrolysates (FPHs), obtained from the hydrolysis of kingfish (KH), carp (CH) and tuna (TH) waste, with 90% of poultry by-product meal (PBM) protein to replace fishmeal (FM) completely from the barramundi diet. At the end of the trial, intestinal mucosal barriers damage, quantified by villus area (VA), lamina propria area (LPA), LPA ratio, villus length (VL), villus width (VW), and neutral mucin (NM) in barramundi fed a PBM-based diet was repaired when PBM was supplemented with various FPHs (p<0.05, 0.01, and 0.001). PBM-TH diet further improved these barrier functions in the intestine of fish (p<0.05 and 0.001). Similarly, FPHs supplementation suppressed PBM-induced intestinal inflammation by controlling the expression of inflammatory cytokines (*tnf-α* and *il-10*; p<0.05 and 0.001) and a mucin-relevant production gene (*i-mucin c*; p<0.001). The 16S rRNA data showed that a PBM-based diet resulted in dysbiosis of intestinal bacteria, supported by a lower abundance of microbial diversity (p<0.001) aligned with a prevalence of Photobacterium. PBM-FPHs restored intestine homeostasis by enhancing microbial diversity compared to those fed a PBM diet (p<0.001). PBM-TH improved the diversity (p<0.001) further by elevating the Firmicutes phylum and the *Ruminococcus*, *Faecalibacterium*, and *Bacteroides* genera. Muscle atrophy, evaluated by fiber density, hyperplasia and hypertrophy and associated genes (*igf-1*, *myf5*, and *myog*), occurred in barramundi fed PBM diet but was repaired after supplementation of FPHs with the PBM (p<0.05, 0.01, and 0.001). Similarly, creatine kinase, calcium, phosphorous, and haptoglobin were impacted by PBM-based diet (p<0.05) but were restored in barramundi fed FPHs supplemented diets (p<0.05 and 0.01). Hence, using circular economy principles, functional FPHs could be recovered from the fish waste applied in aquafeed formulations and could prevent PBM-induced intestinal dysbiosis and muscular atrophy.

KEYWORDS

bioactive peptides, animal protein, mucosal barriers, bacteria diversity, muscle atrophy, sustainable aquaculture



GRAPHICAL ABSTRACT

Introduction

The transformation of fish waste produced by fish processing industries into value-added products such as FPHs, and subsequent utilization in aquafeed, has been an emerging research area in light of the circular economy (1). Such a strategy could potentially result in recycling some of the 1.3 billion tons of food waste produced globally (2) and 7.3 million tonnes waste produced each year in Australia (3). It has been estimated that approximately 100,000 tonnes of waste are produced by seafood industries in Australia every year (4), and an estimated AUD, 15 million *per annum*, is required for disposal (5). High-quality FPHs, characterized by a well-balanced amino acid composition and an abundance of low molecular weight peptides, can be produced from fish processing waste. Such FPH has been considered a suitable immunostimulant for human and animal nutrition (1, 6). Adding a smaller quantity of FPHs has been reported to enhance the palatability of aquafeed, thereby improving the growth and health of aquaculture species (1, 7). The presence, by supplementation, of sufficient bioavailable nutrients in FPHs, has been reported to compensate for nutritional shortcomings of low-quality alternative plants (7) and animal protein aquafeed ingredients (1, 8).

The feasibility of using alternative animal protein aquafeed sources, including PBM, has been investigated for decades in order to facilitate the replacement of FM, a finite and high-cost conventional protein source (9). PBM has been well researched due to its high protein content and amino acid balance similarity close to FM and higher than plant protein sources (10). There has been significant success in the commercial application of PBM and aligned oil in Australia and New Zealand (10, 11). However, the major reason for the historically limited use of PBM on a world scale, as with many animal by-product proteins, is the variation in nutritional composition from batch to batch and among suppliers. This variation has major implications for aquafeed producers due to affecting the biological quality and utilization of the finished feed (9). There is a good number of studies on incorporating PBM in aquafeed formulation with various successes for finfish and crustacean aquaculture (9). One study reported that barramundi fed with high inclusion levels of PBM demonstrated disruption of mucosa barrier functions in the gills and intestine (11). Mucosal barrier functions are important in maintaining cellular and tissue homeostasis (12–14), thereby maintaining intestinal homeostasis, which is directly linked to growth performance and health status of farmed teleost fish (15, 16). Impairment of the fine-tuned intestinal mucosal barrier aggravates intestinal mucosal permeability, contributing to the invasion of pathogenic bacteria and intestinal inflammation of fish (17). Similar to this reported response of barramundi to PBM-based diets, several other studies found that high inclusion of alternative proteins stimulated intestinal dysbiosis by damaging mucosal barriers and stimulating inflammatory responses (18–21).

Such shortcomings of incorporating low-quality alternative proteins into aquafeed could potentially be overcome by complementing with functional additives such as FPHs. For example, supplementation of FPHs ameliorated the quality of PBM, resulting in improved growth performance, immune response, and gut health of barramundi (1, 8). Similarly, 10% of FPH supplemented with 80% of plant protein in the diet of Atlantic salmon, *Salmo salar*, resulted in a significant increase in

growth performance and health (7). Supplementation of FPH also benefited the overall immunity of largemouth seabass, *Micropterus salmoides,* increased anti-inflammatory cytokines (*tgf-β* and *il-10*), and reduced pro-inflammatory cytokines (*il-8*), (22). In alternative protein studies, it is important to understand the interaction between intestinal mucosal barrier functions, microbiota, and anti-inflammatory cytokines in maintaining intestinal homeostasis. This area has not been well-researched in barramundi nutritional studies.

Intestinal mucosal barrier damage and inflammation are reported to be linked with intestinal microbial composition. Like many other factors, the balance of bacterial composition can be reshaped or altered by dietary modification (23, 24), which in turn influences the mucosal barrier maturation and development of fish. Several studies have observed a stimulatory effect of alternative aquafeed protein sources on gut dysbiosis of aquaculture fish (25). It is of interest, therefore, to examine the gut microbial composition when functional ingredients, such as FPHs, are added to ameliorate the quality of low-quality alternative protein. This analysis can be completed with deep surveillance by high-throughput 16S rRNA, a new powerful approach of next-generation sequencing technologies independent of culture-based techniques (23, 26). FPHs supplementation could be a good strategy to maintain intestinal homeostasis by reshaping the bacterial composition since FPHs containing essential amino acids are a good natural source of nitrogen required for the growth of gut microbiota (27). Also, FPHs have been reported to proliferate bacterial composition by accelerating the activity of amino peptides and proteases in bacteria (28). One of the most beneficial effects of FPH is the reduction of pathogenic bacteria with a concurrent increase in the growth of beneficial bacteria, as described in the review of Aloo and Oh (29). Our previous study found that supplementing tuna hydrolysate with PBM enhanced the bacteria diversity in the intestine of barramundi (8). In addition, plant protein influenced opportunistic bacteria, in particular, *Aeromonas* bacteria, in the same species, but the abundance of *Aeromonas* decreased when supplemented with FPHs (30).

In addition to the negative effect of replacing FM with PBM or other alternative protein sources on barramundi gut health, a PBM-based diet also caused a histopathological change, myotome necrosis, in the barramundi muscle (11). Previous studies in our laboratory found negative effects of plant protein on muscle microstructure and creatinine kinase production, associated with muscle damage and thereby impacting the muscle health of barramundi (31, 32). However, no single study is dedicated to understanding the potential effect of FM free diet on the interaction between muscle damaging enzymes, muscle micromorphology, and muscle health-relevant genes. Largely overlooked parameters contributing to muscle growth are hyperplasia (recruitment of new muscle fiber) and hypertrophy (growth of existing fiber), the main determinants of fish growth, which have been reported to be regulated by nutrients in juvenile fish (33, 34). For instance, dietary supplementation of threonine, methionine and tryptophan influences the hyperplasia and hypertrophy of various fish species (33, 34).

The comparison of various FPHs derived from marine and freshwater fish waste was the first attempt to evaluate the efficacy of FPHs in preventing the negative effect of completely replacing FM with PBM. Hence, the present study investigated the effect of various FPHs supplementation with PBM on intestinal homeostasis and muscle growth in juvenile barramundi. Intestinal homeostasis was evaluated by intestinal microbiota composition and anti-inflammatory cytokine expression, while muscle growth was determined by the extent of hyperplasia and hypertrophy. To our knowledge, this is the first study on the effect of PBM on the muscle growth of barramundi specifically and the complementary effect of FPH on preventing negative effects on muscle growth induced by PBM.

Materials and methods

Ethical statement

All experimental procedures involving fish were conducted at Curtin Aquatic Research Laboratory (CARL), subsequent to review and approval by the Animal Ethics Committee of Curtin University (ARE2018-37) in strict accordance with the guidelines and regulations in Australia for the care and use of animals.

Experimental diet and fish husbandry

Details of the feed formulation (Table 1) and fish rearing protocol have been described in our previous articles (1, 11). All hydrolysate produced from fish waste was freeze-dried, and the molecular weight distribution is presented in Table 2. The peptide analysis protocol was determined by size exclusion chromatography of proteins, as illustrated in our previously published article (1). Briefly, five test diets were formulated, including a FM-based diet (Control), a PBM-based diet (PBM) and supplementation of 10% yellowtail kingfish, *Seriola lalandi* hydrolysate (KH), carp hydrolysate, *Cyprinus carpio* (CH) and southern bluefin tuna, *Thunnus maccoyii* hydrolysate (TH) respectively with 90% of PBM (designated as PBM-KH, PBM-CH, and PBM-TH). For feed preparation, all the dried ingredients were weighed, and mixed homogenously; thereafter, oil was added and mixed thoroughly. Distilled water was then gradually added to make a stiff dough which was passed through a mincer to produce pellets. Pellets were dried in an oven for 36 h at 60°C and stored in the refrigerator (4°C) in plastic bags.

Following acclimatization in aligned experimental systems, 25 fishes were stocked in replicated tanks containing 250 L sea water (375 fish in 15 tanks). Water quality, including DO, temperature, and other parameters, was maintained at an optimal level by an aerator, electric heater, and external bio-filter. Ammonia nitrogen and nitrite were checked by commercial kits and maintained at <0.50 mg L^{-1} by water exchange. Experimental diets were fed to fish until visual satiety twice daily, at 8.00 am and 6.00 pm, respectively, over a period of 42 days. After 42 days post-feeding, fish were bulk-weighed and counted to estimate the growth performance of fish.

Histological analysis

Two hindgut and muscle tissue samples per tank were collected from euthanised (AQUI-S®, 175 mg/L) fish that were used for other biometry indices reported in our previous trials (1, 11). Tissue samples were immediately fixed in 10% neutral buffered formalin and slides were prepared following standard protocol for histological analysis. Hindgut tissue was stained with Periodic Acid-Schiff (PAS) to visualize neutral mucus-producing mucin cells, while muscle tissues were stained with Hematoxylin and Eosin (H&E). All slides were subjected

10.3389/fnut.2023.1145068

TABLE 1 Feed formulation and nutritional composition of experimental diets from our previous studies (1, 11).

	Diets				
Ingredients (g/100g)	Control	PBM	PBM+KH	PBM+CH	PBM+TH
[e]PBM[a]	0.00	69.50	61.40	61.40	61.40
[g]KH	0.00	0.00	9.50	0.00	0.00
[h]CH[b]	0.00	0.00	0.00	9.00	0.00
[i]TH[b]	0.00	0.00	0.00	0.00	11.80
[f]Tuna FM[c]	72.00	0.00	0.00	0.00	0.00
Canola oil[c]	1.00	3.00	3.00	3.00	3.00
Cod liver oil[c]	0.50	6.00	6.00	6.00	6.00
Corn/wheat starch[c]	7.00	7.00	3.00	5.00	5.00
Lecithin—Soy (70%)[c]	1.00	1.00	1.00	1.00	1.00
Vitamin C[c]	0.05	0.05	0.05	0.05	0.05
Dicalcium phosphate[c]	0.05	0.05	0.05	0.05	0.05
Methionine	0.00	0.40	0.00	0.00	0.00
Wheat (10 CP)[c]	16.90	11.50	13.50	12.00	9.20
Vitamin premix[c]	0.50	0.50	0.50	0.50	0.50
Cholesterol[c]	0.00	0.00	2.00	2.00	2.00
Salt (NaCl)[c]	1.00	1.00	0.00	0.00	0.00
***Proximate composition* (*dry matter*)[d]**					
Crude Protein (%)	47.88	47.86	48.00	47.71	47.87
Crude Lipid (%)	10.59	12.71	10.73	10.71	10.66
Moisture					
Ash					

[a]Kindly provided by Derby Industries Pty Ltd T/A, Talloman Lot Lakes Rd, Hazelmere WA 6055. [b]SAMPI, Port Lincoln, Australia. [c]Specialty Feeds, Glen Forrest Stockfeeders, 3150 Great Eastern Highway, Glen Forrest, Western Australia 6071. [d]Determined according to Association of Official Analytical Chemists (AOAC). [e]Poultry by-product meal (PBM): 67.13% crude protein, 13.52% crude lipid and 13.34% ash. [f]Fishmeal: 64.0% crude protein, 10.76% crude lipid and 19.12% ash. [g]Kingfish hydrolysate (KH): 57.07% crude protein, 31.98% crude lipid, 2.55% moisture and 0.29% ash. [h]Carp hydrolysate (CH): 59.01% crude protein, 12.89% crude lipid, 0.73% moisture and 46.21% ash. [i]Tuna hydrolysate (TH): 58.4% crude protein, 1.05% crude lipid and 11.3% ash.

TABLE 2 Molecular weight (%) of kingfish hydrolysate (KH), carp hydrolysate (CH), and tuna hydrolysate (TH) (1).

Molecular weight (Da)	Hydrolysates		
	KH	CH	TH
>10,000	5.5	3.2	1.8
10,000–5,000	1.9	11.1	6.8
5,000–1,000	22.3	45.0	36.8
1,000–500	31.5	13.1	22.7
500–238	18.1	15.9	16.8
<238.2	20.7	11.6	15.2

to light microscopy (BX40F4, Olympus, Tokyo, Japan) to take images. Hindgut mucosal morphology were determined by ImageJ software.

Gene expression analysis

The collected intestinal and muscle tissue from the euthanized (175 mg/L AQUI-S®) barramundi were kept in Eppendorf containing RNA-later (Thermo Scientific, United States) and immediately stored at −80°C until analysis. All genes expression analysis associated with intestinal inflammation (*tnf-α* and *il-10*), intestinal defense (*i-mucin c*), and muscle growth (*igf-1*, *myf5*, and *myog*) were conducted in the present study. The forward and reverse primers were designed from the known nucleotide sequence of barramundi, *Lates calcarifer*. During primer design from the predicted sequence, the primer sequences were checked and confirmed using the sequence read achieve (SRA) blast in NCBI (National Center for Biotechnology Information). All the primer sequences with their product size, melting temperature (Tm), and GenBank accession number were given in Table 1. The expression analysis was performed by Quantitative real-time PCR following the method described in our previous study (1). Briefly, the protocols of manufacturer's different test kits including RNeasy Mini Kit (Qiagen, Hilden, Germany), Turbo DNase-free Kit (Thermo Fisher, United States), RNeasy MiniElute Cleanup Kit (Qiagen, Hilden, Germany), and Omnicript RT kit (Qiagen, Hilden, Germany) were followed to extract RNA, digest DNA, purify RNA, and synthesize first strand cDNA, respectively. Following qRT-PCR analysis using PowerUp™ Cyber Green Master Mix (Thermo Scientific, United States) with 7500 Real-Time PCR System (Applied Biosystems, United States), $2^{-\Delta\Delta CT}$ was used to calculate the relative expression of genes against the *ef-1a* which was more stable than other reference genes (*β-actin*) analyzed in the present study (Table 3).

TABLE 3 Primers of tumor necrosis factor-α (*tnf-α*), interleukin-10 (*il-10*), i-mucin C, insulin like growth factor-1 (*igf-1*), *myf5*, *myog* and elongation factor-1a (*ef-1a*) genes used in qPCR.

Genes	Primer sequence	Tm (°C)	Product size (bp)	Accession no.
tnf-α	F: GAGTTTACCACCGGGAATCG	60.5	163	XM_018704368
	R: CCTTTGTCGAACCATCCAGC			
il-10	F: CTGATGCCTCACATGGAGTC	60.5	175	XM_018686737
	R: GCAGATCCAGTTCACCCATG			
i-mucin c	F: CCAACAACTACTACTGCTGC	58	147	XM_018670824
	R: GGTTGTAAGTGCTGCCATTG			
igf-1	F: ACGCTGCAGTTTGTATGTGG	58.4	157	EU136176.1
	R: CTTAGTCTTGGGAGGTGCA	57.5		
myf5	F: GCAATGCCATCCAGTACATC	58.4	167	XM_018661930
	R: TGCATTCACCTGTTGCCACA			
myog	F: AGGAAGACAGTGACCATGGA	58.4	175	XM_018685841
	R: GCAGCCTTTCGATATACTGG			
ef-1a	F: AGGAAGTGAGCACCTACATC	58.4	122	GU188685
	R: CTTGAACCAGGGCATCTTGT			

Hindgut microbiota

Gut DNA extraction

Bacterial DNA from fish samples was extracted using a Blood and Tissue Kit (Qiagen, Hilden, Germany). The DNA extraction was performed following the manufacturer's instructions with additional beads disruption and homogenization using a tissue lyser II (Qiagen, Hilden, Germany). Briefly, the hindgut digesta were collected inside a biosafety cabinet, transferred into 1.5 mL Eppendorf, and resuspended in 100 µL of physiological phosphate-buffered saline (PBS). After homogenization, samples in Eppendorf were centrifuged briefly, and the protocol of the Blood and Tissue Kit was followed. The DNA concentration was measured in a Nanodrop Spectrophotometer 2000 cc (Thermo Fisher Scientific, United States). An even concentration of 50 ng/µL was achieved through dilution with DEPC-treated water (Thermo Fisher Scientific, Waltham, United States).

Amplicon sequencing

The V3V4 region of the 16S rRNA gene was amplified with Illumina overhang adapter in 35 cycles of PCR using a S1000 Thermal Cycler (Bio-Lab Inc., United States) as described previously. Positive amplicons in 1% agarose gel were purified using AMPure Beads, indexed with Nextera® XT Index Kit (Illumina) as described in Illumina 16S Metagenomic Sequencing Library Preparation. Samples were sequenced in a MiSeq platform (Illumina) using V3 kit (600 cycles).

Sequence data processing

Raw sequences were imported in qiime2 (v2021.11) for paired-end processing of reads. Deionizing was performed in the DADA2 algorithm implemented in qiime2. Quality trimming of demultiplexed reads was performed using a q2-DADA2 plug-in with the following parameters: -p-trim-left-l 0; -p-trunc-len-f 280; -p-trim-left-r 0; and -p-trunc-len-r 220. Chimeric sequences and reads with more than five expected errors were filtered out. Most non-chimeric reads (92%) were merged and assigned to feature frequency amplicon sequence variants (ASVs) representing the biological feature of amplicon sequences. The feature ASV table was filtered based on the lowest non-zero frequency, 150. Taxonomic classification of ASVs was performed using the consensus BLAST classifier method against SILVA 138 release. Chloroplast and mitochondrial sequences were removed. *Clostridium sensu stricto* 1 was renamed as *Clostridium*, whereas uncultured, unclassified and ambiguous taxa were grouped into other bacteria. Each sample was rarefied to an even depth of 12,376 for further analysis of alpha-beta diversity and microbial composition.

Bioinformatic and statistical analysis

Downstream bioinformatic and statistical analysis were performed in R software (v4.22; R Core Team, 2013). Alpha-beta diversity analysis was performed using phyloseq (35), microbiomeSeq,[1] microbiome,[2] and vegan R packages. Alpha diversity was measured in terms of observed species, Shannon, and Simpson indices. The Kruskal-Wallis rank test was used to compare diversity measurements among groups. Weighted (relative abundance) and unweighted (presence-absence) UniFrac distance metrics were considered for the visualization of beta-ordination. Permutational multivariate analysis (PERMANOVA) for beta-dispersion with 1,000 permutations was performed using the vegan R package (36) to visualize the feeding effect on gut microbiota. Shared, unique, and core genera in different groups were identified using MicEco, Euler, and microbiome R packages. The relative abundance of bacteria at various taxa levels was calculated with the phyloseq R package. Linear Discriminant Analysis Effect Sizes (LEfSe) at a LDA cut-off value of ≥2.0 was employed to identify differentially abundant bacteria in five different diet groups using the Microbiome Marker R package. *p value* of >0.05 was considered as statistically significant at every phase of the data analysis. The raw sequence data in fastq format have been deposited to the National Center for

1 https://github.com/umerijaz/microbiomeSeq

2 https://github.com/microbiome/microbiome

Biotechnology Information (NCBI) and are currently available under the BioProject accession number PRJNA909982.

Serum metabolites

Blood collection protocols from three fish/tank were described in our earlier study (1). Following blood collection using from anesthetized barramundi (8 mg/L of AQUI-S®) by puncturing the caudal vein, blood was allowed to clot for 4 h on ice and then centrifuged to separate the serum. The collected sera were preserved at −80°C for further analysis. Creatine kinase (CK; OSR6179) calcium (OSR60117), Mg (OSR6189), inorganic phos (OSR6122), iron (OSR6186), gamma-glutamyltransferase (GGT; OSR6020), and albumin (catalog code OSR6102) were run on a AU480 Clinical Chemistry Analyzer (Beckman Coulter Australia Pty Ltd., Lane Cove West, NSW) using Beckman Coulter clinical chemistry kits. A phase haptoglobin assay kit was used to analyze serum haptoglobin following the manufacturer's instructions (Tridelta Development Ltd., Co. Wicklow, Ireland).

Statistical analysis

Unless stated otherwise, all results were represented as mean ± SE. Normality and equal variances of all data were checked by Shapiro-Wilks and Levene's tests and transformed if necessary. The influence of experimental diets with respect to control were compared by one-way variance analysis (ANOVA) with Dunnett's multiple comparisons test. The significance level was set at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

Results

Intestinal mucosal barriers and inflammatory response

Intestinal quantitative measurements and inflammatory responses in barramundi-fed the various test diets are presented in Figure 1. Barramundi fed a PBM-based diet showed a significantly lower villus area (VA; $p < 0.01$) when compared to those fed the control diet (Figure 1B). Supplementing various FPHs attenuated the negative effects of replacing FM completely with PBM, as supported by comparable VA in barramundi-fed PBM supplemented with FPHs to control fed barramundi ($p > 0.05$) and a significantly higher VA in barramundi-fed PBM-TH ($p < 0.05$) when compared to the PBM-only based diet (Figure 1B). However, lamina propria area (LPA; $p < 0.01$) and LPA ratio ($p < 0.001$) increased significantly in barramundi-fed a PBM-based diet but were similar in barramundi-fed PBM-FPHs based diets when compared with those fed the control diet (Figure 1B; $p > 0.05$). Meanwhile, LPA ($p < 0.01$) and LPA ratio ($p < 0.001$) were significantly lower in barramundi-fed PBM supplemented with FPHs than those fed a PBM-based diet.

Poultry by-product meal-based diet negatively affected the villus length (VL), villus width (VW), and neutral mucin (NM; $p < 0.001$; Figure 1C), which all improved in the intestine of barramundi-fed PBM supplemented with various FPHs when compared with the PBM-based diet ($p < 0.05$ and 0.001). Total intestinal wall (TIW), muscularis thickness (MU), muscularis externa (ME), muscularis interna (MI), and submucosa (S; Figure 1E) were unaffected by test diets ($p > 0.05$).

The expression level of *tnf-α* increased significantly in the intestine of barramundi fed PBM-based diet ($p < 0.001$) but supplementation of FPHs regulated the expression level of *tnf-α*, supported by a comparable expression level of *tnf-α* as observed in control fed barramundi ($p < 0.001$). *il-10*, an anti-inflammatory cytokine, showed a significantly lower expression in the intestine of barramundi fed the PBM-based diet ($p < 0.05$), but the expression levels of *il-10* improved significantly in barramundi fed PBM diets supplemented with FPHs when compared to those fed the PBM-based diet ($p < 0.05$). Barramundi fed PBM supplemented FPHs diets showed a similar expression level of *il-10* when compared with the control ($p > 0.05$). *i-mucin c* showed a similar response to *il-10*, with a lower expression in barramundi-fed the PBM-based diet ($p < 0.01$). *i-mucin c* expression improved when FPHs were supplemented with PBM when compared to those fed only a PBM-based diet ($p < 0.001$). There was no statistical difference in the expression level of *i-mucin c* between the control and FPHs-supplemented PBM groups ($p > 0.05$).

Gut microbiome

Illumina reads

After trimming and filtering, 865,019 quality reads were obtained from 45 samples ranging from 7,864 to 29,862. On average, 19659.2 ± 5047.2 reads were merged, accounting for 86.5% of the total reads generated per sample. In total, 1,215 ASVs were generated, wherein 10 and 20 ASVs comprised 72.6 and 86.2% of the total reads. Phylogenetic classification of reads was obtained for both bacteria and archaea, resulting in 26 phyla, 121 families and 146 genera. The rarefaction curve using rarefied read abundance (Figure 2) and average good's coverage index (0.998) value suggested sequencing samples at maximum saturation level.

Alpha-beta diversity

A comparison of alpha diversity showed significant differences in microbial communities (Figure 3A). The highest bacterial diversity was observed in the fish gut from the PBM + TH diet, whereas the lowest diversity was recorded for PBM only when compared to the other groups ($p < 0.001$). Shannon and Simpson's analysis revealed significantly higher abundance and even distribution of top abundant taxa in the gut of fish fed the PBM + TH diet ($p < 0.001$). Beta-ordination showed different bacterial communities in the PBM and PBM + TH groups and clustered separately from the control, PBM + KH and PBM + CH diets ($p = 0.001$) regardless of presence-absence (Figure 3B) and relative abundance (Figure 3C). However, relative abundance generated more distinct separation of gut bacterial communities than presence-absence, signifying a diet-specific increase of top abundant existing bacteria in the gut. Centroid analysis of beta-dispersion showed strong influence of PBM and PBM + TH diets in gut bacterial communities' groups, when compared to the control and PBM + KH which had no distance differences.

Microbial composition

From the 146 identified genera, 106 were found to be unique in the PHM + TH and PBM + CH diet groups suggesting the colonization of new bacteria with these two diets. Among the classified ASVs,

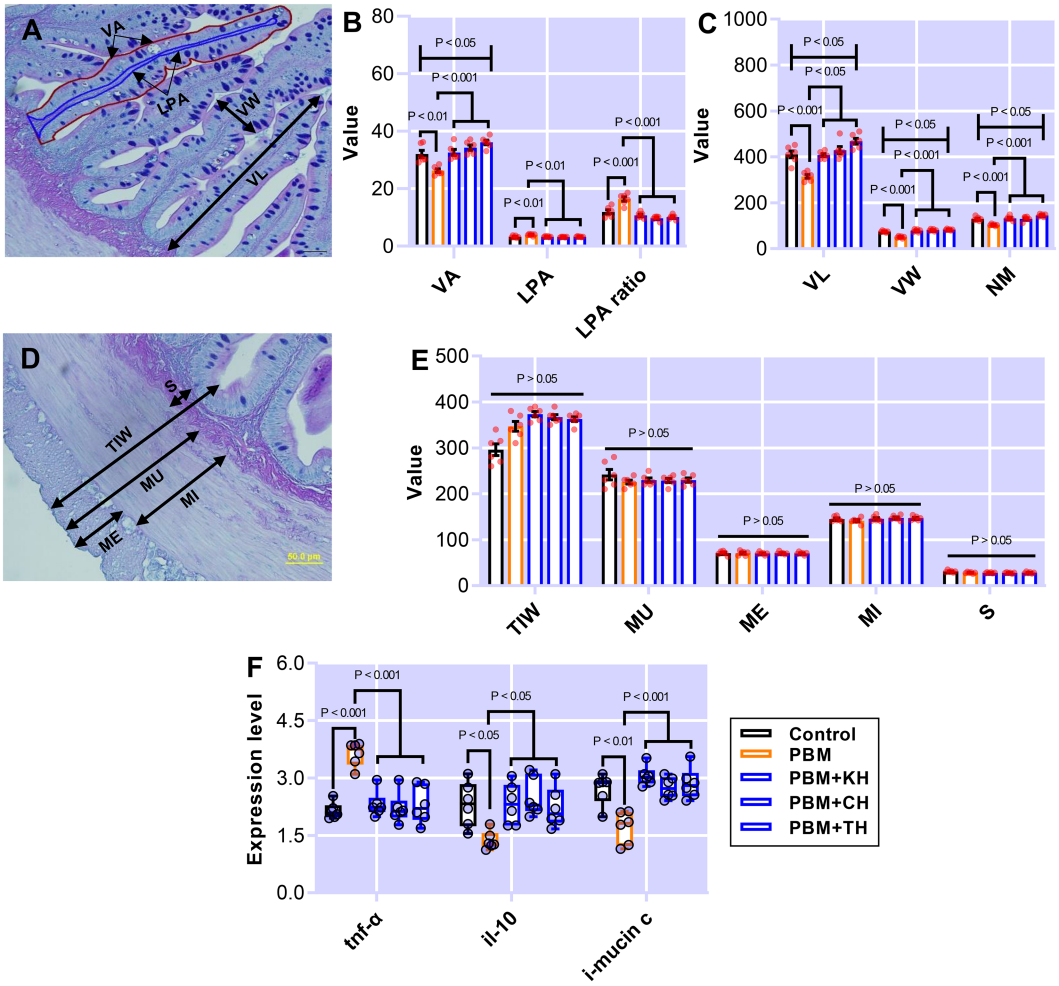


FIGURE 1
The representative histological micrograph of the intestine showing measurements **(A,D)**; the comparison of quantitative measurements of the intestine **(B,C,E)** and fold change in the expression of pro- and anti-inflammatory cytokines and mucin production relevant gene **(F)** of barramundi fed FM-based control, PBM alone, or supplemented with various FPHs supplemented diets over a period of 42 days. VA, villus area; LPA, lamina propria area; VL, villus length; VW, villus width; NM, neutral mucin; TIW, total intestinal wall; MU, muscularis thickness; ME, muscle interna; MI, muscle ineterna; S, submucosa, tnf-*α*, tumor necrosis factor; *il-10*, interleukin 10, and *i-mucin c*, integument mucin c.

Strenotrophomonas was found distributed in more than 90% of samples irrespective of diet groups; and, therefore, can be defined as core genera of juvenile barramundi (Figure 4A). Proteobacteria was found dominant in control, PBM and PBM + KH diets, wherein more than 60% of reads were classified to Proteobacteria in the fish gut from the PBM diet. Fish gut had Actinobacteria-rich communities with the PBM + CH diet, whereas 72% of reads were assigned to *Firmicutes* for the PBM + TH diet group (Figure 4B), higher *Pseudomonas* abundance was detected at the genus level in the control (24.2%) and PBM + KH (34.6%) groups. *Photobacterium* (54.6%) and *Mycobacterium* (42.4%) were dominant in the PBM and PBM + CH groups, respectively (Figure 4C). No single dominancy was observed in the PBM + TH group with the *Ruminococcus* group represented 11% of the sequences.

Linear Discriminant Analysis Effect Sizes-based differential abundance identified 24 taxa at phylum and genus levels with significantly higher abundance in five different feeding groups. Higher Proteobacterial abundance in the PBM diet and *Firmicutes* abundance in the PBM + TH group was detected. At the genus level, the control group had a significantly higher abundance of *Escherichia-Shigella*, *Streptococcus*, and *Enterococcus*. Significantly higher *Photobacterium* with PBM, *Staphylococcus* and *Pseudomonas* with PBM + KH and *Mycobacterium* and *Legionella* with PBM + CH diets were observed when compared to the other treatments. Finally, the PBM + TH diet augmented the abundance of *Ruminococcus*, *Faecalibacterium*, and *Bacteroides* in the aligned fish gut (Figures 5A,B). *Ruminococcus* was positively associated with the *i mucin c* and inflammatory cytokines (*tnf-α and il-10*) in the intestine of the PBM-TH fed barramundi group ($p < 0.05$), while other mucosal barrier functions (LPA, LPA raito, NM, VL, and VW) showed no correlation with any genus in barramundi fed all test diets ($p > 0.05$), as determined by Pearson correlation (Figure 6).

Muscle health

Muscle measurement and quantification, and muscle-health-relevant gene expression, are presented in Figures 7A–E. Muscle fiber area (Figure 7B; $p < 0.001$) and density (Figure 7C; $p < 0.05$)

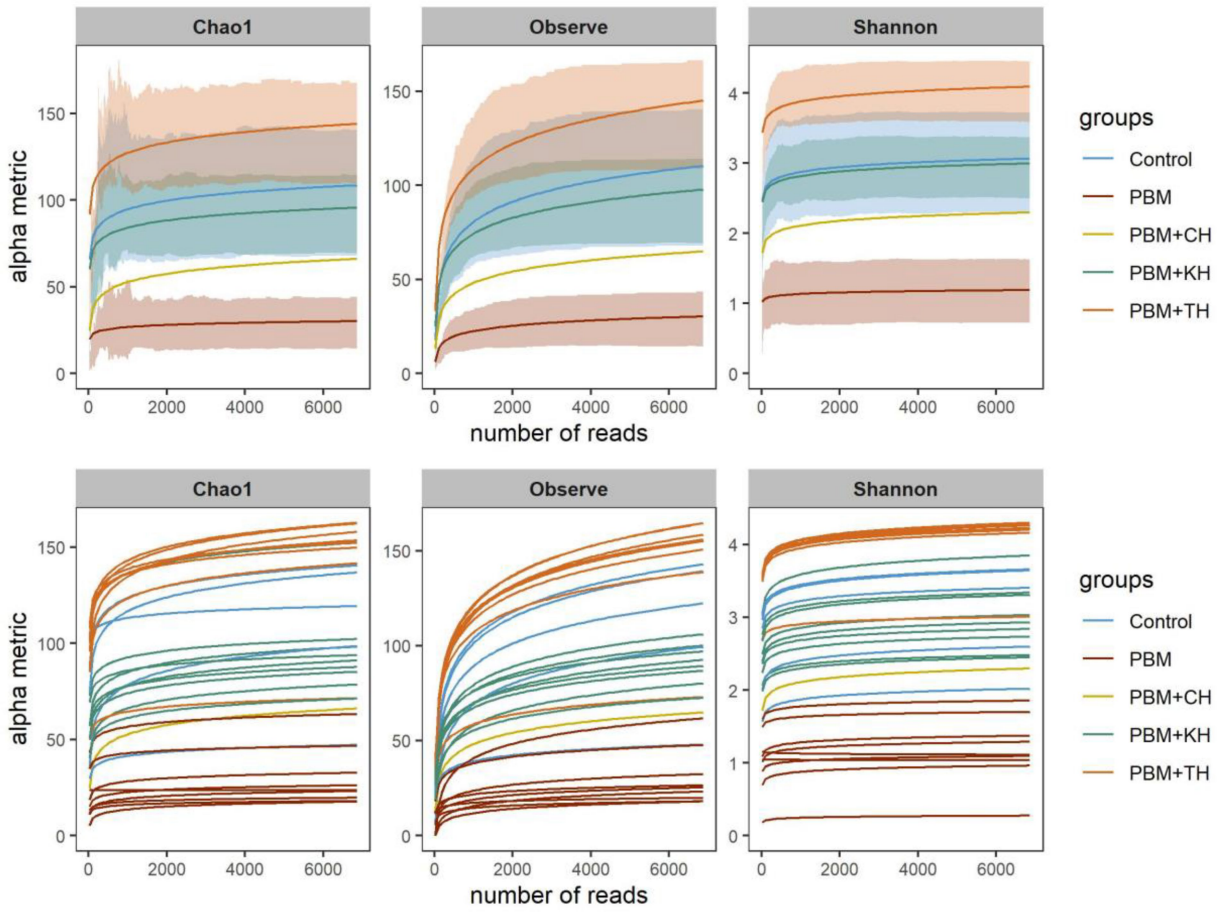


FIGURE 2
Rarefaction curve showing the depth and saturation level of sequences for a specific group (top) and individual (bottom) sample. Rarefied data was used to generate the rarefaction curve where X-axis represents the number of reads (rarefied) and Y-axis is the values for specific alpha-diversity metrics.

decreased significantly in barramundi-fed PBM-based diets, but supplementation of various FPHs improved fiber area and density when compared with the PBM-fed group (Figures 7B,C; $p < 0.001$). PBM-fed barramundi showed a lower number of <20 µm muscle fibers (hyperplasia; $p < 0.05$) which improved in barramundi when fish were fed PBM supplemented with FPHs (Figure 7D; $p < 0.01$). However, when compared with the control diet, 20–50 µm muscle fibers were enhanced in barramundi-fed PBM ($p < 0.001$). 20–50 µm muscle fibers decreased in barramundi fed FPHs supplemented PBM diet when compared to those fed the PBM-based diet ($p < 0.001$) but were comparable to the control-fed barramundi ($p > 0.05$). Similar to hyperplasia, hypertrophy (>50 µm) was significantly impacted by PBM ($p < 0.01$); however, the negative effect of PBM was attenuated when barramundi was fed FPHs-supplemented PBM diets ($p < 0.001$). There was no difference in the hypertrophy measurements of barramundi-fed control and FPHs-supplemented diets ($p > 0.05$). Though the expression of *igf-1 I* ($p < 0.05$), *myf5* ($p < 0.01$), and *myog* ($p < 0.001$) were negatively impacted by the PBM based diet, supplementation of various FPHs prevented the PBM-induced negative effects on the expression levels of these genes ($p < 0.05$, 0.01, and 0.001). The expression of *igf-1*, *myf5* and *myog* did not differ between the control and the FPHs-supplemented PBM fed barramundi ($p > 0.05$).

Serum metabolites

The effect of PBM and PBM-FPHs diets on a panel of serum metabolites is presented in Figure 8. Creatine kinase (CK; Figure 8A) elevated significantly in fish fed the PBM diet when compared to the control ($p < 0.05$), but there was no variation between control and PBM-FPHs fed barramundi ($p > 0.05$). However, compared to those fed only PBM, FPHs supplementation with PBM attenuated CK levels in barramundi ($p < 0.05$). PBM negatively impacted the levels of calcium and phosphorous ($p < 0.05$) in barramundi serum which was restored when PBM was supplemented with FPHs ($p < 0.05$ and 0.01). Barramundi-fed PBM-FPHs showed no variation in the levels of calcium and magnesium when compared with the control ($p > 0.05$). Haptoglobin levels demonstrated a similar trend ($p < 0.05$ and 0.01). Meanwhile, the different experimental diets did not affect on phosphate, iron, GGT, albumin, and AG ratio ($p > 0.05$).

Discussion

Supplementing immunostimulants, such as FPHs, in the aquafeed formulation is being used to ameliorate the impact of sub-optimal

10.3389/fnut.2023.1145068

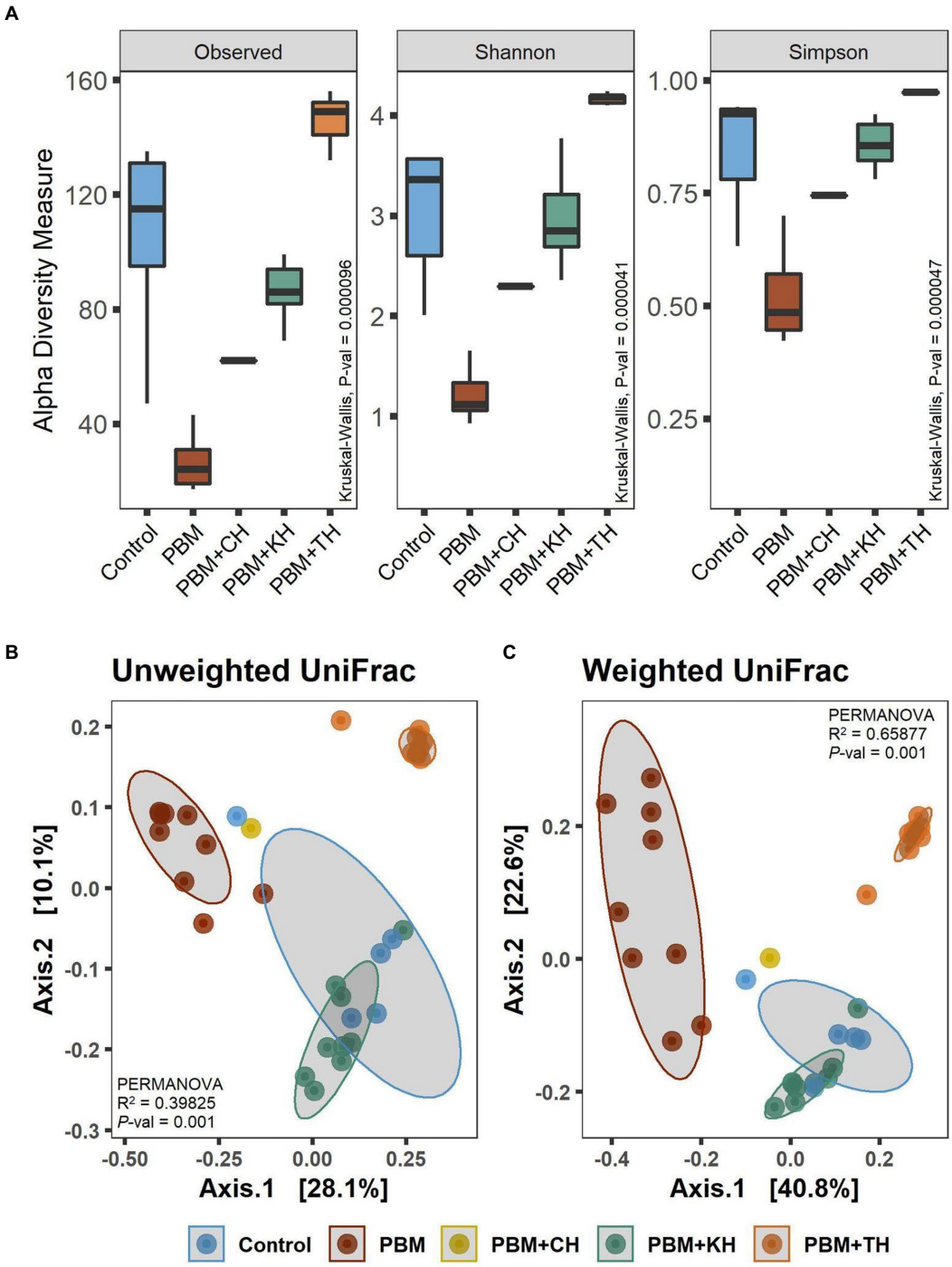


FIGURE 3
Diversity of gut bacteria in barramundi fed FM-based control, PBM alone or supplemented with various FPHs supplemented diet over a period of 42 days. **(A)** Alpha diversity measurements in terms of Observed, Shannon, and Simpson. **(B)** Beta-ordination presenting clustering of samples based on unweighted (presence-absence) and weighted (relative abundance) UniFrac distance metric. Kruskal-Wallis with Wilcoxon-rank test for multiple comparisons were used to compare alpha-diversity within groups. Different superscript letters in the boxplot indicate significantly different mean values at value of $p<0.05$.

alternative protein sources, including the prevention of intestinal dysbiosis (1, 7). Replacing FM protein with PBM damaged the general architecture of the barramundi intestine, as proven by the reported atrophy of mucosal fold and reduction of microvilli height and width (11). However, the effects of PBM alone or in combination with FPHs on a wide range of intestinal mucosal barriers in relation to intestinal microbiota and cytokine expression have not been previously reported and thoroughly investigated.

One of the main consequences of replacing high levels of FM with alternative protein sources is gut enteritis resulting from the widening of the lamina propria area (LPA) and shortening of the mucosal folds, subsequently to be associated with intestinal inflammation (37, 38).

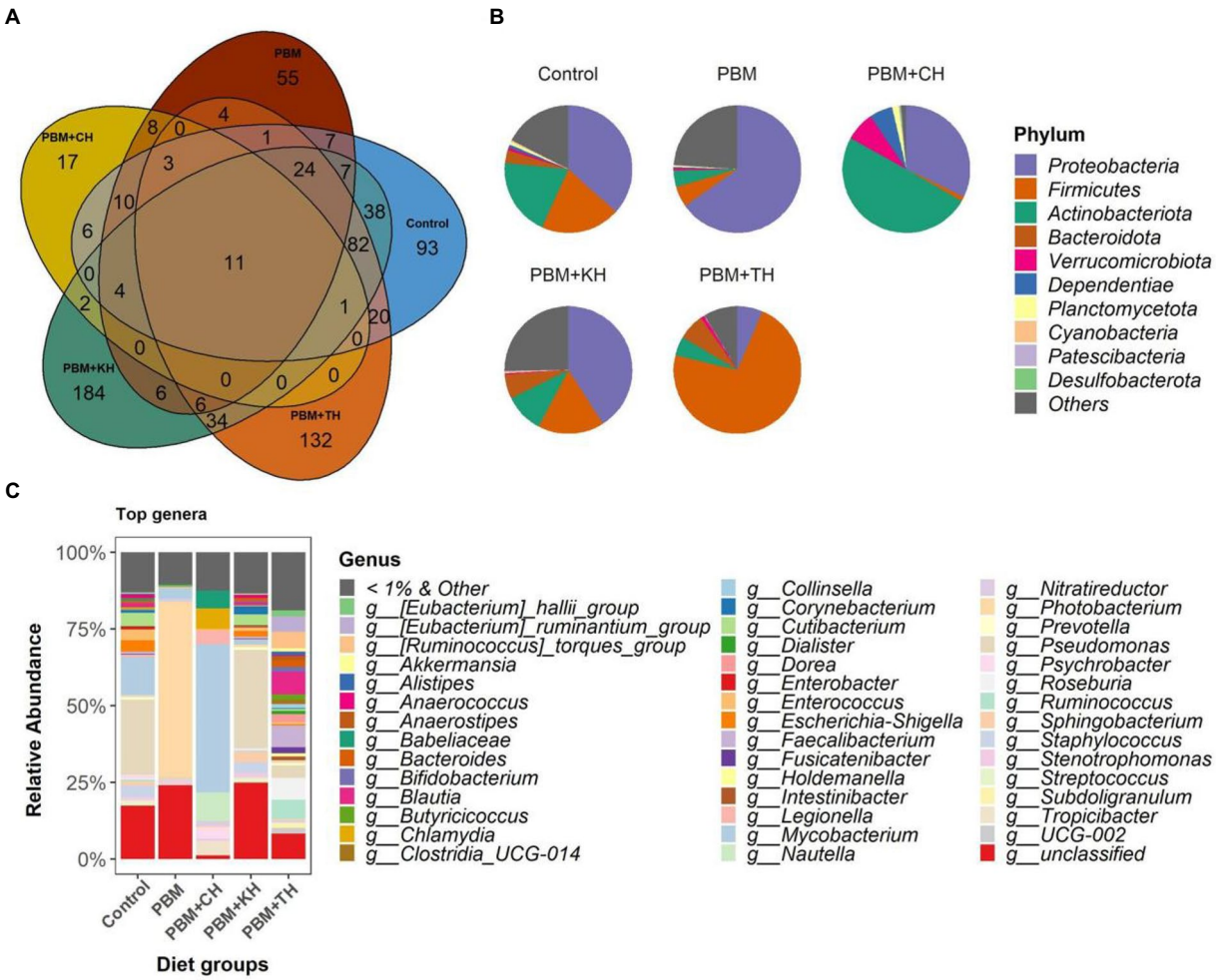


FIGURE 4
Gut bacterial composition in the intestine of barramundi fed FM-based control, PBM alone or supplemented with various FPHs supplemented diet over a period of 42 days. **(A)** The number of shared, unique and core genera in five different feeding groups. **(B)** Pie-chart representing the relative abundance of bacteria at phylum-level. **(C)** Relative abundance of top 1% genera in five different feeding groups.

Such consequences have previously been reported in the gut of barramundi and other carnivorous fish species fed alternative proteins such as PBM and soybean meal (11, 39). In the present study, such an elevation in LPA, and consequently enteritis, in the intestine was found in barramundi-fed a PBM-based diet. The damaging effect of PBM-only diets on intestinal structure were further validated by the lower expression of anti-inflammatory cytokines and the presence of low diversity of microbiota. These negative effects were countered when PBM was supplemented with various FPHs. A similar LPA and LPA ratio in the barramundi fed FPHs supplemented PBM diets to the positive control diets was observed, suggesting that FPHs supplementation could prevent or decline the occurrence of intestinal enteritis. Apart from minimizing intestinal enteritis, FPHs supplementation with PBM increased the villus length and width associated with the absorptive surface area. This may explain the comparable growth performance of barramundi-fed FPHs supplemented diets when compared to those fed a control FM-based diet in an earlier study (1). Similarly, dietary inclusion of tilapia and shrimp hydrolysates separately or concurrently prevented intestinal dysbiosis induced by a low FM-diet and intestinal mucosal health was even better than fish fed a high FM-based diet (40).

The mechanism for enhanced performance when FPHs are included is likely due to various reasons and is therefore difficult to explain. FPHs contain peptides with a shortened length and free amino acids that have been reported to enhance palatability and nutrient absorption by stimulating protein synthesis *via* the activation of the TOR pathway and inhibition of the AAR pathway. These pathways regulation were previously reported to facilitate gastrointestinal development by improving microbiota and regulating inflammatory cytokines expression in largemouth bass, *Micropterus salmoides* (41).

A good number of studies have found a potential anti-inflammatory effect of FPH in both *in vivo* and *in vitro* conditions, coupled with the reduction of the expression levels of pro-inflammatory cytokines, such as *tnf-α*, *il-6*, *il-1β*, and *il-8* (42–44). Intestinal inflammation has been reported to be associated with the higher expression of pro-inflammatory, with a concurrent lower expression of anti-inflammatory cytokines in fish (45). For example, replacing FM with 50 and 75% of soybean meal stimulated gut inflammation by elevating the expression of pro-inflammatory cytokines (*tnf-α*, *il-1β*, *il-2*, and *il-8*) and lowering the expression of anti-inflammatory gene *il-4* (46). A similar result was found in the present study, where the PBM-based diet enhanced the expression of

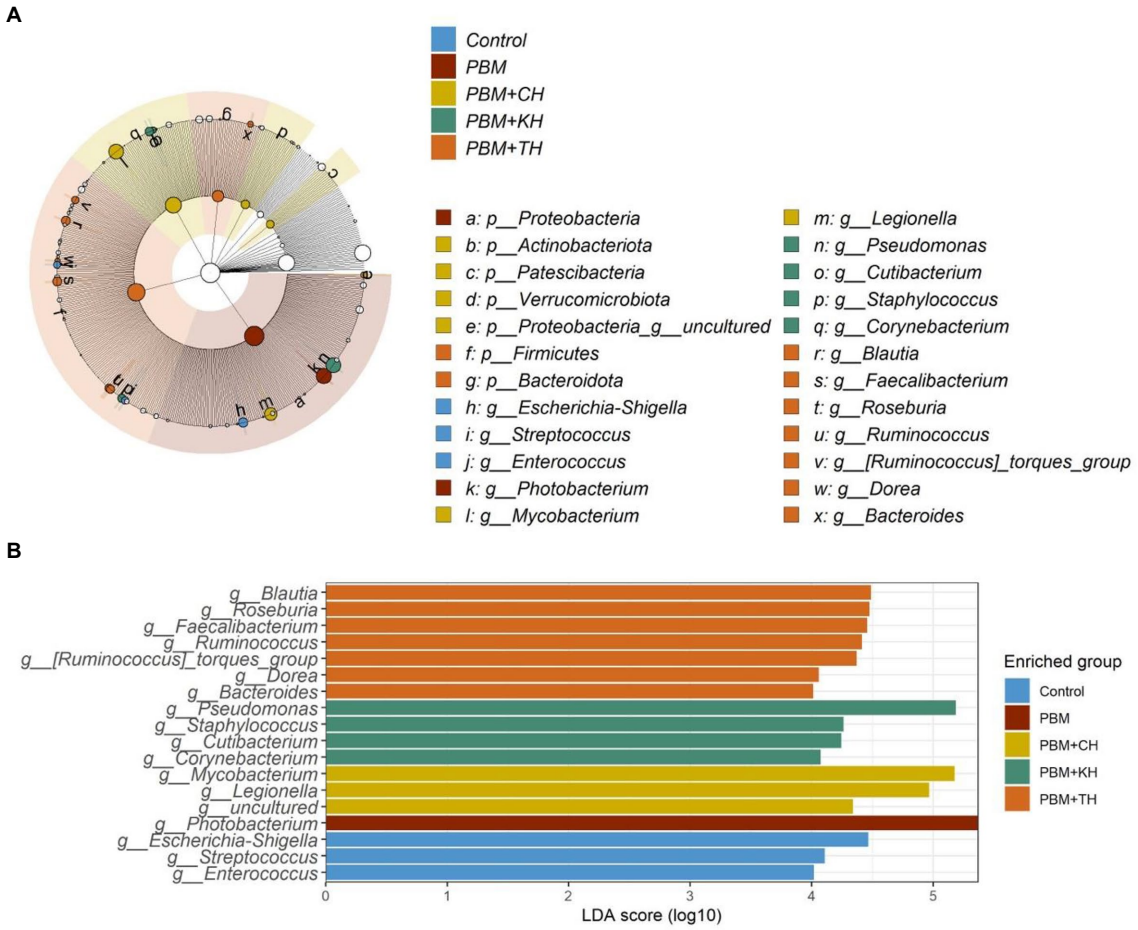


FIGURE 5
Differential abundance of bacterial communities in barramundi fed FM-based control, PBM alone or supplemented with various FPHs supplemented diet over a period of 42 days. LDA value of ≥4.0 and *p value*>0.05 were considered for differential abundance analysis.

tnf-α and reduced the expression of *il-10*, aligning with the results of the LPA and LPA ratio, thereby aggravating intestinal inflammation. A contrasting and balanced inflammatory response was found in the intestine of barramundi when the PBM was supplemented with various FPHs. This was supported by a higher expression of both *tnf-α* and *il-10* in PBM-FPH fed groups when compared to those fed PBM-based diet, and the results were comparable to fish fed the FM control diet. Dietary supplementation of FPHs provided a similar beneficial effect on inflammatory responses in the intestine of larval largemouth bass, manifested by the downregulation of pro-inflammatory cytokines (*5-lox* and *il-8*) and upregulation of anti-inflammatory cytokines (*il-10*) (22). These authors reported that the presence of high amounts of free histidine and glycine in FPHs supressed the inflammatory response in largemouth bass. Also, the inhibitory effects of anti-inflammatory cytokines on the expression of pro-inflammatory cytokines have been reported to be suppressed in the inflammatory response in some teleost fish (22).

Poultry by-product meal supplemented with black soldier fly larvae meal, and FPHs were reported to influence the mucins production, in particular, acidic and neutral mucin, in the gut of barramundi (1, 8). The association between mucin and mucin-relevant production genes, such as *i-mucin c*, and microbial genera composition has been reported for the first in the present study. Similar to neutral mucin production in the intestine of barramundi, the expression of *i-mucin c* was aggravated by the PBM-based diet but restored in the intestine of barramundi-fed PBM-FPH diets, suggesting that supplementation of FPHs could prevent PBM-induced gut mucosal dysfunction thereby maintaining gut homeostasis.

Gut microbial diversity has also been reported to be associated with gut homeostasis (47). Alternative protein ingredients in aquafeed are reported to often reduce bacterial diversity and thus compromise the health of farmed fishes (25). Although the evaluation of gut microbial composition in response to alternative finfish aquafeed protein sources has been gaining importance in the evaluation of gut health of farmed fish, understanding the interaction between gut microbial composition and mucosal epithelial barriers and associated genes has largely been overlooked. In this study, gut microbial diversity were negatively impacted by the PBM-based diet along with an enrichment of the *Photobacterium* genus. The prevalence of this genus was recently reported to increase in the gut system of barramundi when exposed to a variety of environmental stresses (48). In the present study, the observed bacterial dysbiosis in the intestine of barramundi fed PBM protein only was aligned with the results of the negatively altered mucosal barriers and expression of inflammatory cytokines and *i-mucin c*. Thus, the PBM-only based diet compromised gut homeostasis. It has previously been reported that rich bacterial diversity has been associated

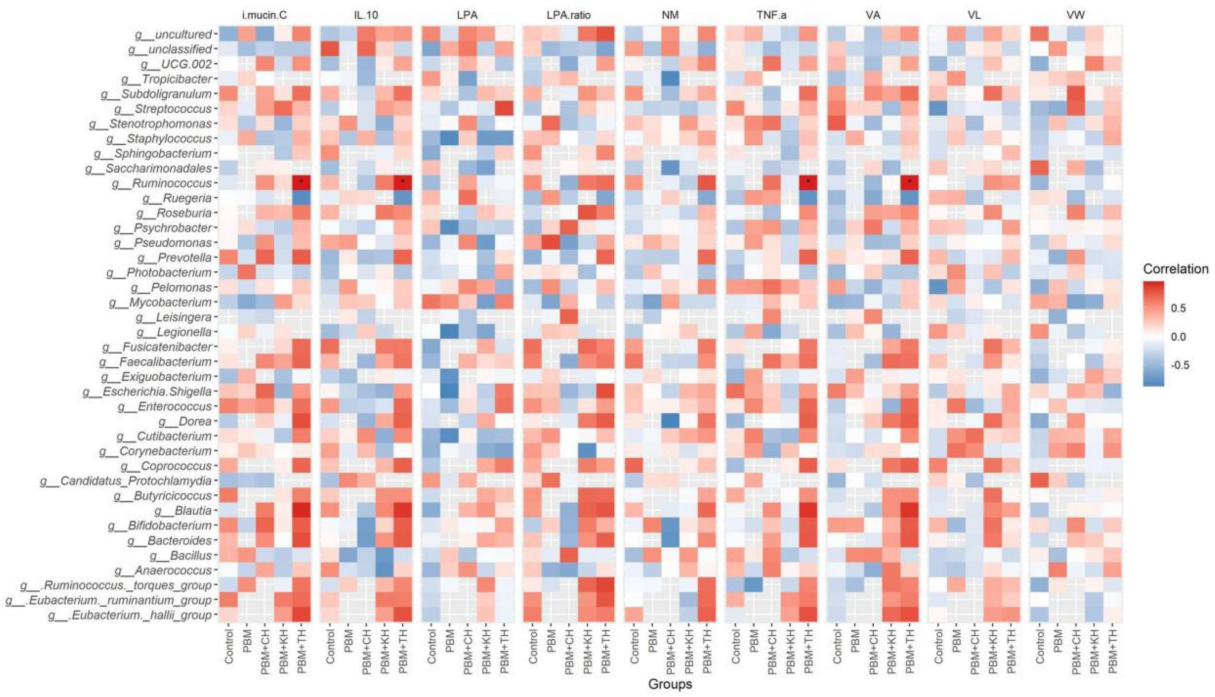


FIGURE 6
Pearson correlation plot of taxa-fish health indices. The top 40 bacterial genera were considered for correlation analysis with end-trial metadata for fish health and immunity. Red represents a positive correlation, whereas blue indicates a negative correlation. *Significant correlation at α-level of 0.05.

with a number of beneficial roles in fish health: stimulation of innate immunity, out-competition of pathogens for nutrients and colonization and production of antimicrobial compounds (e.g., bacteriocins, peptides and proteins). These functions deprive pathogenic bacteria in the gut surface for the establishment, resulting in resistance to pathogen invasion and intestinal infection (8, 49–51).

Fish protein hydrolysates supplementation with PBM restored diverse beneficial microbial composition, as proven by a significantly higher microbial diversity in barramundi-fed PBM-FPHs diets when compared to those fed PBM-based diet. The reasons for this improvement may be multiple. For example, peptides from the hydrolysis process contain a rich source of essential amino acids (not analyzed in the current study), which have been reported to act as natural sources of nitrogen essential for microbiota growth (27). Enzymatic hydrolysis in the present study also produced more than 90% of smaller peptides, which may also be related to the beneficial effect of FPHs on gut microbiota. Notably, a high gut microbial diversity with increased prevalence of *Ruminococcus*, *Faecalibacterium*, and *Bacteroides* in barramundi fed the PBM-TH diet suggested further beneficial effects of TH supplementation specifically. A substantial enrichment in the composition of *Ruminococcus* in mice fed *Spirulina platensis* protease hydrolysate for 8 weeks has also been reported (52). Our previous studies found an enrichment of *Ruminococcus* in the gut of barramundi-fed PBM diets supplemented with black soldier fly larvae meal alone or in combination with TH (3, 8). *Ruminococcus* produces short-chain fatty acids which play an important role in the degradation of indigestible carbohydrates, such as resistant starch (53) and dietary fibers, and have been reported to mitigate metabolic disorders caused by high-lipid diets (54–56). Also, *Ruminococcus* species were used as a probiotic (Zado®) and reportedly boosted the overall health of Nile tilapia, *Oreochromis niloticus* (57). This probiotic effect may explain the strong correlation between the *Ruminococcus* prevalence and mucosal barrier functions and inflammatory cytokines in the present study. Similarly, *Faecalibacterium* is the most important commensal butyrate-producing bacterium, which was abundantly found in healthy shrimp (58) and is considered a bio-indicator of human health (59). *Bacteroides strain* has been documented as a healthy bacteria in grass carp, *Ctenopharyngodon idella* and also has been reported to alleviate lipopolysaccharide-induced inflammation in mice (60). Thus, these genera may contribute to the more efficient energy utilization of feed, and improved intestinal health of the host by producing butyrate as an end product of dietary fiber fermentation and by promoting mucosal barrier functions. The beneficial effect of dietary FPHs on proliferating the abundance of beneficial bacteria (*Plesiomonas*) and reducing the prevalence of harmful bacteria (*Staphylococcus*) was previously observed in the intestine of larval largemouth bass, *Micropterus salmoides* (22). This was concomitant with the observant mucosal barrier results (VA, VL, VW, and NM).

The gut inflammatory response could be associated with the gut microbiota, promoting the health of farmed fish. For instance, the expression of *il-10* in the anterior intestine was positively associated with the abundance *Serratia nematodiphila*, while *tnf-α* expression was positively associated with the abundance of *Paracoccus yeei in* Gilthead Sea Bream, *Sparus aurata* juveniles fed processed and non-processed animal protein (61). A similar positive association between *Ruminococcus* and *tnf-α* and *il-10* was found in barramundi-fed PBM-TH in the present study. Also, in our study, a

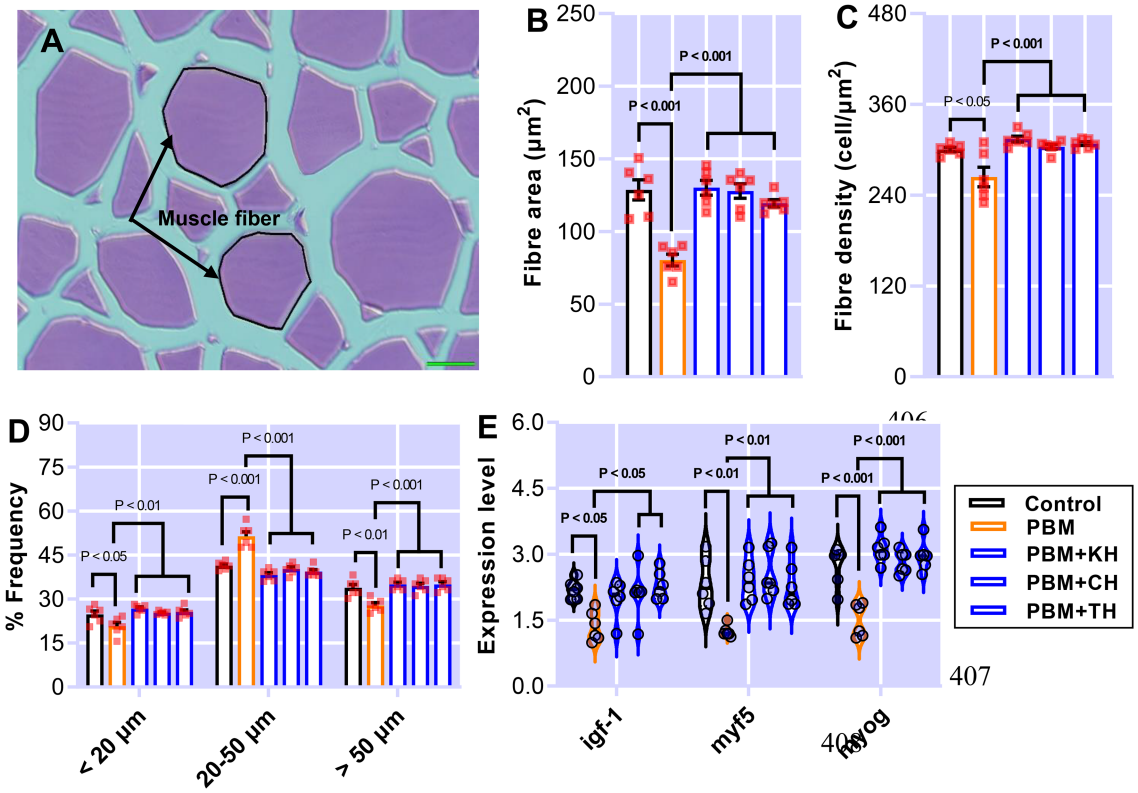


FIGURE 7
The representative histological micrograph of muscle showing the measurements of muscle fiber **(A)**; the comparison of quantitative measurements of muscle fiber **(B,C)** and the frequency percentage of hyperplasia and hypertrophy **(D)**; and fold change in the expression of muscle growth relevant genes **(E)** of barramundi fed FM-based control, PBM alone or supplemented with various FPHs supplemented diet over a period of 42 days.

positive association of *Ruminococcus* with the expression of i-mucin c in the gut of barramundi-fed PBM-TH was observed, suggesting that the abundance of the beneficial *Ruminococcus*, further increased by TH supplementation, played a role in maintaining the gut homeostasis by balancing inflammatory responses and enhancing mucus production. A higher proportion of small peptides in TH than the other FPH's might have provided more beneficial effects on the barramundi gut.

Fish growth is directly linked to muscle growth which results from the hyperplasia and hypertrophy of muscle fibers (33, 62). Quantification of histological muscle fiber morphology is one of the important determinants to understand fish muscle growth in aquafeed nutrition research. This quantification provides information on the recruitment of new muscle fibers (hyperplasia, < 20 μm) and hypertrophy (> 50 μm) of existing muscle which has been reported to be influenced by dietary modifications (33). The effect of FM-free diets on muscle fiber morphology aligned with the expression of muscle growth-regulating genes has been evaluated for the first time in this study. The present study found a decline in the size and number of muscle fibers and frequency of hyperplasia and hypertrophy in barramundi fed the PBM-based diet, suggesting that complete replacement of FM with PBM negatively impacted muscle growth. This negative impact can be alleviated in barramundi when various FPHs were supplemented with PBM, which was validated by a significant increase in the muscle fiber frequency in barramundi-fed FPH supplemented PBM, which was comparable to the control. Similarly, the incorporation of 12% of FPH improved muscle growth by regulating muscle microstructure and ultrastructure and muscle growth-related gene expression in turbot (63).

Insulin-like growth factor (*igf*) genes are growth hormones encoding the highly conserved growth regulatory peptide *igf-1*. *igf-1* is used as a biomarker in aquaculture research and is correlated with classical parameters such as growth to understand better the nutritional status of experimental fish (64). The quality of dietary protein has been reported to affect *igf-1* expression by functioning as a mediator in muscle to promote growth and inhibit protein degradation, thereby affecting the growth of fish (65). The lower expression of *igf-1* in barramundi-fed PBM in the present study, aligning with poor growth performance in our previous study (11), suggested that a PBM-based diet was not palatable, resulting in starvation which might have loosened the sensitivity of muscle tissues to produce *igf*. This was further validated by lower feed intake in barramundi fed the PBM-based diet (11). Similar to *igf*, fish growth is also regulated by myogenic regulatory factors such as (MRF) and myostatin (MSTN), directly stimulating muscle proliferation, differentiation and hypertrophy (66). myf5 and *myog* are specific MRF that regulate myogenesis by contributing to muscle cell proliferation and initiation and maintenance of the differentiation programs (67). As reported here the PBM-based diet down-regulated the expression levels of *myf5* and *myog*, suggesting that PBM could negatively impact the hyperplasia and hypertrophy of barramundi muscle by regulating the expression of *igf* and MRF.

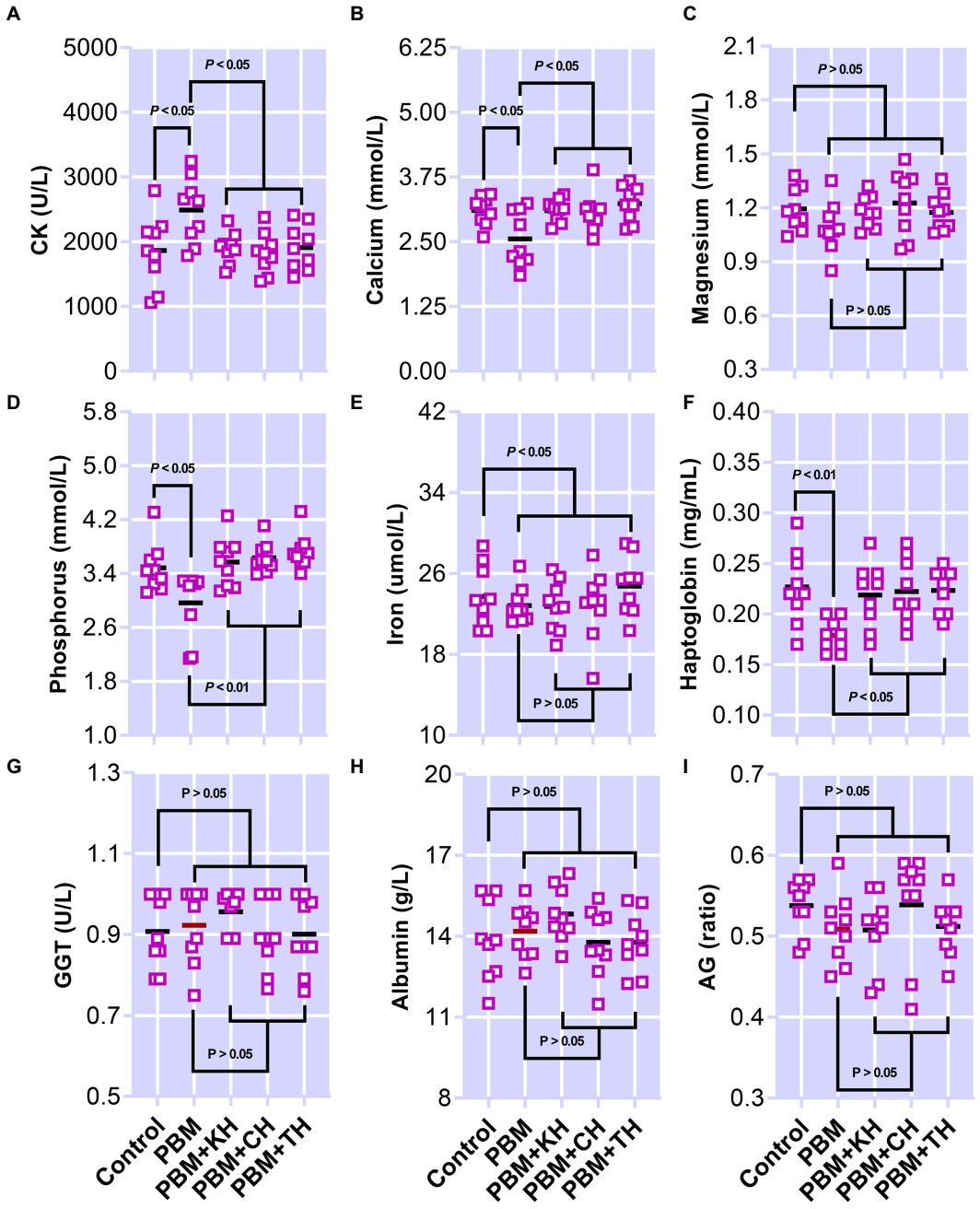


FIGURE 8
Serum Creatine kinase (CK; **A**), calcium **(B)**, Magnesium (Mg; **C**), inorganic phosphate **(D)**, iron **(E)**, haptoglobin **(F)**, gamma-glutamyltransferase (GGT; **G**), albumin **(H)**, and AG **(I)** of barramundi fed FM-based control, PBM alone, or supplemented with various FPHs supplemented diet over a period of 42 days.

Supplementation of 10% of various FPHs alleviated the negative effect of the PBM-only diet on the muscle growth of barramundi. This was supported by significantly higher expression of *igf* and MRF in the muscle of barramundi-fed PBM diets supplemented with FPHs when compared to those fed the PBM-based diet. The expression levels of *igf* and MRF in barramundi fed FPHs supplemented diets were similar to those fed the FM-based control diet. Such attenuation of PBM-induced negative impact on muscle health by FPHs supplementation could be due to the presence of functional molecules or aligned with the amino acids content in FPHs. Such functional molecules in FPHs have been related to increasing plasma *igf-i* levels and liver *igf-i* mRNA expression of fish (68). Two recent studies found that supplementing marine protein hydrolysates and hydrolysed fish protein powder elevated the expression levels of *igf-1* aligned with an increased upregulation of TOR pathway-related genes (41, 69). Hence FPHs could be used to prevent the negative effects of FM omission and alternative protein source replacement in barramundi diets.

Investigation of blood biochemistry parameters has been a powerful analytical tool commonly used in aquaculture studies to monitor the health status of experimental aquacultured animals. Muscle health has been reported to be associated with the levels of CK in barramundi blood, which have been reported to be elevated in

barramundi when fed alternative proteins such as soybean meal and lupin meal (31, 32). In this study, a PBM-based diet increased the CK level, aligning with aggravated muscle growth-relevant gene expression. Also, our previous study found histopathological changes manifested by myotome necrosis in the muscle of barramundi fed a PBM-based diet (11). However, CK activity appeared normal when the PBM diet was supplemented with FPHs, suggesting the alleviation of PBM-induced negative effects on barramundi muscle health. Some minerals are good indicators of the secondary phase of stress response in fish, as levels can be decreased by stress such as starvation and malnutrition (70–72), and this can indicate pathological situations (73) in fish blood. A significant drop in the levels of calcium and total phosphorus in the serum of barramundi fed the PBM diet when compared to the control diet suggested that barramundi fed PBM might have suffered from malnutrition or starvation. This was supported by a lower food intake and various pathological indicators (e.g., hepatic steatosis, gill hyperplasia and muscle necrosis) as previously reported (11). An elevation of these minerals in the PBM-FPH-fed barramundi to levels comparable to the control, when compared to the PBM-only treatment, indicated the alleviating capacity of FPHs to prevent the PBM-induced negative effects on mineral levels and content in barramundi serum. Magnesium levels were not altered by the test diets, suggesting that barramundi might have uptaken magnesium from the water, as previously reported in many marine species (70, 74).

Haptoglobin (Hp), a protein that binds with free hemoglobin, has been reported to be associated with lipids and protein oxidation thereby causing damage in surrounding tissue (75). The formation of a complex between haptoglobin and hemoglobin inhibits free hemoglobin-mediated tissue damage (76). For instance, renal failure was found in mice lacking haptoglobin (77). In the present study, barramundi fed the PBM diet, which lacks haptoglobin, when compared to fish fed the FM control diet, might have suggested that PBM inclusion stimulated oxidative damage in barramundi. This notion was supported by a negative effect of the PBM diet on GPx and MDA activity (11). However, FPHs supplementation with PBM restored the levels of Hp, underpinning the antioxidant activity of FPHs, thereby repairing the tissue damage. The remaining serum metabolites which were analyzed remained unchanged and within the normal range of barramundi health status.

In summary, the PBM-only based diet aggravated intestinal homeostasis by impacting intestinal mucosal barrier function, inflammatory response, and microbial composition. Supplementation of 10% of various FPHs, including KH, CH, and TH, obtained from enzymatic hydrolysis of fish waste, could prevent PBM-induced gut enteritis, manifested by quantifying LP and LPA ratio and inflammation in the intestine of barramundi. Also, various FPHs supplementation with PBM restored gut microbial composition and balanced the inflammatory response. In particular, TH supplementation improved further the intestinal mucosal barrier functions (VA, VL, VW, and NM), supported by a significant improvement in microbial diversity with significant enrichment in the *Firmicutes*, *Ruminococcus*, *Faecalibacterium*, and *Bacteroides* genera. The abundance of *Ruminococcus* may have positively influenced the inflammatory cytokines, mucin production relevant genes and VA in the barramundi intestine. Muscle atrophy was triggered by the PBM-based diet, but this effect was improved with FPHs supplementation, as demonstrated by a significant increase in muscle fiber quantification (fiber density, hyperplasia, and hypertrophy) and muscle health relevant gene expression (IGF-1, myf5, and MyoG). Hence, FPHs could be used as supplementary functional ingredients with low-quality alternative protein sources to prevent PBM-induced negative effects on intestinal homeostasis and muscle health, as well as providing a good option in increasing circularity and resource utilization in the aquaculture industry. However, further commercially relevant long-term studies are needed to confirm the beneficial supplementation effect of FPH with PBM in the barramundi diet along with final product quality to ensure product quality produced on raw material sourced from the circular economy is the same.

Data availability statement

The microbiome datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://www.ncbi.nlm.nih.gov/, PRJNA909982.

Ethics statement

The animal study was reviewed and approved by Curtin University Animal Ethics Committee.

Author contributions

MC: conceptualization, methodology, formal analysis, investigation, data curation, writing—original draft, and visualization. JH: supervision, writing—review and editing, and project administration. MF, MH, and HA-L: formal analysis and writing—review and editing. RF: supervision, conceptualization, and writing—review and editing. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by a Research Training Program (RTP) stipend scholarship, funded by the Australian Government, to MC (No. 19061054-Curtin).

Acknowledgments

The authors would like to thank Australian Center for Applied Aquaculture Research (ACAAR), Fremantle, Australia for providing fish, Rowan Kleindienst for technical support. Special thanks to Future Green Solutions and Fisheries Research and Development Corporation (FRDC) for support in FPH methods and production.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Chaklader MR, Fotedar R, Howieson J, Siddik MA, Foysal J. The ameliorative effects of various fish protein hydrolysates in poultry by-product meal based diets on muscle quality, serum biochemistry and immunity in juvenile barramundi. *Lates Calc Fish Shellfish Immunol*. (2020) 104:567–78. doi: 10.1016/j.fsi.2020.06.014

2. O'Connor J, Hoang SA, Bradney L, Dutta S, Xiong X, Tsang DC, et al. A review on the valorisation of food waste as a nutrient source and soil amendment. *Environ Pollut*. (2020) 272:115985. doi: 10.1016/j.envpol.2020.115985

3. Chaklader MR, Howieson J, Foysal MJ, Fotedar R. Transformation of fish waste protein to Hermetia illucens protein improves the efficacy of poultry by-products in the culture of juvenile barramundi. *Lates Calc Sci Total Environ*. (2021) 796:149045. doi: 10.1016/j.scitotenv.2021.149045

4. Peter D, Clive H. An overview of the Australian seafood industry. Available at: http://aaa.ccpit.org/Category7/mAttachment/2006/Dec/13/asset000070002007202file1.pdf (2006).

5. He S, Franco C, Zhang W. Functions, applications and production of protein hydrolysates from fish processing co-products (FPCP). *Food Res Int*. (2013) 50:289–97. doi: 10.1016/j.foodres.2012.10.031

6. Martínez-Alvarez O, Chamorro S, Brenes A. Protein hydrolysates from animal processing by-products as a source of bioactive molecules with interest in animal feeding: a review. *Food Res Int*. (2015) 73:204–12. doi: 10.1016/j.foodres.2015.04.005

7. Egerton S, Wan A, Murphy K, Collins F, Ahern G, Sugrue I, et al. Replacing fishmeal with plant protein in Atlantic salmon (Salmo salar) diets by supplementation with fish protein hydrolysate. *Sci Rep*. (2020) 10:4194–16. doi: 10.1038/s41598-020-60325-7

8. Chaklader MR, Howieson J, Siddik MAB, Foysal MJ, Fotedar R. Supplementation of tuna hydrolysate and insect larvae improves fishmeal replacement efficacy of poultry by-product in Lates calcarifer (Bloch, 1790) juveniles. *Sci Rep*. (2021) 11:4997. doi: 10.1038/s41598-021-84660-5

9. Galkanda-Arachchige HS, Wilson AE, Davis DA. Success of fishmeal replacement through poultry by-product meal in aquaculture feed formulations: a meta-analysis. *Rev Aquac*. (2020) 12:1624–36. doi: 10.1111/raq.12401

10. Simon CJ, Salini MJ, Irvin S, Blyth D, Bourne N, Smullen R. The effect of poultry protein concentrate and phosphorus supplementation on growth, digestibility and nutrient retention efficiency in barramundi Lates calcarifer. *Aquaculture*. (2019) 498:305–14. doi: 10.1016/j.aquaculture.2018.08.069

11. Chaklader MR, Siddik MA, Fotedar R. Total replacement of fishmeal with poultry by-product meal affected the growth, muscle quality, histological structure, antioxidant capacity and immune response of juvenile barramundi, Lates calcarifer. *PLoS One*. (2020) 15:e0242079. doi: 10.1371/journal.pone.0242079

12. Chen L, Feng L, Jiang W-D, Jiang J, Wu P, Zhao J, et al. Intestinal immune function, antioxidant status and tight junction proteins mRNA expression in young grass carp (Ctenopharyngodon idella) fed riboflavin deficient diet. *Fish Shellfish Immunol*. (2015) 47:470–84. doi: 10.1016/j.fsi.2015.09.037

13. Gomez D, Sunyer JO, Salinas I. The mucosal immune system of fish: the evolution of tolerating commensals while fighting pathogens. *Fish Shellfish Immunol*. (2013) 35:1729–39. doi: 10.1016/j.fsi.2013.09.032

14. Marjoram L, Alvers A, Deerhake ME, Bagwell J, Mankiewicz J, Cocchiaro JL, et al. Epigenetic control of intestinal barrier function and inflammation in zebrafish. *Proc Natl Acad Sci*. (2015) 112:2770–5. doi: 10.1073/pnas.1424089112

15. Rombout JH, Abelli L, Picchietti S, Scapigliati G, Kiron V. Teleost intestinal immunology. *Fish Shellfish Immunol*. (2011) 31:616–26. doi: 10.1016/j.fsi.2010.09.001

16. Zhang H, Ran C, Teame T, Ding Q, Hoseinifar SH, Xie M, et al. Research progress on gut health of farmers teleost fish: a viewpoint concerning the intestinal mucosal barrier and the impact of its damage. *Rev Fish Biol Fish*. (2020) 30:569–86. doi: 10.1007/s11160-020-09614-y

17. Mosberian-Tanha P, Øverland M, Landsverk T, Reveco FE, Schrama JW, Roem AJ, et al. Bacterial translocation and in vivo assessment of intestinal barrier permeability in rainbow trout (Oncorhynchus mykiss) with and without soyabean meal-induced inflammation. *J Nutr Sci*. (2016) 5:e26. doi: 10.1017/jns.2016.7

18. Gu M, Jia Q, Zhang Z, Bai N, Xu X, Xu B. Soya-saponins induce intestinal inflammation and barrier dysfunction in juvenile turbot (Scophthalmus maximus). *Fish Shellfish Immunol*. (2018) 77:264–72. doi: 10.1016/j.fsi.2018.04.004

19. Wang K-Z, Feng L, Jiang W-D, Wu P, Liu Y, Jiang J, et al. Dietary gossypol reduced intestinal immunity and aggravated inflammation in on-growing grass carp (Ctenopharyngodon idella). *Fish Shellfish Immunol*. (2019) 86:814–31. doi: 10.1016/j.fsi.2018.12.014

20. Feng L, Ni P-J, Jiang W-D, Wu P, Liu Y, Jiang J, et al. Decreased enteritis resistance ability by dietary low or excess levels of lipids through impairing the intestinal physical and immune barriers function of young grass carp (Ctenopharyngodon idella). *Fish Shellfish Immunol*. (2017) 67:493–512. doi: 10.1016/j.fsi.2017.06.041

21. Arias-Jayo N, Abecia L, Alonso-Sáez L, Ramirez-Garcia A, Rodriguez A, Pardo MA. High-fat diet consumption induces microbiota dysbiosis and intestinal inflammation in zebrafish. *Microb Ecol*. (2018) 76:1089–101. doi: 10.1007/s00248-018-1198-9

22. Sheng Z, Turchini GM, Xu J, Fang Z, Chen N, Xie R, et al. Functional properties of protein hydrolysates on growth, digestive enzyme activities, protein metabolism, and intestinal health of larval largemouth bass (Micropterus salmoides). *Front Immunol*. (2022) 13:3517. doi: 10.3389/fimmu.2022.913024, MID: 35928824

23. Perry WB, Lindsay E, Payne CJ, Brodie C, Kazlauskaite R. The role of the gut microbiome in sustainable teleost aquaculture. *Proc R Soc B*. (2020) 287:20200184. doi: 10.1098/rspb.2020.0184

24. Ingerslev H-C, Strube ML, von Gersdorff JL, Dalsgaard I, Boye M, Madsen L. Diet type dictates the gut microbiota and the immune response against Yersinia ruckeri in rainbow trout (Oncorhynchus mykiss). *Fish Shellfish Immunol*. (2014) 40:624–33. doi: 10.1016/j.fsi.2014.08.021

25. Infante-Villamil S, Huerlimann R, Jerry DR. Microbiome diversity and dysbiosis in aquaculture. *Rev Aquac*. (2021) 13:1077–96. doi: 10.1111/raq.12513

26. Dam CTM, Booth M, Pirozzi I, Salini M, Smullen R, Ventura T, et al. Alternative feed raw materials modulate intestinal microbiota and its relationship with digestibility in yellowtail kingfish Seriola lalandi. *Aust Fish*. (2020) 5:14. doi: 10.3390/fishes5020014

27. Zhang C, Zhang Y, Li H, Liu X. The potential of proteins, hydrolysates and peptides as growth factors for lactobacillus and Bifidobacterium: current research and future perspectives. *Food Funct*. (2020) 11:1946–57. doi: 10.1039/c9fo02961c

28. Meli F, Lazzi C, Neviani E, Gatti M. Effect of protein hydrolysates on growth kinetics and aminopeptidase activities of lactobacillus. *Curr Microbiol*. (2014) 68:82–7. doi: 10.1007/s00284-013-0445-z

29. Aloo SO, Oh D-H. The functional interplay between gut microbiota, protein Hydrolysates/bioactive peptides, and obesity: a critical review on the study advances. *Antioxidants*. (2022) 11:333. doi: 10.3390/antiox11020333

30. Gupta SK, Fotedar R, Foysal MJ, Priyam M, Siddik MA, Chaklader MR, et al. Impact of varied combinatorial mixture of non-fishmeal ingredients on growth, metabolism, immunity and gut microbiota of Lates calcarifer (Bloch, 1790) fry. *Sci Rep*. (2020) 10:17091–13. doi: 10.1038/s41598-020-72726-9

31. Ilham I, Fotedar R. Growth, enzymatic glutathione peroxidase activity and biochemical status of juvenile barramundi (Lates calcarifer) fed dietary fermented soybean meal and organic selenium. *Fish Physiol Biochem*. (2017) 43:775–90. doi: 10.1007/s10695-016-0331-2. doi:10.1007/s10695-016-0331-2

32. Ilham I, Hapsari F, Fotedar R. Growth, enzymatic glutathione peroxidase activity and biochemical status of juvenile barramundi (Lates calcarifer) fed dietary fermented lupin meal supplemented with organic selenium. *Aquac Res*. (2018) 49:151–64. doi: 10.1111/are.13444

33. Jiang Q, Zhao Y, Zhou X-Q, Wu X-Y, Xu S-X, Feng L, et al. Effects of dietary tryptophan on muscle growth, protein synthesis and antioxidant capacity in hybrid catfish Pelteobagrus vachelli♀× Leiocassis longirostris♂. *Br J Nutr*. (2022) 127:1761–73. doi: 10.1017/S0007114521002828

34. Fang C-C, Feng L, Jiang W-D, Wu P, Liu Y, Kuang S-Y, et al. Effects of dietary methionine on growth performance, muscle nutritive deposition, muscle fiber growth and type I collagen synthesis of on-growing grass carp (Ctenopharyngodon idella). *Br J Nutr*. (2021) 126:321–36. doi: 10.1017/S0007114520002998

35. McMurdie PJ, Holmes S. Phyloseq: an R package for reproducible interactive analysis and graphics of microbiome census data. *PLoS One*. (2013) 8:e61217. doi: 10.1371/journal.pone.0061217

36. Dixon P. Computer program review VEGAN, a package of R functions for community ecology. *J Veg Sci*. (2003) 14:927–30. doi: 10.1111/j.1654-1103.2003.tb02228.x

37. Król E, Douglas A, Tocher DR, Crampton VO, Speakman JR, Secombes CJ, et al. Differential responses of the gut transcriptome to plant protein diets in farmed Atlantic salmon. *BMC Genomics*. (2016) 17:156–16. doi: 10.1186/s12864-016-2473-0

38. Bai N, Gu M, Liu M, Jia Q, Pan S, Zhang Z. Corn gluten meal induces enteritis and decreases intestinal immunity and antioxidant capacity in turbot (Scophthalmus

maximus) at high supplementation levels. *PLoS One*. (2019) 14:e0213867. doi: 10.1371/journal.pone.0213867

39. Booman M, Forster I, Vederas JC, Groman DB, Jones SR. Soybean meal-induced enteritis in Atlantic salmon (Salmo salar) and Chinook salmon (Oncorhynchus tshawytscha) but not in pink salmon (O. gorbuscha). *Aquaculture*. (2018) 483:238–43. doi: 10.1016/j.aquaculture.2017.10.025

40. Leduc A, Zatylny-Gaudin C, Robert M, Corre E, Corguille GL, Castel H, et al. Dietary aquaculture by-product hydrolysates: impact on the transcriptomic response of the intestinal mucosa of European seabass (Dicentrarchus labrax) fed low fish meal diets. *BMC Genomics*. (2018) 19:396–20. doi: 10.1186/s12864-018-4780-0

41. Fan Z, Wu D, Li J, Zhang Y, Cui Z, Li T, et al. Assessment of fish protein Hydrolysates in juvenile largemouth bass (Micropterus salmoides) diets: effect on growth, intestinal antioxidant status, immunity, and microflora. *Front Nutr*. (2022) 9:816341. doi: 10.3389/fnut.2022.816341

42. Gao R, Shen Y, Shu W, Bai F, Jin W, Wang J, et al. Optimization of enzymatic conditions of sturgeon muscles and their anti-inflammatory potential. *J Food Qual*. (2020) 2020:1–12. doi: 10.1155/2020/9698134

43. Gao R, Yu Q, Shen Y, Chu Q, Chen G, Fen S, et al. Production, bioactive properties, and potential applications of fish protein hydrolysates: developments and challenges. *Trends Food Sci Technol*. (2021) 110:687–99. doi: 10.1016/j.tifs.2021.02.031

44. Subhan F, Kang HY, Lim Y, Ikram M, Baek S-Y, Jin S, et al. Fish scale collagen peptides protect against CoCl2/TNF-α-induced cytotoxicity and inflammation via inhibition of ROS, MAPK, and NF-κB pathways in HaCaT cells. *Oxidative Med Cell Longev*. (2017) 2017:1–17. doi: 10.1155/2017/9703609

45. Wang Y-R, Wang L, Zhang C-X, Song K. Effects of substituting fishmeal with soybean meal on growth performance and intestinal morphology in orange-spotted grouper (Epinephelus coioides). *Aquac Rep*. (2017) 5:52–7. doi: 10.1016/j.aqrep.2016.12.005

46. Zhang C, Rahimnejad S, Wang Y-r, Lu K, Song K, Wang L, et al. Substituting fish meal with soybean meal in diets for Japanese seabass (Lateolabrax japonicus): effects on growth, digestive enzymes activity, gut histology, and expression of gut inflammatory and transporter genes. *Aquaculture*. (2018) 483:173–82. doi: 10.1016/j.aquaculture.2017.10.029

47. Yu YY, Ding LG, Huang ZY, Xu HY, Xu Z. Commensal bacteria-immunity crosstalk shapes mucosal homeostasis in teleost fish. *Rev Aquac*. (2021) 13:2322–43. doi: 10.1111/raq.12570

48. Spilsbury F, Foysal MJ, Tay A, Gagnon M. Gut microbiome as a potential biomarker in fish: dietary exposure to petroleum hydrocarbons and metals, metabolic functions and cytokine expression in juvenile Lates calcarifer. *Front Microbiol*. (2022) 13:827371. doi: 10.3389/fmicb.2022.827371

49. Huyben D, Vidaković A, Hallgren SW, Langeland M. High-throughput sequencing of gut microbiota in rainbow trout (Oncorhynchus mykiss) fed larval and pre-pupae stages of black soldier fly (Hermetia illucens). *Aquaculture*. (2019) 500:485–91. doi: 10.1016/j.aquaculture.2018.10.034

50. Cerezuela R, Fumanal M, Tapia-Paniagua ST, Meseguer J, Moriñigo MÁ, Esteban MÁ. Changes in intestinal morphology and microbiota caused by dietary administration of inulin and Bacillus subtilis in gilthead sea bream (Sparus aurata L.) specimens. *Fish Shellfish Immunol*. (2013) 34:1063–70. doi: 10.1016/j.fsi.2013.01.015

51. Levine JM, D'Antonio CM. Elton revisited: a review of evidence linking diversity and invasibility. *Oikos*. (1999):15–26. doi: 10.2307/3546992

52. Hua P, Yu Z, Xiong Y, Liu B, Zhao L. Regulatory efficacy of Spirulina platensis protease hydrolyzate on lipid metabolism and gut microbiota in high-fat diet-fed rats. *Int J Mol Sci*. (2018) 19:4023. doi: 10.3390/ijms19124023

53. Rimoldi S, Torrecillas S, Montero D, Gini E, Makol A, Valdenegro VV, et al. Assessment of dietary supplementation with galactomannan oligosaccharides and phytogenics on gut microbiota of European sea bass (Dicentrarchus Labrax) fed low fishmeal and fish oil based diet. *PLoS One*. (2020) 15:e0231494. doi: 10.1371/journal.pone.0231494

54. Yang Y, Zhang Y, Xu Y, Luo T, Ge Y, Jiang Y, et al. Dietary methionine restriction improves the gut microbiota and reduces intestinal permeability and inflammation in high-fat-fed mice. *Food Funct*. (2019) 10:5952–68. doi: 10.1039/c9fo00766k

55. Lee P-S, Lu Y-Y, Nagabhushanam K, Ho C-T, Mei H-C, Pan M-H. Calebin-a prevents HFD-induced obesity in mice by promoting thermogenesis and modulating gut microbiota. *J Tradit Complement Med*. (2022). doi: 10.1016/j.jtcme.2022.01.001

56. Neyrinck AM, Possemiers S, Druart C, Van de Wiele T, De Backer F, Cani PD, et al. Prebiotic effects of wheat arabinoxylan related to the increase in bifidobacteria, Roseburia and Bacteroides/Prevotella in diet-induced obese mice. *PLoS One*. (2011) 6:e20944. doi: 10.1371/journal.pone.0020944

57. Gayed MA, Elabd H, Tageldin M, Abbass A. Probiotic Zado® (Ruminococcus Flavefaciens) boosts hematology, immune, serum proteins, and growth profiles in Nile tilapia (Oreochromis niloticus). *Fish Shellfish Immunol Rep*. (2021) 2:100021. doi: 10.1016/j.fsirep.2021.100021

58. Xiong J, Wang K, Wu J, Qiuqian L, Yang K, Qian Y, et al. Changes in intestinal bacterial communities are closely associated with shrimp disease severity. *Appl Microbiol Biotechnol*. (2015) 99:6911–9. doi: 10.1007/s00253-015-6632-z

59. Ferreira-Halder CV, de Sousa Faria AV, Andrade SS. Action and function of Faecalibacterium prausnitzii in health and disease. *Best Pract Res Clin Gastroenterol*. (2017) 31:643–8. doi: 10.1016/j.bpg.2017.09.011

60. Tan H, Zhao J, Zhang H, Zhai Q, Chen W. Novel strains of Bacteroides fragilis and Bacteroides ovatus alleviate the LPS-induced inflammation in mice. *Appl Microbiol Biotechnol*. (2019) 103:2353–65. doi: 10.1007/s00253-019-09617-1

61. Naya-Català F, Do Vale Pereira G, Piazzon MC, Fernandes AM, Calduch-Giner JA, Sitjà-Bobadilla A, et al. Cross-talk between intestinal microbiota and host gene expression in gilthead sea bream (Sparus aurata) juveniles: insights in fish feeds for increased circularity and resource utilization. *Front Physiol*. (2021) 12:748265. doi: 10.3389/fphys.2021.748265

62. Zhao H, Xia J, Zhang X, He X, Li L, Tang R, et al. Diet affects muscle quality and growth traits of grass carp (Ctenopharyngodon idellus): a comparison between grass and artificial feed. *Front Physiol*. (2018) 9:283. doi: 10.3389/fphys.2018.00283

63. Wei Y, Li B, Xu H, Liang M. Fish protein hydrolysate in diets of turbot affects muscle fiber morphometry, and the expression of muscle growth-related genes. *Aquac Nutr*. (2020) 26:1780–91. doi: 10.1111/anu.13129

64. Moon JS, Oh DH, Park SJ, Seo JS, Kim DU, Moon SH, et al. Expression of insulin-like growth factor genes in olive flounder, Paralichthys olivaceus, fed a diet with partial replacement of dietary fish meal. *J World Aquacult Soc*. (2022) 54:131–42. doi: 10.1111/jwas.12914

65. Yuan XY, Jiang GZ, Cheng HH, Cao XF, Wang CC, Dai YJ, et al. Replacing fish meal with cottonseed meal protein hydrolysate affects growth, intestinal function, and growth hormone/insulin-like growth factor I axis of juvenile blunt snout bream (Megalobrama amblycephala). *J World Aquacult Soc*. (2020) 51:1235–49. doi: 10.1111/jwas.12679

66. Fuentes EN, Valdés JA, Molina A, Björnsson BT. Regulation of skeletal muscle growth in fish by the growth hormone–insulin-like growth factor system. *Gen Comp Endocrinol*. (2013) 192:136–48. doi: 10.1016/j.ygcen.2013.06.009

67. Vélez EJ, Lutfi E, Jiménez-Amilburu V, Riera-Codina M, Capilla E, Navarro I, et al. IGF-I and amino acids effects through TOR signaling on proliferation and differentiation of gilthead sea bream cultured myocytes. *Gen Comp Endocrinol*. (2014) 205:296–304. doi: 10.1016/j.ygcen.2014.05.024

68. Zheng K, Liang M, Yao H, Wang J, Chang Q. Effect of dietary fish protein hydrolysate on growth, feed utilization and IGF-I levels of Japanese flounder (Paralichthys olivaceus). *Aquac Nutr*. (2012) 18:297–303. doi: 10.1111/j.1365-2095.2011.00896.x

69. Wei Y, Liang M, Xu H. Fish protein hydrolysate affected amino acid absorption and related gene expressions of IGF-1/AKT pathways in turbot (Scophthalmus maximus). *Aquac Nutr*. (2020) 26:145–55. doi: 10.1111/anu.12976

70. Peres H, Santos S, Oliva-Teles A. Blood chemistry profile as indicator of nutritional status in European seabass (Dicentrarchus labrax). *Fish Physiol Biochem*. (2014) 40:1339–47. doi: 10.1007/s10695-014-9928-5

71. Peres H, Santos S, Oliva-Teles A. Selected plasma biochemistry parameters in gilthead seabream (Sparus aurata) juveniles. *J Appl Ichthyol*. (2013) 29:630–6. doi: 10.1111/j.1439-0426.2012.02049.x

72. Roque A, Yildiz HY, Carazo I, Duncan N. Physiological stress responses of sea bass (Dicentrarchus labrax) to hydrogen peroxide (H_2O_2) exposure. *Aquaculture*. (2010) 304:104–7. doi: 10.1016/j.aquaculture.2010.03.024

73. Ziskowski J, Mercaldo-Allen R, Pereira J, Kuropat C, Goldberg R. The effects of fin rot disease and sampling method on blood chemistry and hematocrit measurements of winter flounder, Pseudopleuronectes americanus from New Haven Harbor (1987–1990). *Mar Pollut Bull*. (2008) 56:740–50. doi: 10.1016/j.marpolbul.2007.12.007

74. Ye CX, Tian LX, Mai KS, Yang HJ, Niu J, Liu YJ. Dietary magnesium did not affect calcium and phosphorus content in juvenile grouper. *Aquac Nutr*. (2010) 16:378–84. doi: 10.1111/j.1365-2095.2009.00675.x

75. Wicher KB, Fries E. Haptoglobin, a hemoglobin-binding plasma protein, is present in bony fish and mammals but not in frog and chicken. *Proc Natl Acad Sci*. (2006) 103:4168–73. doi: 10.1073/pnas.0508723103

76. Gutteridge JM. The antioxidant activity of haptoglobin towards haemoglobin-stimulated lipid peroxidation. *BBA Lipid Lipid Met*. (1987) 917:219–23. doi: 10.1016/0005-2760(87)90125-1

77. Lim YK, Jenner A, Ali AB, Wang Y, Stephen I, Hsu H, et al. Haptoglobin reduces renal oxidative DNA and tissue damage during phenylhydrazine-induced hemolysis. *Kidney Int*. (2000) 58:1033–44. doi: 10.1046/j.1523-1755.2000.00261.x

frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 27 June 2023
DOI 10.3389/fsufs.2023.1194321

OPEN ACCESS

EDITED BY
Luca Secondi,
University of Tuscia, Italy

REVIEWED BY
Luis F. Goulao,
University of Lisbon, Portugal
Evans Brako Ntiamoah,
Sichuan Agricultural University, China
David Nartey Obemah,
Kwame Nkrumah University of Science and Technology, Ghana

*CORRESPONDENCE
Yong-Guan Zhu
ygzhu@iue.ac.cn

RECEIVED 05 April 2023
ACCEPTED 05 June 2023
PUBLISHED 27 June 2023

CITATION
Afriyie E, Zurek M, Asem FE, Okpattah B, Ahiakpa JK and Zhu Y-G (2023) Consumer food storage practices and methods at the household-level: a community study in Ghana. *Front. Sustain. Food Syst.* 7:1194321. doi: 10.3389/fsufs.2023.1194321

Consumer food storage practices and methods at the household-level: a community study in Ghana

Ebenezer Afriyie[1,2], Monika Zurek[3], Freda E. Asem[4], Bernard Okpattah[5], John K. Ahiakpa[6] and Yong-Guan Zhu[1]*

[1]Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, China, [2]University of Chinese Academy of Sciences, Beijing, China, [3]Environmental Change Institute, University of Oxford, Oxford, United Kingdom, [4]University of Ghana, Accra, Ghana, [5]Asinyo Agri-Commerce Ltd., Accra, Ghana, [6]Research Desk Consulting Ltd., Accra, Ghana

Introduction: Household-level food storage can make food available to consumers, and promotes food security. Nevertheless, attention is mostly devoted to enhancing food storage at the farmer and national levels, neglecting the household level. It is therefore critical to assess food storage practices of households. This study examined food storage practices of households, evaluated expert opinions on household-level food storage, and assessed the effect household characteristics has on food storage and food security.

Methods: Dzorwulu and Jamestown communities in Accra, Ghana, were chosen as the study locations. The study consisted of a survey, expert interviews and structural equation modeling. For the survey, 400 food household heads selected using systematic sampling method responded to a semi-structured questionnaire. Seventeen (17) experts were also purposively sampled and interviewed.

Results and Discussion: The results showed that, most households stored foodstuffs they often consumed, with generally low storage of fruits and vegetables. Perishable foods such as cassava, tomato, yam, and banana were stored by 37.8, 42, 38.3 and 43.8% of households, respectively, for 1–3days. Households often stored food within a period of 2weeks, due to poor storage facilities and lack of food storage knowledge. About 85.8% of households had never received training on food storage. Most households used baskets, bowls, sacks and polyethylene bags to store food at home, and some used refrigerators and deep freezers. Regarding the link between food storage and food security, household heads' income showed a significant positive moderating effect ($p \leq 0.01$), households' socioeconomic status had a positive effect, while household size indicated a significant negative moderating effect ($p \leq 0.01$). The experts asserted that, household-level food storage enhances food security and food safety, and reduces food expenditure and food wastage. The limited food storage knowledge of households should be a basis for intervention to enhance proper food storage practices within households.

KEYWORDS

household-level food storage, food security, food safety, food waste, household income, Ghana

1. Introduction

Achieving food security and ending hunger is a major aim of the United Nations' sustainable development goals, SDG 2 (United Nations, 2015). Nevertheless, the number of people affected by hunger in the world were between 702 and 828 million in 2021, and about 2.3 billion people were moderately or severely food insecure in the world in the same year (FAO et al., 2022). Another concern is also the pressure on food security from climate change – the Food and Agriculture Organization (FAO) noted that because of its impact on agriculture, climate change will negatively affect food security in all of its dimensions (FAO, 2016), and hence increase economic pressure on food access. Simulations performed using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) predict that inflation-adjusted prices of maize, rice and wheat (the three most important staple grains in the world) would increase between 31 to 106% by the year 2050 (Nelson et al., 2010). Generally, rise in food prices will lead to increase in food insecurity and poverty, especially for urban poor households.

A key contributing factor towards global food insecurity is post-harvest losses (Makalle, 2012). Post-harvest loss causes direct physical and quality loss of food which can reduce its economic value and may also make it unsuitable for human consumption. It is estimated that about one-third of food produced globally (valued at US $1 trillion) is lost or wasted annually, with *per capita* food losses in Sub-Saharan Africa projected to be about 37% or 120–170 kg/year (FAO, 2011; Sheahan and Barrett, 2017). Although there are losses along the food value chain from production to consumer level, food loss during storage is regarded to be most critical, particularly in developing countries, since most losses occur at this stage (Aulakh et al., 2013; Majumder et al., 2016). There can be 50 to 60% loss of food grains during storage due to factors such as poor storage practices (Kumar and Kalita, 2017). Also, nearly 50% of most food crops cultivated in Ghana for example are wasted and do not get to the final consumer, and food wastage in Accra, the capital city of Ghana, is mainly attributed to factors such as inadequate financing and inappropriate food storage structures (Nyo, 2016). Nevertheless, food storage can make enough food available to consumers and enhance food security when adequate effort is made in promoting efficient food storage methods and use of improved storage structures.

In most parts of the world, attention is usually devoted to enhancing food storage at the national and farmer levels, neglecting food storage at the consumer or household-level. In India for instance, the central government procures food from farmers, store and distribute it to mostly vulnerable urban and rural consumers or households at affordable prices (Spielmann and Aggarwal, 2017). Governments of several countries in Africa including Ghana undertake similar food policy to stabilize food prices and help farmers to easily market their produce. The National Food Buffer Stock Company (NAFCO) established in 2010 in Ghana is responsible for avoiding food surpluses from the market by buying cereals such as rice and maize from farmers at a minimum guaranteed price and store them in warehouses during the glut season. In the lean season, the cereals are released onto the market to stabilize prices and make the food readily available to consumers (Armah et al., 2019). Despite this food policy capable of making food prices stable and ensuring food availability during lean seasons, it has still not been able to eradicate hunger and avoid food insecurity, especially in poor households (Spielmann and Aggarwal, 2017). In China, the Scientific Grain Storage Project has been implemented by the government to minimize food storage losses by promoting advanced storage facilities including metal mesh warehouses, metal silos and steel framework warehouses to farmers at subsidized prices (Luo et al., 2021). Similarly, improved storage facilities such as hermetic storage bags and silos are being promoted for use to farmers in Ghana to reduce postharvest losses. Regardless of the effort geared towards enhancing food storage at the national and farmer levels in Ghana, little attention is paid to promoting food storage at the consumer or household-level in the country.

In prehistoric times, household-level food storage was a robust and common adaptation strategy for coping with inter-annual variability in crop production and securing annual supply of food. A study by Dean (2006) assessed the variations in household food storage capacity within prehistoric households in Tsegi Canyon, Northeastern Arizona, around 1,250 and 1,300 CE. The study revealed that households increased their corn store rooms or granaries while their living spaces decreased, in order to store more grains. Overall, in the study area, granary spaces increased by 61% at the expense of living spaces, during the period when agricultural production worsened. Household storage bins were also used to store 3 to 10 tons of grains for 2 to 3 years among the Hausa people of present-day Nigeria around the 18th century (Spielmann and Aggarwal, 2017). Household-level food storage is critical for minimizing postharvest losses and securing food supply to consumers. Hence, it is important to channel efforts on investigating and developing appropriate strategies for enhancing food storage within households. The aim of this study was therefore to assess food storage practices of households in Accra, Ghana. We also evaluated the opinions of experts on household-level food storage practices, and assessed the direct and moderating effect of household characteristics on food storage and food security.

2. Methods

2.1. Study design

The study consisted of a survey, expert interviews and partial least squares-structural equation modeling (PLS-SEM). The survey was carried out from November, 2020 to January, 2021. Semi-structured questionnaires were administered to food household heads – the person who has the major task of planning and preparing food for members of a household (Webber et al., 2010). The interviews were conducted between October to November, 2020 by interviewing experts in food storage, food security, food safety, food value chain and post-harvest technology. The structural equation modeling was done by using data collected from the survey to predict the impact of household characteristics on food storage and food security.

2.2. Data collection

2.2.1. Survey

This study forms part of a larger study, and so the procedure for collecting the survey data is the same as described earlier by Afriyie et al. (2022). Data was collected from households in two communities,

Dzorwulu and Jamestown, located within Accra, Ghana, (5°33'00" N, 0°12'00" W, 61 m) (Attipoe and Li, 2016). These study areas were selected because of the different socioeconomic statuses of their inhabitants. Dzorwulu is inhabited by 3,309 households who are mainly of middle-income socioeconomic status, with some high-income status households (Owusu et al., 2013; AWMA, 2019). Jamestown has 5,013 households that are mostly regarded to be of low-income status, residents usually live in congested housing and have low educational levels (Boatemaa et al., 2018; AMA, 2019). Using stratified random sampling procedure, a total of 400 respondents were selected for the study, with 160 respondents from Dzorwulu and 240 from Jamestown [using Eqs. (1)–(2)]. Systematic sampling method was used to select households at an interval of 1:22 [using Eq. (3)]. Pieces of paper with numbers from 1 to 22 written on them were shuffled in a container, and one number was randomly chosen to decide the penultimate household (Ovuga et al., 2005). We observed a spacing of 22 households from a selected household to the next.

Sample size was determined at 95% level of confidence, 50% degree of variability and 5% level of precision (Cochran, 1963):

$$n = \frac{z^2 p(1-p)}{d^2} \quad (1)$$

Proportional allocation

$$n_h = \frac{N_h}{N} \times n \quad (2)$$

Estimating the systematic sample interval (k) was done according to Subramani et al. (2014) and Sudakar (1978):

$$k = \frac{n}{N} \quad (3)$$

Where; N = total number of households, n = sample size, N_h = number of households in a community, n_h = sample size of a community, d = margin of error, z = the confidence interval, and p = degree of variability.

The survey questionnaire was made up of 47 questions and required about 40 min to complete. Generally, it aimed to find out the food storage behavior and practices of households, and effect of food storage on food security, safety, food wastage and expenditure as indicated in the supplementary file. A total of 400 questionnaires that were administered were all valid, which represents 100% response rate. The questionnaire was pre-tested by administering to 35 households in Osu, a community in Accra that has similar characteristics as the study areas. In pre-testing the questionnaire, we were able to; ensure respondents understood its content, avoid ambiguity, and determine the time needed to complete it. The survey was conducted in Ga and Twi (local languages), and English, which were the languages preferred by the respondents.

2.2.2. Expert interviews

The expert interviews were done by face-to-face interviewing 17 experts from the Ministry of Food and Agriculture of Ghana (MoFA), Departments of Agriculture (Regional, Metropolitan and Municipal), Kwame Nkrumah University of Science and Technology (KNUST), Council for Scientific and Industrial Research (CSIR) and SEND Ghana (Non-Governmental Organization promoting agricultural development in Ghana), using purposive sampling technique. The interviews were all carried out in English language by the same researcher by asking questions about household-level food storage methods, factors affecting it, and its influence on food security, waste, food safety and expenditure, using open-ended interview guide which consisted of nine (9) questions.

2.3. Data analyses

Data obtained from the survey were subjected to descriptive analysis using Statistical Package for the Social Sciences (SPSS) (version 26). Food commodities stored by households, storage period for various foods within households, and storage methods for food commodities were assessed. Food commodities were classified under the six food groups of Ghana including starchy roots and plantain; cereals and cereal products; legumes; animal products; fruits, vegetables and mushrooms; and fats and oils (Nti, 2008). Canned, cooked and leftover foods were also included in the analysis. The SPSS was also used to estimate the socioeconomic status (SES) of households through principal component analysis (PCA). The PCA is a statistical technique that is used for reducing variables in a dataset into smaller set of variables or dimensions (Vyas and Kumaranayake, 2006). Data for variables that capture living standards, including, household ownership of durable assets (example; car, television, refrigerator), and infrastructure and housing characteristics (example; sanitation facility, housing floor material, source of water) were subjected to PCA to estimate the SES of the sampled households (Rutstein and Johnson, 2004; Vyas and Kumaranayake, 2006). Additionally, the expert interviews were directly transcribed verbatim in English. Analysis of the transcripts was carried out by inductive coding using NVivo (version 12), *in vivo* codes and codes assigned by the researcher were used for data coding (Lamers et al., 2021). Key themes emerged were used to analyze the results based on the responses from the participants. The partial least squares-structural equation modeling was carried out by the use of SmartPLS software 3.2 (Ringle et al., 2015). Validity and reliability of formative and reflective constructs were tested (Hair et al., 2017). The model did not have any formative constructs and all concepts were modeled as reflective constructs, hence reliability was assessed using Cronbach's alpha and composite reliability tests (Hair et al., 2019). Composite reliability values were between 0.71 and 1.00, well beyond the 0.70 recommended threshold, and average variance extracted values were also between 0.56 and 1.00, indicating acceptable convergent validity, because they were beyond the recommended 0.50 threshold (Saunders et al., 2019; Afriyie et al., 2022).

3. Results

3.1. Socio-demographic characteristics of respondents

The survey comprised of participants who were mainly females (85%), mostly had Junior High School/Middle level education (31.5%) and were mainly between 40 to 59 years of age (40.8%). A majority of the survey participants were also traders (60.8%) (Table 1). The expert interviews were done with interviewees who were between ages 27 to

TABLE 1 Distribution (%) of respondents and households by characteristics (n=400).

Variable	%	Variable	%
Age of respondents		*Household size*	
Less than 18 years	0.3	1	18.8
18–25 years	13	2–3	41
26–39 years	38.8	4–5	28.5
40–59 years	40.8	6 or more	11.8
60 years and above	7.2	*Socioeconomic status of households (SES)*	
Sex of respondents		Higher-income/richest	2.3
Female	85	Upper-middle-income	6.5
Male	15	Middle-income	18
Education of respondents		Lower-middle-income	16.5
Tertiary (Degree/diploma)	15.8	Lower-income/poorest	56.8
SHS/secondary	25.8	*Education of household heads*	
JHS/middle	31.5	Tertiary (Degree/diploma)	20.3
Primary	19.5	SHS/secondary	26
None	7.5	JHS/middle	28
Occupation of respondents		Primary	17.8
Professional/technical/managerial/clerical	6.3	None	8
Agricultural self-employed	0.8	*Occupation of household heads*	
Trade	60.8	Professional/technical/managerial/clerical	13
Service	6.3	Agricultural self-employed	2.5
Skilled manual	15.8	Trade	41.8
Unskilled manual	9.3	Service	7.2
None	1	Skilled manual	23
Monthly income of respondents (GH₵)		Unskilled manual	12.5
above 2,500	22.8	None	0
2001–2,500	10.5	*Monthly income of household heads (GH₵)*	
1,501–2000	2	above 2,500	29
1,001–1,500	15.5	2001–2,500	7
501–1,000	38	1,501–2000	4
500 and below	11.3	1,001–1,500	13.8
		501–1,000	39.5
		500 and below	6.8

SHS, Senior High School; JHS, Junior High School; GH₵, Ghana Cedi. Principal Component Analysis (PCA) was used to estimate the socioeconomic status of households (Rutstein and Johnson, 2004; Vyas and Kumaranayake, 2006; Kabudula et al., 2017).

58 years, with 35.3% being males and 64.7% females (Table 2). The experts had educational levels of Bachelor's degree (47.1%), Master's degree (35.3%), and Doctorate degree (Ph.D.) (17.6%).

3.2. Survey

3.2.1. Food storage methods used by households

The study showed that most households stored starchy roots such as cassava in polyethylene bag (15.8%), bowl (15.8) and on the floor (10.3%) (Figure 1A). Yam and plantain were usually kept on the floor (28.4, 31% respectively), in deep freezer (12.1, 10.8% respectively) and in a polyethylene bag (13.3, 16% respectively). Rice was mainly stored by 49.8% of households in a sack while 22.2% kept maize in a bowl. Bread was usually stored by households in a refrigerator (40.5%) and polyethylene bag (31.5%). Majority of households kept meat (48%) and fish (47%) in deep freezer, 49.8% of households stored milk in a refrigerator while 37.5% stored groundnut in a polyethylene bag. Additionally, households usually used basket to store orange (23%), pepper (29.6%), onion (38.3%) and garden eggs (28.1%) (Figure 1B). Banana was mainly stored in a polyethylene bag (17%) while tomato was mostly kept in a bowl (28.1%). Deep freezer was often used to store cooked food (39.5%) and leftover food (34.5%). Overall, middle- and higher-income households usually used refrigerator and deep freezer to store perishable foods. Households without these storage facilities resorted to using methods such as storing in a bowl, basket, and on the floor, and therefore could not store food for longer period. Non-perishable food commodities were often stored using a sack, polyethylene bag and bowl.

The study also revealed that 65.8 and 31% of households owned refrigerator and deep freezer, respectively for storing food (Table 3). We found that 2.6% of lower-income households rented spaces in deep freezers from other people to store their food and paid an amount ranging from 2 to 5 Cedis (which is 0.34 to 0.86 United States Dollars; using Bank of Ghana exchange rate) per day, as at the time of the study. Some other households also used various

TABLE 2 Characteristics of expert interview participants.

Serial number (SN)	Sex	Age	Education	Specialization
01	Male	41	Bachelor's degree	Food security
02	Female	55	Master's degree	Food safety
03	Female	50	Bachelor's degree	Food safety
04	Female	58	Master's degree	Food value chain
05	Male	34	Bachelor's degree	Food storage
06	Female	37	Bachelor's degree	Post-harvest technology
07	Female	41	Master's degree	Food value chain
08	Female	29	Bachelor's degree	Food safety
09	Female	38	Ph.D.	Food security
10	Male	35	Bachelor's degree	Post-harvest technology
11	Male	53	Ph.D.	Food storage
12	Male	42	Master's degree	Post-harvest technology
13	Female	37	Master's degree	Food security
14	Female	49	Master's degree	Food safety
15	Female	33	Bachelor's degree	Food value chain
16	Female	46	Ph.D.	Food security
17	Male	27	Bachelor's degree	Food storage

indigenous ways to store food. For instance, wood ash is sprinkled or smeared on cut surfaces of leftover fresh yam to increase shelf life, onion is mixed together with lime, and pieces of charcoal are put into soup when storing to avoid spoilage (Table 4). Additionally, a majority of households (85.8%) had not received any training on food storage (Table 5), meaning that a training intervention could have helped households to enhance their food storage practices.

3.2.2. Food commodities stored by households

The results showed that food commodities stored by most households included yam (80%), rice (80.7%), bread (86.7%), fish (80.2%), groundnut (81.2%), tomato (86.2%), pepper (89.2%), onion (90.5%), palm oil (91.5%), and leftover food (84.5%) (Figures 2A,B). Generally, there was low storage of fruits and vegetables, and maize, a staple food commodity was stored by 61% of households. Leftover food being mostly stored implies that majority of households avoided food wastage by not throwing away foods they were unable to finish consuming. Households did not generally store millet, snail, taro, Bambara nuts, palm kernel oil, groundnut oil and coconut oil probably because they did not usually consume them. The study also revealed that all households stored basic foodstuffs including tomato, pepper, onion, garden eggs, bread, and palm oil (Figures 3A,B). The higher the socioeconomic status of a household, the more it is able to store most foods. Lower-income households were generally the least to store most food commodities. This can be attributed to the fact that they do not have appropriate storage facilities, or they usually buy what they can consume for the day, since poor households often do not have enough money to buy food in bulk to store.

3.2.3. Storage period for various foods by households

The results showed that food commodities mostly stored by households for 1–3 days were cassava (37.8%), yam (38.3%), plantain (36.5%), bread (40%), milk (27.8%), orange (43.3%), banana (43.8%), tomato (42%), cooked food (60.5%), and leftover food (78.8%) (Tables 6A,B). Majority of households stored maize (25%), fish (32.8%), egg (32%), groundnut (36.8%), pepper (39.5%), onion (42.5%), garden eggs (35.8%), and canned food (18%) for 4–6 days. Rice, palm oil, and refined vegetable oil were mainly stored by 29.8, 27.5, and 21.3% of households, respectively for 1–2 weeks. Although a majority of households generally stored most food commodities within a period of 2 weeks, some of them stored rice, oats, meat, fish, poultry, groundnut, onion, palm oil, palm kernel oil, refined vegetable oil, coconut oil, shea butter, and canned food for a month or more.

3.3. Expert interviews

The results of the expert interviews are grouped into six main themes: the effect of household-level food storage on (1) the eating pattern and food preference of consumers, (2) food security, (3) food expenditure, (4) food wastage, (5) food-based nutrition and safety, and (6) factors that affect household-level food storage.

3.3.1. Eating pattern and food preference of consumers

The majority of participants mentioned that food storage at the household-level compels consumers to eat the same food over the period during which it remains in storage. Although households may prefer to eat a different food, they do not, because the food in storage will go bad if not eaten, especially when the storage facility is not suitable, as narrated by a participant below;

> *"People eat what food is available at home so that it doesn't go bad. Once the food is there and I know it may go bad, I am forced to eat the same food more often so that it will finish without going bad, even though I may prefer to eat a different food"*. (Food safety expert, SN03)

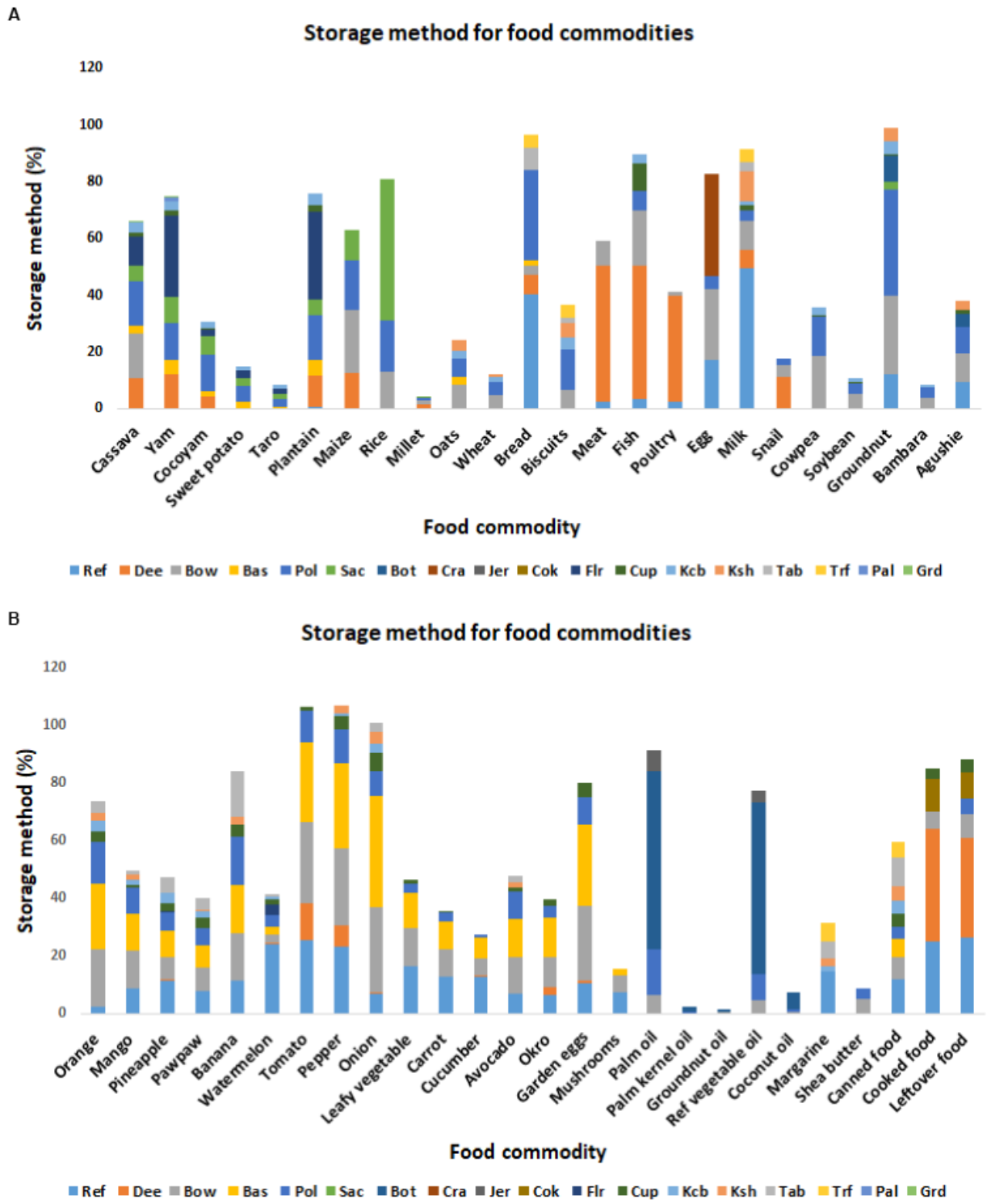


FIGURE 1
(A) Common storage methods for starchy roots and plantain, cereals and cereal products, animal products, and legumes, **(B)** common storage methods for fruits, vegetables and mushrooms, fats and oils, canned, cooked, and leftover foods. Ref, refrigerator; Dee, deep freezer; Bow, bowl; Bas, basket; Pol, polyethylene bag; Sac, sack; Bot, bottle; Cra, crate; Jer, jerry can; Cok, cooking pot; Flr, floor; Cup, kitchen cupboard; Kcb, kitchen cabinet; Ksh, kitchen shelf; Tab, on top of table; Trf, on top of refrigerator; Pal, pallet; Grd, in the ground.

One of the experts revealed that even for households having proper storage facilities, most of them cook food, particularly stews and soups, and store them for use during the week or beyond. This helps to save time and energy needed to cook frequently every day, but compels households to eat the same stew and soup for the period they remain in storage till they are exhausted, which affects their eating pattern and food preference.

> *"Some households with proper storage facilities cook stews and soups during weekends and store them in refrigerators and deep freezers for use during the week or beyond"*. (Food value chain expert, SN15)

3.3.2. Food security

Most participants asserted that household-level food storage improves food security within households. Some of them affirmed that when there is food scarcity, households that always store food will be secured compared to those who do not. Some dimensions of food security such as availability, accessibility and utilization were cited, as recorded verbatim below;

> *"When households are able to buy food in bulk and store at home, it makes food always available, accessible and properly utilized by the households"*. (Post-harvest technology expert, SN12)

> *"The ideal situation is to be able to shop for and eat fresh and healthy food every day, but in cases of food disruptions, consumers may face challenges. For instance, when there is food price increase or food shortage, consumers who always store food at home will have an upper hand compared to those who do not. Therefore, it is important to always store food to ensure food availability at home"*. (Food value chain expert, SN07)

TABLE 3 Households that have refrigerator and deep freezer to store food.

Socioeconomic status	Refrigerator	Deep freezer
Lower-income	91(22.8%)	1(0.3%)
Lower-middle-income	65(16.3%)	20(5%)
Middle-income	72(18%)	68(17%)
Upper-middle-income	26(6.5%)	26(6.5%)
Higher-income	9(2.3%)	9(2.3%)
Total	263(65.8%)	124(31%)

It was observed that 2.6% of households in the lower income class rented spaces in deep freezers to store their food and paid an amount ranging from 2 to 5 Cedis (0.34 to 0.86 USD; using Bank of Ghana exchange rate) per day, as at the time of the study.

Additionally, it was revealed that in order to improve food security, households should be able to buy food in bulk and store for longer period, preferably beyond the lean season. Participants noted that food prices in Ghana are lower during glut seasons and higher during lean seasons, therefore it will be in the best interest of households to buy food in bulk to store during glut seasons to avoid the high food prices and possible food scarcity during lean seasons.

> *"When food is in abundance during surplus season and you are able to store, you can always fall on what you have stored during the lean season since it will be available"*. (Food security expert, SN13)

> *"Most foods are seasonal and prices change, hence it is good to store when in season and the cost is less so that during off-season there will be food available for use"*. (Food safety expert, SN03)

3.3.3. Food expenditure

According to some participants, household-level food storage is cost-effective and enhances food surplus due to bulk purchases and discount deals which helps households to buy more food with the same amount of money or less. Also, by planning and avoiding frequent food purchases, households are able to save money, to minimize food expenditure.

> *"Storing food in bulk at home cuts down on costs since you get reduced price when you buy in bulk or you can even get surplus or additional foodstuff"*. (Post-harvest technology expert, SN06)

> *"When food is stored at home, it helps to spend less money on food since it prevents buying food regularly and in bits which may be expensive"*. (Food storage expert, SN11)

However, storage facilities such as deep freezer and refrigerator needed to store food require the use of electricity, which can be costly. Therefore, the participants indicated that whilst purchasing food in bulk and storing makes food available and minimizes costs, keeping the foodstuff in good condition and of high quality can be expensive. Below are the verbatim responses from some of the participants.

TABLE 4 Various indigenous ways of food storage used by households.

Commodity	Different forms of storage	% Response
Cassava	Stored in granular flour form (*gari*)	10.2
	Pour hot water on cassava in sack to store for longer period	0.8
Yam	Sprinkle wood ash on cut surfaces to prevent it from going bad quickly	6.5
Maize	Store maize in dough or flour form	19.3
Meat	Stored as smoked	9
Poultry	Stored as smoked	1.3
Fish	Stored as smoked, salted or fried	26.3
Snail	Stored as smoked	6.3
Milk	Store opened can milk in cold water in a bowl	2.5
Onion	Mix onion together with lime when storing to increase shelf life	4.1
Cooked food	Put pieces of charcoal in soup before storing to prevent it from going bad quickly	1.5

10.3389/fsufs.2023.1194321

TABLE 5 Household training status on food storage.

Socioeconomic status	Have you or your household received training on food storage?		
	Yes	No	Not sure
Lower-income	5(2.2%)	194(85.5%)	28(12.3%)
Lower-middle-income	1(1.5%)	56(84.8%)	9(13.6%)
Middle-income	1(1.4%)	66(91.7%)	5(6.9%)
Upper-middle-income	2(7.7%)	21(80.8%)	3(11.5%)
Higher-income	3(33.3%)	6(66.7%)	0(0%)
Total	12(3%)	343(85.8%)	45(11.3%)

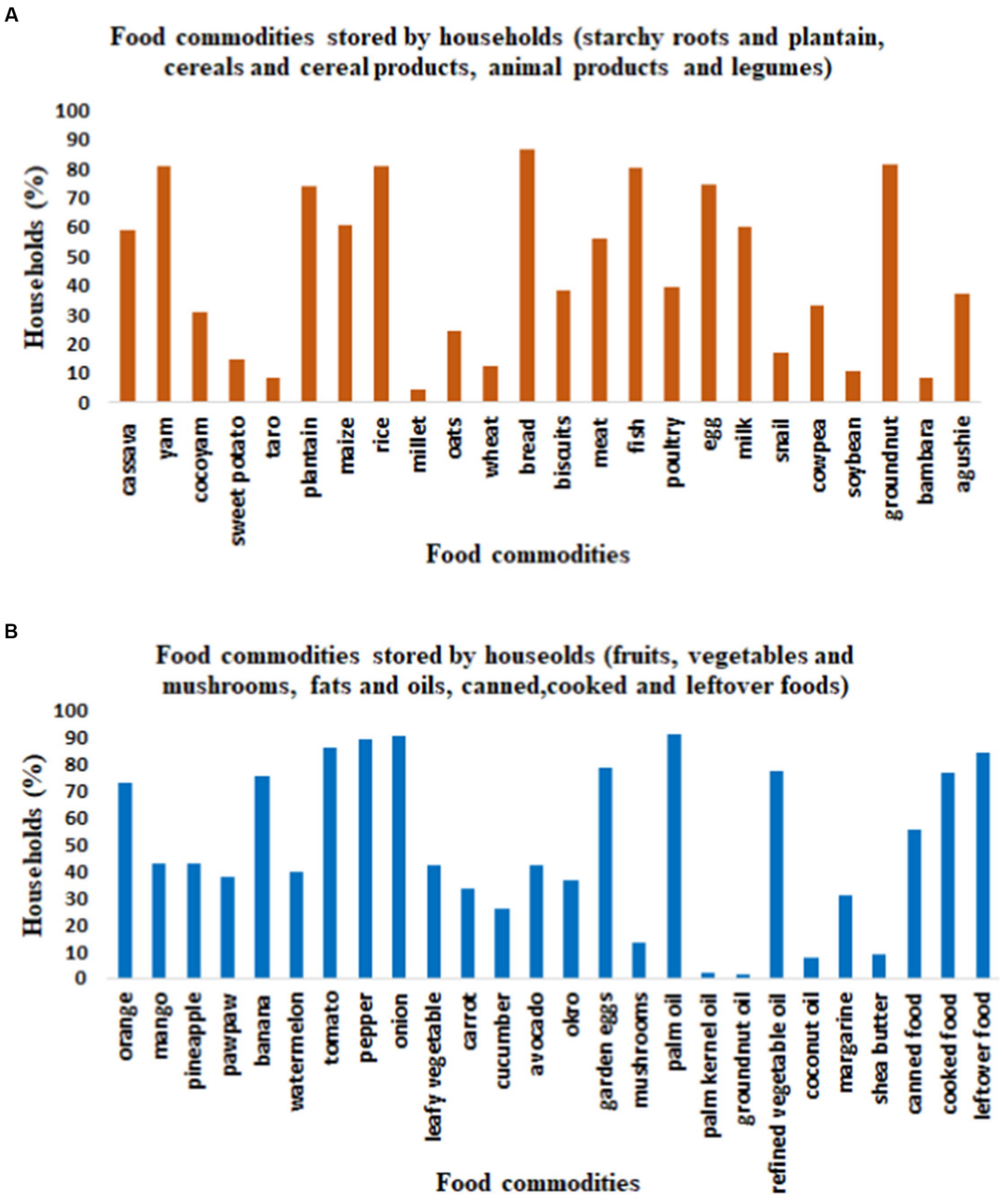


FIGURE 2
(A) Food commodities stored by households – starchy roots and plantain, cereals and cereal products, animal products, and legumes, **(B)** food commodities stored by households – fruits, vegetables and mushrooms, fats and oils, canned, cooked, and leftover foods.

10.3389/fsufs.2023.1194321

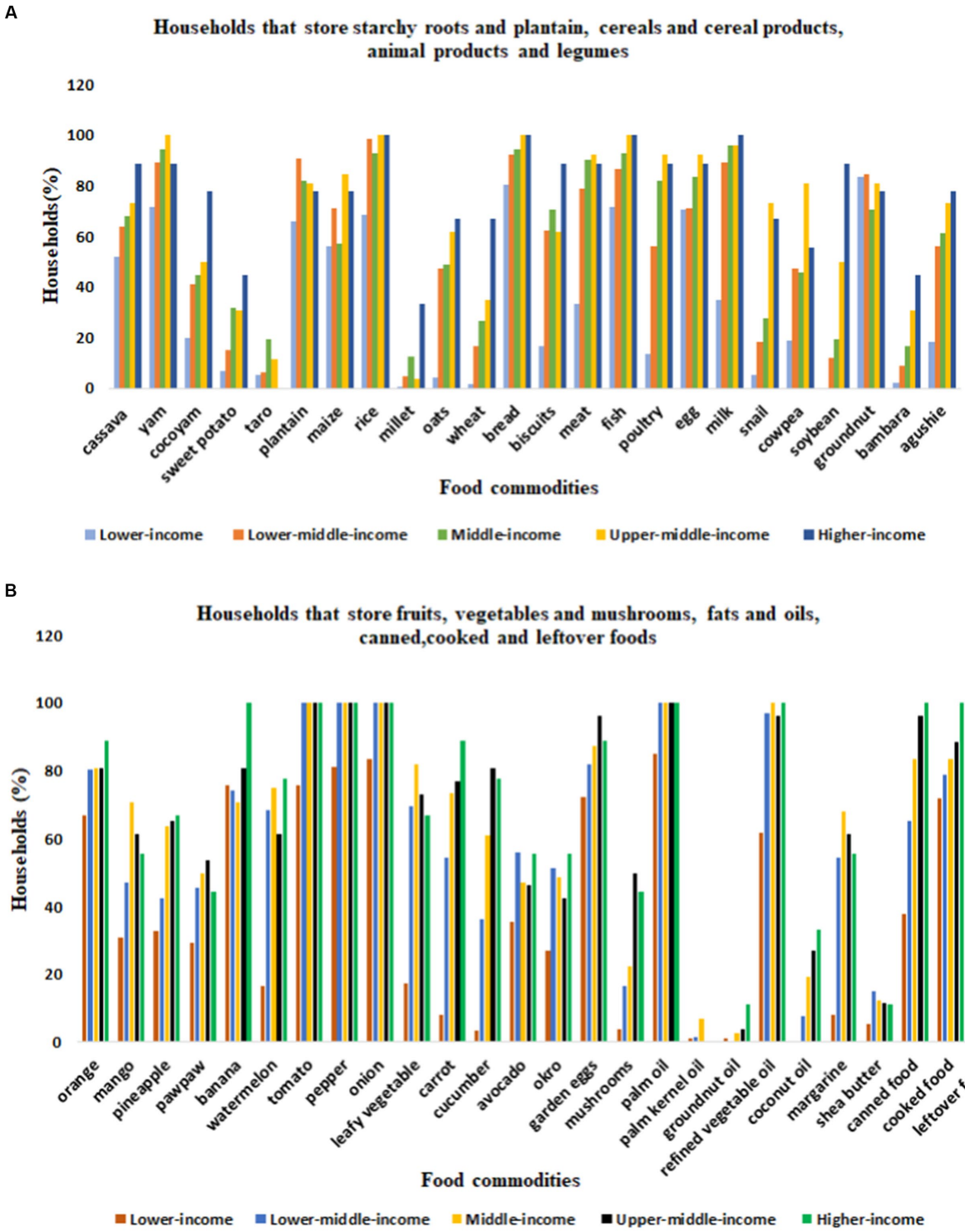


FIGURE 3
(A) Various socioeconomic households storing starchy roots and plantain, cereals and cereal products, animal products, and legumes, **(B)** various socioeconomic households storing fruits, vegetables and mushrooms, fats and oils, canned, cooked, and leftover foods.

> *"I don't think it helps much, because for instance if I buy tomatoes in bulk at a cheaper price but I store in the refrigerator or deep freezer for longer period, the problem is, the cost goes into the electricity bill"*. (Food value chain expert, SN04)

> *"Buying food in bulk and storing is relatively cheaper but ability to pay for electricity to store some foods in refrigerators and freezers is also a factor to consider"*. (Post-harvest technology expert, SN12)

10.3389/fsufs.2023.1194321

TABLE 6 (A) Storage period for starchy roots and plantain, cereals and cereal products, animal products, and legumes.

Commodity	% Response					
	Never	1–3days	4–6days	1–2weeks	3–4weeks	More than 1month
Starchy roots and tubers						
Cassava	41	37.8	15	4.8	1.5	0
Yam	19	38.3	33.3	9.5	0	0
Cocoyam	69	15.8	10.5	3.5	1.3	0
Sweet potato	85	9	4.5	1.5	0	0
Taro	91.8	5.8	2.5	0	0	0
Plantain	25.8	36.5	25.5	11.3	1	0
Cereals and cereal products						
Maize	39	18.5	25	12.3	5.3	0
Rice	19.3	17.5	16	29.8	12.3	5.3
Millet	95.8	1.3	1.5	1.3	0.3	0
Oats	75.5	11.5	5	5.5	1.8	0.8
Wheat	87.8	6	3.5	1.8	1	0
Bread	13.3	40	39.5	7.2	0	0
Biscuits	61.5	20.3	13.3	5	0	0
Animal products						
Meat	44	29.5	17.8	6.3	1.8	0.8
Fish	19.8	25	32.8	16.5	3.5	2.5
Poultry	60.3	21	11.3	5	1.3	1.3
Egg	25.3	20.3	32	21	1.5	0
Milk	39.8	27.8	24	8.3	0.3	0
Snail	82.8	7.2	5	5	0	0
Legumes						
Cowpea	67	6.8	16.5	9.5	0.3	0
Soybean	89.2	3.8	4.5	1.8	0.8	0
Groundnut	18.8	26.2	36.8	15.5	2	0.8
Bambara	91.3	3	3.8	1.5	0.6	0
Agushie	63	17	15.5	4.3	0.3	0

3.3.4. Food wastage

The analysis revealed that household-level food storage contributes to reducing food wastage, especially when food is properly stored. The participants mentioned that because households plan and store the quantity of food they need within a particular period of time, they do not usually waste the food.

> *"Storing food at home reduces food wastage, especially when there is proper means of storing"*. (Food safety expert, SN08)

> *"If food is stored well in the house, it reduces food going waste since you plan and store the quantity you need"*. (Food storage expert, SN11)

Improper storage of foodstuff, unplanned use of foodstuff and unforeseen circumstances such as electricity failure can however cause stored food, particularly in refrigerators and deep freezers, to go bad or wasted.

> *"If you don't store food well or if you don't check how long you are storing the food, it will go bad and become waste"*. (Food value chain expert, SN04)

> *"Sometimes electricity or power outage causes food stored in refrigerators and deep freezers to go bad, thereby wasting the food"*. (Food security expert, SN16)

3.3.5. Food-based nutrition and safety

The participants held that storing food at the household-level has a positive effect on food-based nutrition and safety. Food storage encourages households to cook food at home, therefore they are not exposed to food handled or stored and cooked outside under unhygienic conditions or food that do not contain enough nutrients.

> *"When you store food at home, it makes you cook food at home and so you will rarely buy cooked food outside. Food cooked outside may*

10.3389/fsufs.2023.1194321

TABLE 6 (B) Storage period for fruits, vegetables and mushrooms, fats and oils, canned, cooked, and leftover foods.

Commodity	% Response					
	Never	1–3days	4–6days	1–2weeks	3–4weeks	More than 1month
Fruits, vegetables and mushrooms						
Orange	27	43.3	24.8	5	0	0
Mango	56.8	29.3	11.5	2.5	0	0
Pineapple	57	29.8	12.3	1	0	0
Pawpaw	62.3	22	13.5	2.3	0	0
Banana	24.5	43.8	27.8	4	0	0
Watermelon	60	23.5	13	3.3	0.3	0
Tomato	13.8	42	34.8	4	5.5	0
Pepper	10.8	37.5	39.5	7	5.3	0
Onion	9.5	26.5	42.5	15.5	3.5	2.5
Leafy vegetable	57.8	23.3	14.5	4.3	0.3	0
Carrot	66.3	18.8	8.8	6	0.3	0
Cucumber	74	15.8	7.8	2.5	0	0
Avocado	57.8	26.5	13.3	2.5	0	0
Okro	63.5	25.8	9.5	1.3	0	0
Garden eggs	21.5	35.3	35.8	7.5	0	0
Mushrooms	86.8	4.8	5.2	3.3	0	0
Fats and oils						
Palm oil	8.5	16.5	21.3	27.5	19.8	6.5
Palm kernel oil	97.8	0.5	0.3	1	0.3	0.3
Groundnut oil	98.3	1	0.5	0.3	0	0
Refined vegetable oil	22.5	19	19.3	21.3	14.5	3.5
Coconut oil	92.3	0.8	0.5	3.5	2	0.8
Margarine	69	10.5	12.8	6.8	1	0
Shea butter	91.3	0.5	2.5	3.3	2	0.5
Canned food	44.3	17.3	18	11	7.2	2.3
Cooked food	23.3	60.5	14	2.3	0	0
Leftover food	15.5	78.8	5.3	0.5	0	0

> *not contain all the necessary nutrients, it may also be cooked in an unhygienic place and hence may pose health problems".* (Food security expert, SN01)

> *"When you store food well at home, you are able to eat safe and healthy food because you make sure you store in a clean and suitable environment".* (Food security expert, SN16)

A majority of the participants also asserted that household-level food storage enhances food nutrition and safety through diet planning. They revealed that storing food helps households to plan their meals and diets to ensure that optimum amounts of nutrients are retained and does not pose any health challenges.

> *"Mostly when storing food at home, you store the ones you can get enough nutrients from and once food is stored well it will not have any health problems".* (Food value chain expert, SN04)

> *"Once you have the various foods stored at home, when planning meals, cooking or eating, you will ensure you have all the needed nutrients and because you are cooking or handling it yourself, you take the necessary safety measures".* (Food safety expert, SN14)

3.3.6. Factors that affect household-level food storage

Most participants cited some factors that affect household-level food storage to be electricity, temperature, shelf life of food, pest infestation, improper storage practices, unsuitable storage facilities and financial capability of households. Electricity is important because *"if there is no power or electricity supply, you cannot use storage equipment like refrigerator and deep freezer"* (Food security expert, SN01). These storage equipment or facilities are at the core of household-level food storage. Some of the participants asserted that the shelf life of food is critical in determining the storage period of food. Additionally, fertilizers and agro-chemicals used to spray

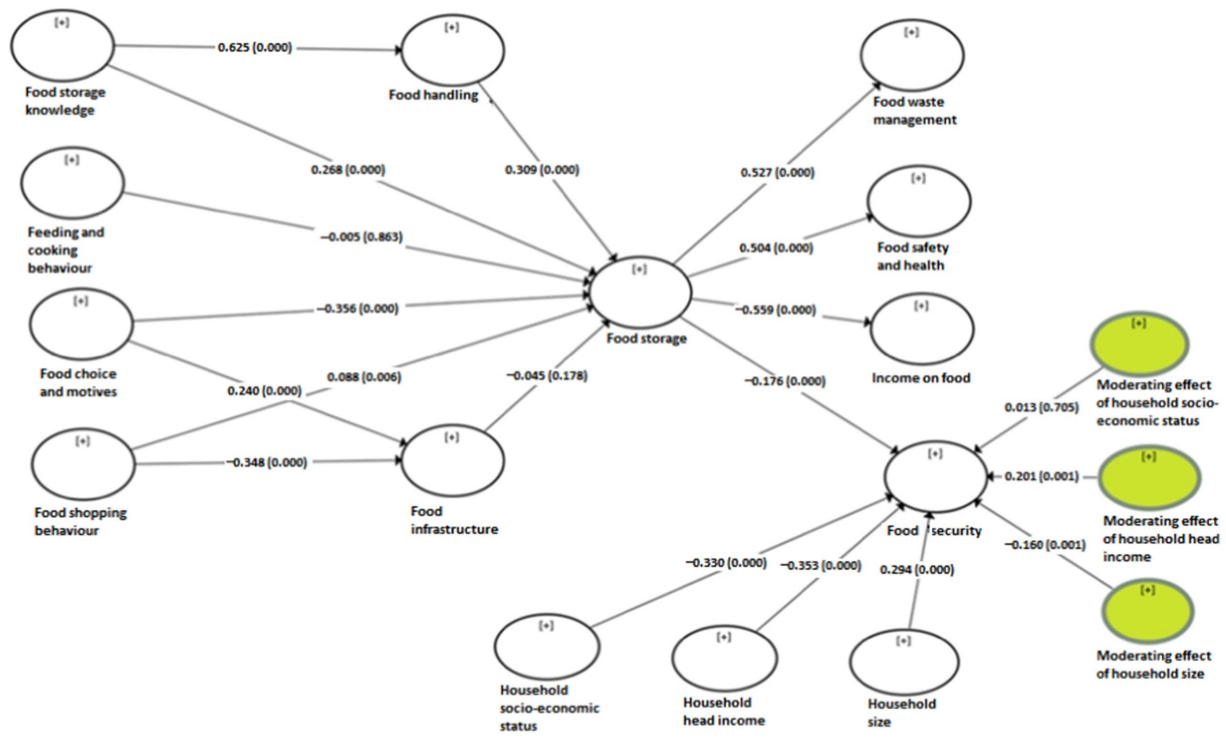


FIGURE 4
A network analysis of direct and moderating effect of household characteristics on the relationship between food storage and food security. The +/− shows the strength of the association between and among the clustering variables, and the [+] shows a positive association between variables at significance level $p \leq 0.05$.

foodstuff just before harvesting can also affect the shelf life of food, as indicated by the verbatim responses below;

> *"The period or time of storage should be considered with regards to the shelf life of the food commodity, and the use of proper storage facilities should be of importance"*. (Food safety expert, SN02)

> *"The shelf life of the food commodity, and the fertilizer and agro-chemicals used to spray the food before harvesting can affect how long it can be stored"*. (Food security expert, SN09)

Food in storage should be well protected against pests since *"stored foods can be easily infested by storage pests when they are not properly handled and stored"* (Food safety expert, SN14), especially when households do not have suitable storage facilities. Also, *"some people do not have the capital or money to purchase storage equipment like a refrigerator or deep freezer"* (Food storage expert, SN05) or they use improper food storage methods due to lack of knowledge.

> *"Inadequate knowledge in storing the various types of food affects the way food is stored at home"*. (Food security expert, SN16)

3.4. Partial least squares-structural equation modeling

3.4.1. Direct effect of household characteristics on food storage and food security

Results from the PLS-SEM showed that, the direct effect of households' socioeconomic status on food security was negative and statistically significant ($\beta = -0.330$, p value $= 0.000$, $p \leq 0.01$) (Figure 4). Income of household head also exhibited a negative and statistically significant relationship with food security ($\beta = -0.353$, p value $= 0.000$, $p \leq 0.01$). This indicates that averagely the socioeconomic status of sampled households in the study was low with majority of household heads having low income, hence this will generally not lead to achieving household food security through food storage. Household size showed a positive and statistically significant direct effect on food security ($\beta = 0.294$, p value $= 0.000$, $p \leq 0.01$). This implies that the average household size of participants in the study does not put a household at a food security risk, but could rather promote food security.

3.4.2. Moderating effect of household characteristics on food storage and food security

The PLS-SEM results also revealed that households' socioeconomic status had a positive moderating effect on the relationship between food storage and food security, although not significant ($\beta = 0.013$, p value $= 0.705$, n.s) (Figure 4). This means that improving households' socioeconomic status can increase the strength of the link between food storage and food security, and vice versa. Therefore, higher socioeconomic status of a household can help to improve food security through food storage. Income of household head also showed a significant positive moderating effect on the relationship between food storage and food security ($\beta = 0.201$, p value $= 0.001$, $p \leq 0.01$). This implies that to ensure household-level food storage lead to the attainment of food security, the income of household head needs to be improved, particularly within poor households. The findings also indicated that moderating household size had a negative and significant effect on the link between food storage and food security ($\beta = -0.160$, p value $= 0.001$, $p \leq 0.01$). Hence, large

household size will impede the achievement of household food security through food storage.

4. Discussion

The study findings indicate that food commodities such as rice, groundnut, fish, tomato, palm oil, and pepper were often stored by most households. These are some of the key food commodities used for preparing major dishes consumed by households in Ghana daily, which implies that households in the study areas usually store foodstuffs they mostly consume. Aberman et al. (2022) in their study in Ghana reported that these were some of the main food commodities that participants usually purchased for consumption. The generally low storage of fruits and vegetables by households in the study communities can be attributed to the fact that, relatively their consumption is usually low, which affected their overall storage since households infrequently consumed them. We also observed that, higher-income households were capable of storing most foods compared to lower-income households. Higher-income households had the financial resources to acquire improved storage facilities that enabled them to store most foodstuffs than what lower-income households could store. Since rich households have the ability and capacity to invest in and adopt improved agricultural technologies (Ali and Erenstein, 2017).

The study found that households mostly stored perishable foods including cassava, bread, yam, tomato, plantain, cooked food, banana and leftover food for 1 to 3 days. Food commodities have period of time they can be stored before deteriorating and are not safe to consume. The type of food, type of storage facility and storage conditions like temperature are some of the factors that affect the shelf life of food (Xue et al., 2014; Garden-Robinson, 2020). Participants for the expert interviews also acknowledged that the period of storing food at home can be influenced by fluctuations in the supply of electricity, financial capability of households and food storage practices employed by households. Bread for example when stored at room temperature has about 7 days shelf life, but when it is stored in a deep freezer, the shelf life can increase to 3 months (Boyer and Mckinney, 2018). Meat and fish can be kept for between 4 to 12 months when frozen; vegetables and fruits can also be stored for about 2 weeks or longer and still be of good quality when appropriate storage techniques are employed (Boyer and Mckinney, 2018; Garden-Robinson, 2020). The findings also revealed that most of the sampled households stored food within a period of 2 weeks, which can be ascribed to the use of inappropriate storage facilities, and lack of adequate up-to-date knowledge in storing the various foods for a longer period, since most the households do not have any training in food storage.

Furthermore, our findings revealed that, well-to-do households usually used deep freezer and refrigerator for storing perishable foods, due to their suitability in preventing food spoilage. Refrigerator and deep freezer are effective for; slowing down bacterial growth, minimizing food spoilage and preserving food quality, hence prolonging the shelf life of food commodities (Aung and Chang, 2014). During freezing, the physical state of the substance or food is changed by converting water into ice when energy is removed through cooling below freezing temperature, such as −18°C (Rahman, 2007). The results also showed that households made use of various storage methods to store their food including; using a basket, sack, bowl, polyethylene bag and in the ground. Households used polyethylene bags for storing food in this study due to its relatively cheaper price, durability and ease of use, and also because it is capable of delaying deterioration of perishable foodstuffs such as cassava for some days. However, Rujnic-Sokele and Baric (2014) noted that polyethylene bag is non-degradable, poses great danger to aquatic life and in some countries there is a levy on its use or it is banned. A study carried out to assess food storage practices of farmers by Prempeh et al. (2017) reported that cassava was stored by 27% of farmers in polyethylene bags, 8% in the ground or pit, 34% in sacks, 26% in water and 6% stored cassava under a shade. Wumbei et al. (2019) also conducted a study in Wulensi, Ghana to show that 63% of farmers stored yam in traditional barns, while 8% stored it in the ground, and 29% of farmers kept it under trees covered with grass.

In addition to the survey outcomes, the expert interviews also revealed findings regarding the impact of household-level food storage. We found from the experts that, most households are compelled to eat the same food for the period it remains in storage until it is finished, lest it goes to waste, particularly due to inappropriate storage facilities. With appropriate cost-effective storage facilities and up-to-date knowledge in food storage practices, households can store varieties of food commodities so that they can have options to choose any food they prefer to eat. Having dietary diversity or eating different food types is critical for obtaining various micro- and macro-nutrients to ensure nutrient adequacy (Sibhatu et al., 2015). All the experts who were interviewed asserted that storing food at the household-level promotes food security. This supports a study by Tesfaye and Tirivayi (2018) who reported that storing food, particularly using improved storage technologies promotes food and nutrition security, and could be an important factor in alleviating the problems of feeding the increasing global population. Darfour and Rosentrater (2016) also reiterated that in order to minimize food and nutrition insecurity in Ghana, it is critical to improve food storage practices in the country by building the capacity of households, consumers and relevant stakeholders. Although most experts acknowledged that household-level food storage helps to reduce food expenditure, some of them asserted that using facilities such as refrigerator and deep freezer to store food can be costly due to high electricity bills. A study by Sakah et al. (2019) showed that households in Ghana use refrigerators and deep freezers for a whole 24 h period, with spikes around 8:00 pm and 2:00 pm because of dinner and lunch times, respectively. Their study revealed that households' use of these storage facilities contributes to 15% of peak electricity load, which makes it the third priority target for minimizing high electricity consumption in Ghana. It is therefore ideal for households to always buy and use energy efficient food storage facilities in order to minimize electricity consumption and save some money.

The expert interviews also indicated that storing food within households helps to reduce food wastage, especially when households have suitable storage facilities to store food. On the other hand, when households do not store food or do not take full responsibility of ensuring that food is properly handled and stored, there could be significant food waste generation. Food wastage within households is mostly caused by unplanned or unintended outcome of entangled daily routines revolving around food, including improper handling and storing of food (Dobernig and Schanes, 2019). The food waste generation rate of sampled households in Accra was reported to be averagely 0.12 kg/person/day (Attipoe and Li, 2016). Rutten and Verma (2014) however noted that, reducing food waste by 50% in Ghana by the year 2025 will help to improve food production and enhance food security in the country. The qualitative results revealed that, food storage at the household-level enhances food-based nutrition and safety, because it encourages households to plan their diets and also cook food at home. Therefore, households are able to obtain optimum nutrients from food and are not exposed to any health problems by eating

food cooked under unhygienic conditions outside home. This is in support of a research by Lin and Guthrie (2012), which indicated that due to dietary guidance or planning, food cooked at home were richer in nutrients than food cooked away from home. Food cooked at home was higher in nutrients such as calcium and significantly lower in fat content, while food cooked away from home was higher in cholesterol, sodium and saturated fat, and lower in dietary fiber. Improper food hygiene and food safety practices by street-cooked food handlers have also been reported to be a major cause of food-borne illness among consumers (Sani and Siow, 2014; Ayaz et al., 2018). It is therefore important to promote food storage within households in order to enhance effective food safety practices and safeguard the health and wellbeing of consumers.

Additionally, the results showed household head's income and socioeconomic status of household to have a positive effect on the link between food storage and food security. Increasing the income of household head and improving household's socioeconomic status therefore enhances the achievement of household food security through food storage, and vice versa. Income is a key determinant that affects food storage and food security of households. Poor households struggle to acquire sufficient nutritious food and adequate resources such as proper food storage structures (De Marco and Thorburn, 2009). They become vulnerable to limited availability and access to food, which subsequently affect its re-distribution to household members (Drammeh et al., 2019). However, rich households are able to buy and consume adequate nutritious food, and acquire suitable food storage facilities. Various studies have reported that increase in household income lead to improvement in food security. For example, studies done in Nigeria and Ghana revealed that household food security improved by 1.65 times by increasing households' monthly income (Babatunde and Qaim, 2010; Owusu et al., 2011). Antwi and Lyford (2021) also reported that a unit increase in the income of households lead to increasing the probability of achieving high household food security status by 5.3%. Also, household size had a negative effect on the relationship between food storage and food security. This implies that large household size has the likelihood of worsening food security, regardless of the food storage techniques used. When there are more members in a household, demand for food increases, and can outweigh the household's food supply, especially for poor households (Antwi and Lyford, 2021). The larger the size of a household, the likelihood of available food to each household member becoming lesser, which subsequently affect the household's food and nutrition security status (Olayemi, 2012). According to a study by Antwi and Lyford (2021), a unit increase in household size reduced the likelihood of household to attain high food security status by 3.4%.

5. Conclusion

To increase food security in urban households, it is crucial to understand consumer food storage practices at the household-level. The study found that rich households are able to store more food than poor households, since they have financial capability to acquire appropriate food storage facilities, while poor households mainly resort to traditional food storage methods and facilities. The findings indicated that most households do not have any training in food storage, contributing to the short period they stored food. The study also revealed that households must eat the same stored food until it is finished to avoid wasting it, especially due to poor storage facilities. Income of household head and socioeconomic status of households was found to positively affect food security through food storage.

Policies that promote the use of cost-effective storage facilities, enhance up-to-date food storage expertise, and facilitate the provision of social interventions to particularly poor households, will enable consumers to store varieties of food commodities for longer periods at home, to be able to always access available food and consume variety of foods, in order to promote food and nutrition security. Future research and assistance geared towards providing training interventions and upgrading indigenous food storage methods and facilities are necessary for building households' capacity to adopt proper food storage practices.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of the Institute of Urban Environment, Chinese Academy of Sciences. The participants provided their written informed consent to participate in this study.

Author contributions

EA collected the data, performed the analysis, and wrote the manuscript's draft. BO participated in data analysis and commented on the first draft of the manuscript. JA contributed to the writing and revising the manuscript. MZ, Y-GZ, and FA supervised the overall project and revised the manuscript. All authors contributed to the article and approved the submitted version.

Funding

Financial support for the study was provided by University of Chinese Academy of Sciences (UCAS) and Institute of Urban Environment, Chinese Academy of Sciences.

Acknowledgments

The authors are grateful to Franz Gatzweiler for his guidance during the study. Our appreciation goes to Zhong Chuyue for providing administrative assistance, and Felix Bonsu, Andrews Larbi, Armand Anderson for the help during data collection. We would like to also thank all the participants who took part in the study.

Conflict of interest

BO was employed by Asinyo Agri-Commerce Ltd. JA was employed by Research Desk Consulting Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1194321/full#supplementary-material

References

Aberman, N. L., Gelli, A., Agandin, J., Kufoalor, D., and Donovan, J. (2022). Putting consumers first in food systems analysis: identifying interventions to improve diets in rural Ghana. *Food Secur.* 14, 1359–1375. doi: 10.1007/s12571-022-01277-w

Afriyie, E., Gatzweiler, F., Zurek, M., Asem, F. E., Ahiakpa, J. K., Okpattah, B., et al. (2022). Determinants of household-level food storage practices and outcomes on food safety and security in Accra, Ghana. *Foods* 11:3266. doi: 10.3390/foods11203266

Ali, A., and Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Clim. Risk Manag.* 16, 183–194. doi: 10.1016/j.crm.2016.12.001

AMA (2019). *Medium term development plan 2018–2021*. Accra: Accra Metropolitan Assembly.

Antwi, K. D., and Lyford, C. (2021). Socioeconomic determinants of rural households' food security status in northern Ghana. *J. Agric. Food Sci.* 19, 86–94. doi: 10.4314/jafs.v19i2.9

Armah, E., Kissi, A. E., and Fiankor, D. D.-D. (2019). The impact of the national food buffer stock company on price transmission in Ghana. *African J. Agric.Resour. Econ.* 14, 169–183. doi: 10.22004/ag.econ.301040

Attipoe, S. G., and Li, Z. (2016). Assessing the impact of household food waste on the Ghanaian economy from selected communities in Accra metropolitan area. *Res. J. Agric.* 3, 1–12.

Aulakh, J., Regmi, A., Fulton, J., and Alexander, C. (2013). *Estimating post-harvest food losses: developing a consistent global estimation framework*. Washington DC: Agriculture and Applied Economics Association.

Aung, M. M., and Chang, Y. S. (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control* 40, 198–207. doi: 10.1016/j.foodcont.2013.11.016

AWMA (2019). *Medium term development plan 2018–2021*. Accra: Ayawaso West Municipal Assembly.

Ayaz, W. O., Priyadarshini, A., and Jaiswal, A. K. (2018). Food safety knowledge and practices among Saudi mothers. *Foods* 7:193. doi: 10.3390/foods7120193

Babatunde, R. O., and Qaim, M. (2010). Impact of off-farm income on food security and nutrition in Nigeria. *Food Policy* 35, 303–311. doi: 10.1016/j.foodpol.2010.01.006

Boatemaa, S., Badasu, D. M., and Aikins, D.-G. A. (2018). Food beliefs and practices in urban poor communities in Accra: implications for health interventions. *BMC Public Health* 18, 1–12. doi: 10.1186/s12889-018-5336-6

Boyer, R., and Mckinney, J. (2018). Food storage guidelines for consumers. *Virginia Coop. Ext.* 348–960, 1–12.

Cochran, W. G. (1963). *Sampling technique*. New York: Wiley.

Darfour, B., and Rosentrater, K. A. (2016). Agriculture and food security in Ghana. *Agric. Biosyst. Eng.* 1–11. doi: 10.13031/aim.20162460507

De Marco, M., and Thorburn, S. (2009). The relationship between income and food insecurity among Oregon residents: does social support matter? *Public Health Nutr.* 12, 2104–2112. doi: 10.1017/S1368980009990243

Dean, J. (2006). *Subsistence stress and food storage at Kiet Siel, northeastern Arizona*. Salt Lake City, UT: University of Utah Press.

Dobernig, K., and Schanes, K. (2019). Domestic spaces and beyond: consumer food waste in the context of shopping and storing routines. *Int. J. Consum. Stud.* 43, 480–489. doi: 10.1111/ijcs.12527

Drammeh, W., Hamid, N. A., and Rohana, A. J. (2019). Determinants of household food insecurity and its association with child malnutrition in sub-Saharan Africa: a review of the literature. *Curr. Res. Nutr. Food Sci.* 7, 610–623. doi: 10.12944/CRNFSJ.7.3.02

FAO (2011). *Global food losses and food waste: extent, causes, and prevention*. Rome: Food and Agriculture Organization.

FAO (2016). *The state of food and agriculture: climate change, agriculture and food security*. Rome: Food and Agriculture Organization. (Accessed January, 2023).

FAO, IFAD, UNICEF, WFP, and WHO (2022). *The state of food security and nutrition in the world: Repurposing food and agricultural policies to make healthy diets more affordable*. Rome: Food and Agriculture Organization. (Accessed January, 2023).

Garden-Robinson, J. (2020). Food storage guide. *Packaging* 579, 1–16. (Accessed December, 2022).

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. A. (2019). *Multivariate data analysis*. Boston, MA: Cengage.

Hair, J. F., Hult, G. T. M., Ringle, C. M., and Sarstedt, M. (2017). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Thousand Oaks, CA: Sage.

Kabudula, C. W., Houle, B., Collinson, M. A., Kahn, K., Tollman, S., and Clark, S. (2017). Assessing changes in household socioeconomic status in rural South Africa, 2001–2013: a distributional analysis using household asset indicators. *Soc. Indic. Res.* 133, 1047–1073. doi: 10.1007/s11205-016-1397-z

Kumar, D., and Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods* 6, 1–22. doi: 10.3390/foods6010008

Lamers, C. R., De Roos, N. M., Koppelman, L. J. M., Hopman, M. T. E., and Witteman, B. J. M. (2021). Patient experiences with the role of physical activity in inflammatory bowel disease: results from a survey and interviews. *BMC Gastroenterol.* 21, 172–179. doi: 10.1186/s12876-021-01739-z

Lin, B.-H., and Guthrie, J. (2012). Nutritional quality of food prepared at home and away from home, 1977–2008. *USDA Econ. Inf. Bull.* 105, 1–18. doi: 10.22004/ag.econ.142361

Luo, Y., Huang, D., Miao, H., Wu, L., and Zhu, J. (2021). Impact of advanced storage facilities on households' maize storage losses and food security in China. *Environ. Dev. Sustain.* 24, 221–237. doi: 10.1007/s10668-021-01406-z

Majumder, S., Bala, B. K., Arshad, F. M., Haque, M. A., and Hossain, M. A. (2016). Food security through increasing technical efficiency and reducing postharvest losses of rice production systems in Bangladesh. *Food Secur.* 8, 361–374. doi: 10.1007/s12571-016-0558-x

Makalle, A. M. (2012). Post harvest storage as a rural household food security strategy in Tanzania. *ARPN J. Sci. Technol.* 2, 814–821.

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., et al, (2010). *Food security and climate change: Challenges to 2050 and beyond*. (Accessed December, 2022).

Nti, C. A. (2008). Household dietary practices and family nutritional status in rural Ghana. *Nutr. Res. Pract.* 2, 35–40. doi: 10.4162/nrp.2008.2.1.35

Nyo, A. K. (2016). Inadequate infrastructure: the bane behind food loss and food security in the Savannah zone of Ghana. *J. Dev. Sustain. Agric.* 11, 43–47. doi: 10.11178/jdsa.11.43

Olayemi, A. O. (2012). Effects of family size on household food security in Osun state Nigeria. *Asian J. Agric. Rural Dev.* 2, 136–141. doi: 10.22004/ag.econ.197951

Ovuga, E., Boardman, J., and Wassermann, D. (2005). Prevalence of suicide ideation in two districts of Uganda. *Arch. Suicide Res.* 9, 321–332. doi: 10.1080/13811110500182018

Owusu, V., Abdulai, A., and Abdul-Rahman, S. (2011). Non-farm work and food security among farm households in northern Ghana. *Food Policy* 36, 108–118. doi: 10.1016/j.foodpol.2010.09.002

Owusu, P. A., Odai, S. N., Annor, F. O., and Adjei, K. A. (2013). Reservoir storage for managing floods in urban areas: a case study of Dzorwulu basin in Accra. *Hydrol. Process.* 27, 1615–1625. doi: 10.1002/hyp.9286

Prempeh, R., Manu-Aduening, J. A., Asante, B. O., Asante, I. K., Offei, S. K., and Danquah, E. Y. (2017). Farmers' knowledge and perception of postharvest physiological deterioration in cassava storage roots in Ghana. *Agric. Food Secur.* 6, 1–7. doi: 10.1186/s40066-017-0103-y

Rahman, M. S. (2007). *Handbook of food preservation*. Boca Raton: CRC Press

Ringle, C. M., Wende, S., and Becker, J. M. (2015). SmartPLS 3. SmartPLS GmbH, Boenningstedt. *J. Serv. Sci. Manag.* 7, 411–418. doi: 10.4236/me.2016.74045

Rujnic-Sokele, M., and Baric, G. (2014). Life cycle of polyethylene bag. *ANNAL Fac. Eng. Hunedoara - Int. J. Eng.* 12, 41–48.

Rutstein, S. O., and Johnson, K. (2004). *The DHS wealth index: DHS comparative reports*. Calverton, AR: ORC Macro. (Accessed October, 2022).

Rutten, M., and Verma, M. (2014). *The impacts of reducing food loss in Ghana: a scenario study using the global economic simulation model MAGNET*. Wageningen: LEI Wageningen UR. (Accessed March, 2023).

Sakah, M., De La Rue, D., Can, S., Diawuo, F. A., Sedzro, M. D., and Kuhn, C. (2019). A study of appliance ownership and electricity consumption determinants in urban Ghanaian households. *Sustain. Cities Soc.* 44, 559–581. doi: 10.1016/j.scs.2018.10.019

Sani, N. A., and Siow, O. N. (2014). Knowledge, attitudes and practices of food handlers on food safety in food service operations at the Universiti Kebangsaan Malaysia. *Food Control* 37, 210–217. doi: 10.1016/j.foodcont.2013.09.036

Saunders, M. N. K., Lewis, P., and Thornhill, A. (2019). *Research methods for business students*. New York: Pearson.

Sheahan, M., and Barrett, C. B. (2017). Review: food loss and waste in sub-Saharan Africa. *Food Policy* 70, 1–12. doi: 10.1016/j.foodpol.2017.03.012

Sibhatu, K. T., Krishna, V. V., and Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proc. Natl. Acad. Sci.* 112, 10657–10662. doi: 10.1073/pnas.1510982112

Spielmann, K. A., and Aggarwal, R. M. (2017). *Household- vs. national-scale food storage: Perspectives on food security from archaeology and contemporary India*. Cambridge: Cambridge University Press

Subramani, J., Gupta, S. N., and Prabavathy, G. (2014). Circular systematic sampling in the presence of linear trend. *Am. J. Math. Manag. Sci.* 33, 1–19. doi: 10.1080/01966324.2013.869188

Sudakar, K. (1978). A note on circular systematic sampling. *Sankhya C.* 40, 72–73.

Tesfaye, W., and Tirivayi, N. (2018). The impacts of postharvest storage innovations on food security and welfare in Ethiopia. *Food Policy* 75, 52–67. doi: 10.1016/j.foodpol.2018.01.004

United Nations (2015). *Transforming our world: the 2030 agenda for sustainable development*. New York: United Nations.

Vyas, S., and Kumaranayake, L. (2006). Constructing socioeconomic status indices: how to use principal components analysis. *Health Policy Plan.* 21, 459–468. doi: 10.1093/heapol/czl029

Webber, C. B., Sobal, J., and Dollahite, J. S. (2010). Shopping for fruits and vegetables: food and retail qualities of importance to low-income households at the grocery store. *Appetite* 54, 297–303. doi: 10.1016/j.appet.2009.11.015

Wumbei, A., Bawa, J. K. A., Akudugu, M. A., and Spanoghe, P. (2019). Absence of effects of herbicides use on yam rots: a case study in Wulensi. *Ghana. Agric.* 9, 1–15. doi: 10.3390/agriculture9050095

Xue, M., Zhang, J., and Tang, W. (2014). Optimal temperature control for quality of perishable foods. *ISA Trans.* 53, 542–546. doi: 10.1016/j.isatra.2013.12.011

frontiers | Frontiers in Nutrition

TYPE Original Research
PUBLISHED 09 October 2023
DOI 10.3389/fnut.2023.1249310

OPEN ACCESS

EDITED BY
Luca Secondi,
University of Tuscia, Italy

REVIEWED BY
Meleksen Akin,
Iğdır Üniversitesi, Türkiye
Nino Adamashvili,
University of Foggia, Italy

*CORRESPONDENCE
Xavier Gabarrell Durany
✉ Xavier.Gabarrell@uab.cat

RECEIVED 28 June 2023
ACCEPTED 08 September 2023
PUBLISHED 09 October 2023

CITATION
Tonini P, Odina PM and Durany XG (2023) Predicting food waste in households with children: socio-economic and food-related behavior factors.
Front. Nutr. 10:1249310.
doi: 10.3389/fnut.2023.1249310

Predicting food waste in households with children: socio-economic and food-related behavior factors

Pietro Tonini[1], Pere Muñoz Odina[1,2] and Xavier Gabarrell Durany[1,2]*

[1]Sostenipra Research Group (2017 SGR 1683), Unitat de excelencia Maria de Maetzu MDM CEX2019-000940-M, Institut de Ciència i Tecnologia Ambientals (ICTA-UAB), Universitat Autònoma de Barcelona, Barcelona, Spain, [2]Department of Chemical, Biological and Environmental Engineering, School of Engineering, Universitat Autònoma de Barcelona (UAB), Barcelona, Spain

Introduction: The consumption phase accounts for approximately half of the food waste generated within the food system. Numerous studies have identified families with children as the primary contributors to food waste. The aims of this paper is to enhance the comprehension of food waste behaviors in households with children by characterizing it and studying how socioeconomic characteristics and food-related behaviors can predict it.

Methods: A survey was conducted among 806 families with children, categorized by the child's age and family structure. The study utilized descriptive statistics to summarize the food waste behaviors and binary regression to evaluate the predictive abilities of 12 variable related to the socio-economic characteristic, purchase, and preparation behaviors and diet quality factors.

Results: Perishable food items, such as fruits, vegetables, cereal-based product, and dairy products, were the primary items wasted in households with children. Two patterns of food waste were identified: inadequate food management leading to small amounts of waste in families with young and middle-aged children, and over-purchasing perishable items leading to waste in other households with children. Household type and purchasing habits were significant predictors, while the purchaser's age and buying channel showed lower predictive capacity.

Discussion: Policies to reduce food waste should prioritize raising awareness among children, promoting good practices at the household level, and creating favorable conditions during purchases. Strategies include enlisting children's participation in meal planning and food preparation as well as limiting the promotion of ultra-processed products and incentivizing the sale of bulk products at supermarket.

KEYWORDS

waste, household, parametric model, food related behavior, socio-economic

Highlights

- Perishable foods and dairy product are the most important contributors of food waste;
- Two distinct patterns of food waste identified in households with children;
- Household type and shopping list use as key factors in predicting food waste generation;
- Policies should focus on young families with small and medium-sized children;

1. Introduction

The exponential growth of the global population by 2050 is expected to drive a 50% increase in demand for food products, thereby intensifying resource consumption and greenhouse gas emissions associated with the food system (1, 2). Therefore, it is crucial to increase resource use efficiency to prevent food insecurity and reduce the food system's environmental impact in the foreseeable future. Among the strategies, the reduction of food waste has been identified as a practical measure to improve resource use efficiency and increase food availability while reducing pressure on natural resources (3). In particular, the consumption stage of the food value chain has received increasing attention, as it generates the highest contribution in terms of quantities and environmental impacts (4, 5). Consequently, reducing domestic food waste has become a crucial global target under Sustainable Development Goal 12.3 (6), particularly in high-income regions such as the United States of America and Europe, where the problem is particularly acute (7).

Domestic food waste comprises spoilage, products thrown away without use, and leftover meals (8). Food spoilage constitutes the bulk of food waste and is easy to estimate since the entire product is discarded; meanwhile, leftovers are the least quantifiable form of food waste among consumers (9). The composition of household waste primarily comprises items that are associated with high levels of consumption and low economic value (10). Specifically, perishable items such as fruits, vegetables, and baked goods are responsible for generating more than half of the food waste produced by households, whereas animal-based products such as meat, fish, and eggs contribute to a negligible proportion of the waste stream [(11, 12)].

Many authors revealed that households with children tend to generate more food waste than households without children (13–17). In particular, research has demonstrated that the quantity of food waste increases as the number of children in the household increases, and the drivers of food waste may vary based on the child's age (18). Households with young children and adolescents commonly over-purchase and over-prepare food due to their changing food preferences (15), picky eating behaviors (19), and parental intention to provide nutritious and suitable meals for their children (20). In contrast, in households with older children, the primary reason for food waste is the difficulty in predicting their eating habits, such as their presence during mealtimes (21).

Despite this evidence, there still needs to be more representative, reliable primary data on food waste generation at the household with children level (22). In particular, more empirical studies are required to unveil the drivers of food waste and existing framework conditions leading to domestic food waste in these household (23). This segmentation is required to pave the way to curb domestic food waste and point out directions to design policies and interventions specifically for this type of household (24). Indeed, interventions targeting specific characteristics of homogeneous groups of consumers have been proven to be more effective than "one-size-fits-all" ones (25).

The aim of this paper is to enhance the comprehension of food waste behaviors in households with children by characterizing it and studying how socioeconomic characteristics and food-related behaviors can predict it. A questionnaire was administered to 806 families with children categorized by life-cycle stages based on the child's age and family composition. Unlike previous questionnaire-based studies (13, 15, 26), the objective of this research was not to measure the amount of food waste produced at home but rather to determine which households with children were more likely to produce food waste at home. A binary regression model was used to assess the predicting capacity of the socioeconomic factors and food-related behaviors in the household with children. The variable included in the model were identified in studies with the same focus but with different sample designs (13, 15, 20, 27, 28). The results were used to identify interventions and policy implications that can target specific aspects of drivers to influence food waste behaviors.

2. Methods

2.1. Study design

The current investigation is part of an exploratory analysis that investigates household expenses, food waste behavior, and residue generation in the population of Cerdanyola del Valles, a municipality situated in the Vallès Occidental region of Catalunya, Spain, with an estimated population of 60,000 people (29). Three online surveys with different designs and objectives were conducted during the study, involving 1,854 households in the municipality. Our study administered the questionnaire to 806 households, with 23% responding to at least one of the two preceding surveys. The questionnaire collected data on food waste behaviors, socioeconomic characteristics, food purchase and preparation behaviors, and diet quality. A professional market research organization was contracted for the recruitment and data collection of the survey. The sample was selected based on the percentage of households with young children (<5 years old) (27%), households with middle age children (5–17 years old)(36%), households with mayor age children (18–30 years old) (25%) and single-parent households (mother or father, children<30 years old)(12%) present in the Spanish population with representative quotas for gender and age (Sampling error: 3.8%) (30). For further details on the socio-demographic characteristic lifecycle stage see also Supplementary Table S1 in the Supplementary Material.

Only the person responsible for at least half of the shopping trips and preparing meals at home were involved in the study. The survey encompassed a total of 14 questions that were administered in both the Catalan and Spanish languages. The initial segment of the questionnaire centered on food waste behaviors, while the subsequent segment inquired into socioeconomic attributes and food-related behaviors. The survey was conducted online and presential between October 2022 with CAWI methodology, for a total of 15 min for each interview. The in-person interview was conducted in supermarkets, municipal markets, and grocery shops to obtain a heterogeneous sample. Before administering the questionnaire, a pre-test was carried out with 25 families with children to check the comprehensibility of the questions and answers and to calculate the average interview time.

2.2. Ethical statement

The Research Ethics Committee of the Autonoma University of Barcelona (Barcelona, Spain) approved this study protocol (code number 5539). All procedures were in accordance with the ethical standards established by the Declaration of Helsinki (31). All

respondents were informed about the objectives and procedures of the study and provided informed consent before filling out the survey, which was compliant with the General Data Protection Regulation (GDPR). The processing of personal data complies with current Spanish and European legal regulations on data protection.

2.3. Food waste behavior

Respondents were asked whether they had discarded edible food in the past seven days to investigate food waste behavior. Food waste was defined as any edible food, liquid or solid, not intended for human consumption, including disposal in the garbage bin, use as pet food, or composting organic matter, as defined by the High-Level Panel of Experts on Food Security and Nutrition (32). Therefore, the study excluded the inedible portion of the products to identify only the household that discarded food which could have been consumed. A seven-day recall period for the food waste question was intended to simplify responses and reduce potential respondent bias (33).

In order to characterize food waste, the person responsible for purchasing food was asked to list the products or dishes that had been discarded during the week. The questionnaire's administrator subsequently categorized the product or dish into food product categories, such as fresh vegetables, fresh fruit, fresh bread, cereal products, milk and dairy products, animal-based products (e.g., fish, meat, and eggs), frozen or canned products, and ready-to-eat or ready-to-made products. If a dish was composed of multiple products, only the category of the main ingredient was recorded in the questionnaire. Additionally, the disposal reason of the product category was recorded to classify them in quantity-related problems at purchase, quantity-related problems at home and durability. The quantity-related problems are related to the purchase of a too large packaging size or wrong product as well as the preparation of too much food at home. Meanwhile, durability is associated to the fact that a product becomes spoilt, unsavory or past the best-before or use-by date.

2.4. Socio-economic characteristics and food-related behaviors

The socioeconomic characteristics and the food-related behavior are listed in Tables 1, 2. The socio-demographic variables considered were the type of household with children, the age and working status of the responsible for the purchase, the size of the household, and monthly household income. In particular, the responsible for purchase was asked to provide numerical values for the age, number of household members, and monthly household income. Meanwhile, a multiple-choice question was applied to collect the data related to the type of household and the working status (see Table 3).

Regarding food purchase and preparation behavior, the questionnaire includes questions related to the main purchasing channel, the frequency and organization of food purchases, and the frequency of food preparation. The main purchasing channel was identified among supermarkets, grocery shops, and alternative markets; meanwhile, the frequency of purchase was assessed with a multiple-choice question (answer format: "I buy the majority of food in a single purchase+supplement shopping" and "I buy the majority of my food at different times throughout the week"). The organization of the purchase was assessed with yes or no questions related to the realization of a shopping list. Furthermore, the preparation behavior was identified based on the number of times the household prepares food at home during a week (answer format: four-point scale ranging from one time per week to daily). Finally, the diet quality at home was assessed with either the frequency of fresh food consumption (Seven-point scale ranging from once a fortnight to never to daily) and the type of diet through a multiple-choice question (answer format:" Mainly animal-based, animal product consumption >4 days per week" and "Mainly plant-based (animal product consumption <4 days per week").

2.5. Data analysis

The statistical analysis for this study was performed using the latest available version of R software (R-4.3.0). In particular, the analysis was divided into two subsequent steps such as (1) the descriptive statistics to summarize the data and (2) the binary logistic regression to assess the variable's capacity to predict food waste generation.

First, the socioeconomic and food-related behaviors were analyzed and summarized. Then the waste generated during the last seven days, the number of wasted products, product group, and the disposal reason were examined regarding the household life cycle stage. The analysis at household level has a specific interest regarding potential policy and prevention measures. Then, the relationship between food waste behavior and the socio-demographic variable and food behavior was assessed though a binary logistic regression. A dummy variable called "Declared food waste" was used as a dependent variable in the binary logistic regression, and the 14 variables were used as explanatory variables. After the first round of analysis, the explanatory variables that were not significant were excluded, and a second regression was performed with the remaining variables. A value of p of less than 0.05 was considered statistically significant. Multicollinearity was checked using Pearson correlation to determine the correlation between independent variables. The outliers have been examined and removed from the numerical variables such as age and household monthly purchase. The results were presented with an interval corresponding to a confidence level of 95%. ANOVA analysis was performed to assess the relative importance of the variable on predicting food waste generation. Furthermore, the accuracy test was conducted to evaluate the predictive performance of the logistic regression model. Specifically, the proportion of correct predictions over 500 observations obtained from the same model was assessed. As a fundamental diagnostic measure for logistic regression, the accuracy test provides valuable insights into the model's predictive accuracy.

3. Results

Table 1 provides an overview of the demographic composition of the sample analyzed in this study. The majority of responsible individuals for food purchases were female (70%), under the age of 54 (79%), and employed part-time or full-time (78%). Approximately half of the families with children included in this study comprised less than four members (Mean: 3.57). Regarding household income, 16% reported a monthly income below 1.500 Euros, while 32% reported a monthly income greater than 3.500 Euros. Given that Catalonia's

10.3389/fnut.2023.1249310

TABLE 1 Socio-demographic characteristics of the sample analyzed in Cerdanyola del Valles.

Socio-economic factors	Variable	Missing value	No. Observation	Frequency
Gender	Male	2	242	30%
	Female		562	70%
Age	<54 years old	0	636	79%
	≥54 years old		170	21%
Work status	Employed	0	630	78%
	Not employed		176	22%
Household size	<4 people	0	380	47%
	≥4 people		423	53%
Household income	Low income	94	116	16%
	Medium low-income		194	27%
	Medium high-income		172	24%
	High-income		230	32%
Household food expenditure	<500 Euro/month	132	410	61%
	>500 Euro/month		264	39%

average net household income is 3,000 Euros per month (29), families reporting a *monthly income* below 1,500 Euros were defined as "low-income households.," between 1.500 Euros and 2.000 Euros were defined as "medium low-income household," between 2.500 Euros and 3.500 Euros were defined as "medium high-income" and higher than 3.500 Euros "high-income household." Among the families with children in the study, 61% reported spending less than 500 Euros per month on food and non-alcoholic beverages, however several outliers were identified (mean: 537 Euros/month). This value is higher than the regional statistics reported for Catalonia, which indicates an average monthly expenditure of 450 Euros on food and non-alcoholic beverages in families with children (34). The difference in reported expenditures may be attributed to the difficulty responsible individuals face in accurately estimating the amount spent on food and beverages each month. This difficulty is supported by the fact that approximately 15% of families could not respond to the expenditure question and the presence of several outliers in the analysis.

Table 2 provides an overview of the food-related behaviors reported by families with children. Consistent with regional food consumption trends, half of the households purchase groceries from supermarkets/hypermarkets (35). Two out of three families make a single shopping trip and supplement it with smaller purchases throughout the week, while one out of three families only shop at one location. Moreover, 70% of families reported making a grocery list based on what is needed at home before heading to the store. Regarding food consumption behavior, 66% of families reported consuming fresh products at home daily, while almost all families consume animal products at home more than four days a week.

3.1. Food waste generation in the household with children

During the seven days analyzed through a questionnaire, 63% of households with children reported disposing of less than two food items. Families with young (3.2) and middle-aged (2.4) children had the highest average number of discarded products, while single-parent families (1.8) and families with adult children (1.5) reported the lowest values. The food items most frequently discarded belonged to the category of vegetables (80%), followed by fruit (78%) and cereal-based product (63%). Dairy products also represented a frequently discarded product group, with 25% of families reporting throwing them away particularly, the household with young reported the highest percentage of dairy products wasted during the analysis (Figure 1). Meanwhile, animal-derived products such as meat, fish, and eggs were the least frequently discarded, along with ready-to-prepare/eat products.

Regarding the reasons for disposal, two out of three families reported throwing away most of their food items without having used them. The vast majority of the food were wasted due to the durability of the product (76%), while only a tiny portion of the products were discarded due to quantity problems related at purchase (10%) or at home (14%). In Figure 2, it can be observed that families with young and middle-aged children reported the highest levels of food waste due to quantity-related issues. In these families, quantity problems were mainly related to preparing too much food, and to a lesser extent, to over-purchasing. Conversely, most of the families with adult children and single-parent households wasted products due to durability. Furthermore, the causes of waste due to quantity were primarily related to over-purchasing, which was often attributed to purchasing products in excessively large packaging sizes.

3.2. Regression results

The last data analysis step was estimating the binary regression models to investigate the drivers generating domestic food waste in households with children. The regression model included six socioeconomic factors such as the sex of the responsible for purchase (reference value: male), age of the responsible for purchase (from smallest to largest, numerical value), working status of the responsible for purchase (reference value: employed), type of household

TABLE 2 Food-related behaviors of the household with children analyzed in Cerdanyola del Valles.

Food-related behavior factors	Variable	No. Observation	Frequency
Market channel	Supermarket	418	52%
	Other: grocery store, municipal market, alternative market	388	48%
How do you organize your food shopping?	I buy the majority of food in a single purchase+supplement shopping	574	71%
	I buy the majority of my food at different times throughout the week	232	29%
Do you prepare a shopping list before purchasing?	Yes	556	69%
	No	250	31%
How do you organize the food preparation at home?	I cook every day	126	16%
	I do not cook every day	680	84%
How do you define your diet?	Mainly animal-based(animal product consumption >4 days per week)	774	96%
	Mainly plant-based (animal product consumption <4 days per week)	31	4%
Frequency of fresh food consumption at home	Daily	532	66%
	Not daily	274	34%

(reference: household with young children), household size (from smallest to largest, numerical value), annual household income (reference value: <2.500 Euro per month) and household expenditure in food (from smallest to largest, numerical value). In addition, the food-related behavior included six factors in the regression model as the primary purchase channel (reference value: supermarket/hypermarket), frequency of purchase (reference value: one general purchase per week + complimentary shopping), elaboration of a shopping list (reference value: yes), frequency of food preparation (reference: daily), the type of diet (reference value: mainly animal-based(animal product consumption >4 days per week) and the frequency of fresh product consumption (reference value: daily).

The logistic regression model successfully identified four predictors of food waste generation in households with children. Table 3 illustrates each factor's variables, degree of significance, odds ratio at the 95% confidence level, and the results of the ANOVA analysis. After the first round of the binary regression model, four factors with statistically significant parameters were retained and inputted in the final regression model. Table 2 illustrates each factor's variables, degree of significance, odds ratio at the 95% confidence level, and the results of the ANOVA analysis. No factors were excluded due to multicollinearity during the analysis. The outlier analysis excluded 20% of the data concerning monthly household expenditure, while no outliers were identified for the age of the household head. For further details on the results of the first regression model see Supplementary Table S2 in the Supplementary Material.

Among the socioeconomic variables examined, the age of the household head and family type were significant predictors of food waste generation. The analysis revealed a negative relationship between the age of the household head and the likelihood of food waste generation, indicating that older household heads were associated with a lower probability of generating food waste (odds ratio = 1.04, $p < 0.01$). In terms of family type, households with adult children (odds ratio = 2.27, $p < 0.05$) and single-parent families (odds ratio = 2.8, $p < 0.001$) were found to have a lower probability of wasting food compared to households with small and medium-sized children. Regarding food-related behaviors, households that reported procuring their food from grocery stores and municipal markets had a lower probability of generating food waste than those who obtained their food from the supermarket/hypermarket channel (odds ratio = 1.54, $p < 0.05$). Moreover, a lower probability of food waste was associated with creating a shopping list before grocery shopping (odds ratio = 1.82, $p < 0.05$).

The ANOVA analysis highlighted that the household type (LR Chisq = 20.7) and the realization of the shopping list before purchase (LR Chisq = 7.6) are the factors with the higher impact on the variation in the prediction of food waste generation. On the other hand, the age responsible for the purchase (LR Chisq = 6.6) and the purchase channel for groceries (LR Chisq = 6.1) have a lower impact on the prediction.

4. Discussion

4.1. Food waste characterization in the household with children

The data set showed that 31% of the households did not record food waste during the previous seven days. Related information from food waste studies realized in Spain, Italy, and Denmark suggest that between 15 and 40% of respondents to questionnaires stated not wasting any edible food within a regular week or during the previous week (27, 28, 35). As self-reported food waste is prone to social desirability and memory bias (33), the request to declare whether the household wastes some edible product instead of quantifying we attempted to minimize this bias. Indeed, several studies found self-reported food waste highly subjected to underreporting (13, 36, 37), especially in households with multiple members (38). Despite our efforts, the findings of our study are influenced by subjective perceptions of edibility, particularly when determining whether certain parts of a food item, such as vegetable peels, are edible or not. This makes it challenging to categorize food products as either edible or inedible in advance. However, unlike other studies that rely on questionnaires to measure household food waste, we aimed to gain a more nuanced understanding of households with children prone to generating food waste.

TABLE 3 Socio-economic and food-related behaviors identifies as predictors for food waste generation in the household with children.

Variable	Odd ration	Confidential level 95%		Pr > Chi²	LR Chisq
		Lower bound	Upper bound		
Age of the responsible of purchase	1.0	1.0	1.1	<0.001	6.6
Household with young children					20.7
Household with middle-age children	1.0	0.6	1.6	0.83	
Household with adult children	2.2	1.2	4.2	>0.01	
Single-parents household	2.8	1.5	5.5	>0.001	
Main purchase channel: Supermarket					6.1
Main channel: no supermarket	1.6	1.1	2.3	>0.05	
Realize shopping list (No)					7.6
Realize shopping list(Yes)	1.8	1.2	2.8	>0.05	

The probability of declared food waste is expressed in odds ratio with the upper and lower bound to achieve a confidence level of 95%.

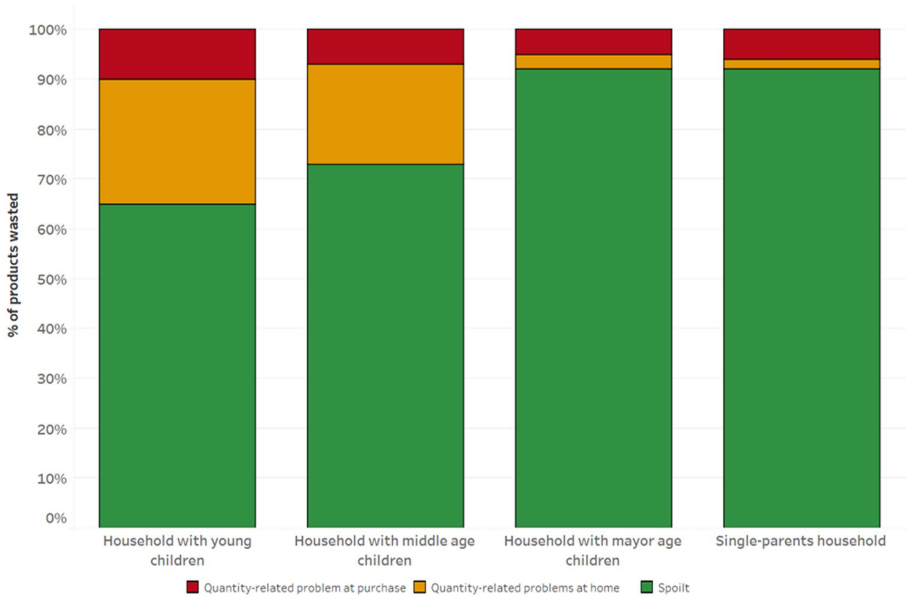


FIGURE 1
Product categories wasted in the different types of household with children.

Unsurprisingly perishable food, such as fruits, vegetables, and cereal-based product, are the primary items discarded, as previous studies have shown (13, 39). In addition, our findings indicate that dairy product contribute significantly to domestic food waste in households with young children and middle-aged individuals. This result highlights the importance of not excluding a specific dairy product, such as milk, from food waste quantification studies in households with children, as it is a common practice to exclude liquids in current literature (28, 40). Respondents reported spoilage as the primary reason for food waste in their homes, which aligns with other literature (14, 36).

Previous research by Herzberg et al. (13), Koivopuro et al. (41), and Falasconi et al. (27) has indicated that households with young and middle-aged children exhibit a higher prevalence of quantity-related issues in the context of serving or preparing excessive food compared to other family types. Such problems may be attributed to these households' challenges in providing healthy and appropriate food for their children (20, 42, 43) while also managing their children's finicky eating habits (15). The analysis confirmed the higher presence of quantity-related problems in families with young and middle-aged children. Additionally, it was highlighted that households with older children and single-parent households reported the most significant waste causes due to spoilt and quantity-related problems during purchase. This evidence suggests the presence of two distinct patterns of food waste in the household with children. Specifically, households with young and middle-aged children

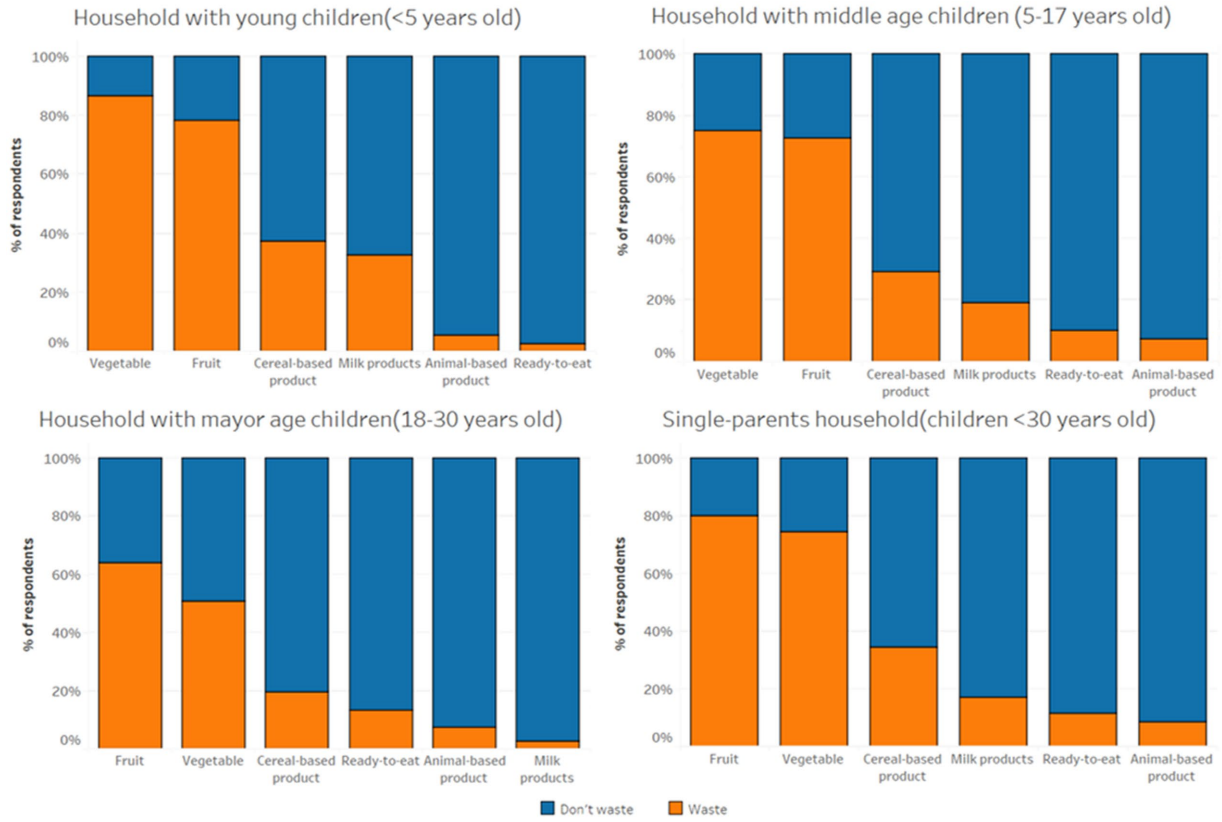


FIGURE 2
Reasons for disposal are listed for the different type of the households with children. The reasons for disposal included in the analysis are the quantity-problems at purchase, home and spoilt.

appear to waste food due to inadequate food management strategies, resulting in frequent small amounts of waste. In contrast, food waste in other households with children, and more in general to the other type of households, may result from over-purchasing perishable items discarded before consumption.

4.2. Prediction of food waste generation through socio-demographic and food-related behavior variables

Binary logistic regression identified four variables to identify which households and behaviors should be prioritized for food waste reduction. Household type and making a shopping list before going shopping are the two most influential factors in the model studied. The higher likelihood of food waste in families with young and middle-aged children empirically confirms the child's age as a valid variable for predicting food waste generation, consistent with the qualitative analysis of Kansal et al. (18). The greater time and money constraints may underlie this higher likelihood of food waste, as indicated by Parizeau et al. (14). Meanwhile, careful grocery shopping planning has been confirmed as a critical behavior to reduce food waste at home, even for families with children. Many studies have stated that careful grocery shopping planning is an effective tool to prevent overbuying and, consequently, food waste (14, 44, 45). Moreover, the limited use of the shopping list could serve as a proxy for other planning behaviors, which might explain the increased occurrence of food waste (46). Indeed, Quested et al. (37) have shown a robust positive association between the creation of shopping lists and "planning behavior," such as the premeditated planning of meals, inspection of existing food inventories before shopping, employment of freezing techniques to prolong the shelf life of food, and repurposing of leftovers.

In addition to the type of household and the purchase planning, the buyer's age and the purchasing channel were found to be factors with predictive power within the model. The inverse relationship between the age of the person in charge of food purchasing and the probability of generating food waste is consistent with previous studies (13, 36, 47). As well as other studies have also reported a higher likelihood of waste among individuals who purchase groceries from supermarkets (48–50). Specifically, products in predetermined packaging or products on discount (i.e., 3×2) induce consumers to buy more food than necessary for their families. In addition to the method of selling products, the presence of ultra-processed food items such as unhealthy snacks, frozen pizza, ice cream, and flavored yogurt in supermarkets has been indicated as a reason for food waste generation at home. Indeed, consuming these products, particularly appreciated by adolescents and young children (51), can compete with healthy product products such as fruits and vegetables served during mealtimes. Graham-Rowe et al. (20) showed that some parents frequently over-portion dinner for children to discourage eating unhealthy snacks, which could lead to significant food waste.

Moreover, supermarkets are known for their persuasive marketing appeals targeting children. Chen et al. (52) and Haselhoff et al. (53) highlight that children can employ persuasion, begging, and emotional appeals to influence their parents into purchasing products with attractive packaging or advertised on television.

In contrast to several studies, household income (36, 47, 54, 55) and the number of household members (56–58) were not found to be predicting factors for food waste generation in families with children. The focus of this study on a specific segment of the population characterized by a similar number of household members and monthly income levels explains this finding. This result puts into perspective the importance of these two factors as predictors of food waste within the population, given that families with children typically have higher incomes and a more significant number of household members. However, the fact that the analysis does not quantify food waste but only assesses whether or not waste was generated in the last week may explain why these two variables were not significant.

Regarding the methodology used in this study, the application of predictive models in food waste research during the consumption phase is increasing during the last decade (59). Previous research has demonstrated how predictive models can be customized for various sectors with limited utilization of these statistical techniques (60, 61). The food waste behavior was analyzed both with parametric (17, 62) and no parametric machine learning algorithm (63, 64). The choice to employ a parametric model for this research is based on two primary factors. Firstly, the analyzed variables have been observed in numerous studies, emphasizing the need for a well-established and interpretable approach. Secondly, the main objective of this analysis is to achieve accurate predictions rather than exploring intricate relationships or uncovering hidden patterns within the data. Additionally, focusing on a specific segment of the population helps mitigate the presence of outliers within the sample, while the ample sample size enables the model to be less susceptible to overfitting. Parametric models using both linear regressions (10, 13, 62) and logistic regression (17, 27, 28). These two predictive models differ in their output and data requirements. Logistic regression, utilizing a dummy variable, determines whether a household wastes food but does not provide information on the extent of the food waste. However, challenges and costs associated with quantitative analyses of consumption-related food waste, along with uncertainties due to cognitive biases and different perceptions of food waste among users (65, 66), limit the scalability of the predictive linear regression model. The use of categorical variables to assess food waste behavior (i.e., Declared food waste) enables quick and cost-effective data collection through questionnaires giving the possibility to increase the number of samples analyzed. The increase in the number of studies on food waste is fundamental for deepening knowledge about food waste and developing strategies to decrease it.

4.3. Policy implications

This section presents policy implications for addressing food waste in households with children based on the findings of this research and evidence from the literature. As highlighted by the analysis, policies aimed at preventing food waste should focus on young families with small and medium-sized children. Specifically, policy actions are required to facilitate changes in the perception of waste, promote good practices, and create favorable conditions for reducing food waste in these families. Placing the child at the center of policies to raise awareness about food waste is crucial, given their ability to directly and indirectly, influence waste (18). In this regard, promoting a healthy diet and describing the impact of food waste in schools can help reduce waste in families in the short term and create greater awareness of food waste in future families in the long term (15). As well as promoting local and seasonal products and menus mainly based on plants within schools can play a crucial role in educating children and supporting families in this critical aspect of daily life (67). Regarding this aspect, Šimanskienė et al. (68) recommended that educational institutions design lessons or lectures centered around responsible consumption topics. In particular, the development of methodological resources, such as exercise books and the creation of computer games that demonstrate the impact of individual consumption and behavior, can help educate students about responsible consumption and its role in environmental preservation.

Concerning good practices, the policies should stimulate planning behavior within the household with children, such as creating a shopping list, pre-planning meals and inspecting existing food stocks before purchasing (37). These behaviors can be stimulated through the promotion of online tools and apps for creating shopping lists (69), managing existing food stocks (70). Given the significance of food waste related to quantity problems arising from over-preparation of food, it would be beneficial to assist households in reusing leftoversby providing recipes particularly for perishable product. This can be achieved by promoting food reusing apps [e.g., (71)], launching campaigns [e.g., (72)], and incorporating them into product packaging. Moreover, enlisting children's participation in activities such as meal planning and food preparation, such as cooking together, are practices that have been found to have a constructive impact on dietary patterns and food waste generation (18).

Public policies should strive to create favorable conditions to reduce food waste in households with young and middle age children. Firstly, policies should encourage responsible consumption within the population through awareness-raising campaigns (73). In particular, parents should be informed as much as possible about the food waste impact on the environment and the region in which they live. Concerns about food waste and moral attitudes (i.e., feelings of guilt when discarding food) are crucial to determine their intention not to waste food and reshape the individual attitude toward buying and consuming food (74). For example, positive correlation between the variables planning routines and awareness of environmental problems has been observed by Fiore et al. (75). Secondly, specific policies are required to incentivize the sale of bulk products and limit the promotion of ultra-processed products in the supermarket. Focusing on supermarkets is necessary since most people use this purchasing channel as the main one due to time and money constraints. In this sense, promoting the sale of bulk products helps the shopper buy the exact amount of products needed for the household by limiting overbuying and reducing the generation of other packaging waste. Furthermore, developing customized packaging for products such as fruits and vegetables targeted toward families with children could partially alleviate quantity-related problems at purchase (i.e., less quantity and more variety). On the other hand, to reduce the consumption and potential distractions caused by ultra-processed products when purchasing goods, limiting their promotion campaigns aimed at adolescents and young children is crucial. One strategy to

achieve this is placing these products in less visible locations, such as on top shelves or in areas the responsible shopper may not pass by.

Finally, it is essential to mention that policies for managing organic waste should be implemented in addition to food waste prevention policies. Food waste management accounts for approximately one-third of the entire food system's greenhouse gas (GHG) emissions (76) due to the widespread use of landfilling and open dumping, both of which are strongly linked to high GHG emissions (77). By implementing the separate collections in the neighborhoods with a high percentage of households with children, the potential to employ low-carbon-footprint waste management technologies such as aerobic digestion and composting is increased, which can help to mitigate GHG emissions. This two-pronged approach of preventing and managing organic waste is essential to decrease food waste and its impact on families with children in parallel.

5. Conclusion

The issue of food waste is a significant challenge faced by societies worldwide. This study adds to the growing body of literature on household food waste by examining the food waste behaviors of households with children and identifying factors that can predict food waste generation. Our results show that perishable food items such as fruits, vegetables, bread, and dairy products are the primary items discarded. In particular, quantification analyses of food waste in households with children should take into account liquid waste, especially from milk, to avoid underestimating the problem. The study also identified two patterns of food waste in households with children: inadequate food management strategies resulting in frequent small amounts of waste in families with young and middle-aged children, and over-purchasing perishable items discarded before consumption in other households with children.

These findings are crucial for policymakers and stakeholders as they can help in developing targeted interventions to reduce household food waste, particularly for families with young and middle-aged children. Based on our study, strategies to reduce food waste in households with children should focus on improving food management strategies and promoting planning behavior such as making shopping lists. Schools can play a vital role in educating children and supporting families, while online tools and apps can encourage good practices such as planning and reusing leftovers. Policies that incentivize the sale of bulk products and limit the promotion of ultra-processed items in supermarkets can also be implemented, along with policies for managing organic waste to decrease their impact on families with children. It is important to note that reducing household food waste requires a multi-stakeholder approach involving policymakers, food manufacturers, retailers, and consumers. The results of this study contribute to the growing body of literature on household food waste and emphasize the importance of considering socio-demographic and food-related behavior variables in predicting food waste generation and implementing effective interventions.

Future research using a predictive model for food waste behavior should focus on young people living alone or sharing a house, identified by different studies as the household type generating the highest kg *per capita* of food waste (13, 16, 41). As well as in comparing different populations with different levels of awareness on food waste aspects or shed light on the cultural impact of food waste. Finally, to advance in the study of food waste in households with children, research should focus on assessing which variable identified by logistic regression has the most significant weight. In this case, quantifying food waste in a small sample would make it possible to define which behavior should be prioritized in a given population segment.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PT: Conceptualization, Data curation. XD, PO and PT: Formal Analysis. PT: Methodology. XD: Funding acquisition. XD: Project administration. PT: Roles/Writing — original draft. XD and PO: Writing — review & editing. All authors contributed to the article and approved the submitted version.

Funding

This study was funded by the European Union under the European Horizon 2020 research and innovation program under grant agreement n° 862663 (Food Systems in European Cities, FoodE); Ministerio de Ciencia e Innovación under grant n° PID2021-126845OB-C21 (MOVE4EDU, MCIN/AEI/10.13039/501100011033/FEDER) and Maria de Maeztu award (CEX2019-000940-M); Ministerio de Ciencia e Innovación under grant n° TED2021-130047B-C21 (BINAFET, MCIN/AEI/10.13039/501100011033/) and the European Union under the grant NextGenerationEU/PRTR. In addition, the research group as supported by the SGR 00734 funded by the AGAUR, Generalitat de Catalunya. The publication reflects the author's views. The Research Executive Agency (REA) is not liable for any use that may be made of the information contained therein.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2023.1249310/full#supplementary-material

References

1. IISD (International Institute for Sustainable Development) (2020). *World population to reach 9.9 billion by 2050*. Avaialable at: https://sdg.iisd.org/news/world-population-to-reach-9-9-billion-by-2050/

2. Searchinger T, Waite R, Hanson C, Ranganathan J. *Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050*. Washington: World Resource Institute (2019).

3. Schanes K, Giljum S, Hertwich E. Low carbon lifestyles: a framework to structure consumption strategies and options to reduce carbon footprints. *J Clean Prod*. (2016) 139:1033–43. doi: 10.1016/J.JCLEPRO.2016.08.154

4. Jeswani HK, Figueroa-Torres G, Azapagic A. The extent of food waste generation in the UK and its environmental impacts. *Sustain Prod Consum*. (2021) 26:532–47. doi: 10.1016/J.SPC.2020.12.021

5. Scherhaufer S, Moates G, Hartikainen H, Waldron K, Obersteiner G. Environmental impacts of food waste in Europe. *Waste Manag*. (2018) 77:98–113. doi: 10.1016/J.WASMAN.2018.04.038

6. United Nations. *Transforming our world: The 2030 agenda for sustainable development; UN*. New York, NY, USA: United Nation. (2015).

7. FAO (Food and Agricultural Organization of the United Nations) (2019). *The state of food and agriculture: Moving forward on food loss and waste reduction*. Rome. Licence: CC BY-NC-SA 3.0 IGO. Available at: https://www.fao.org/3/ca6030en/ca6030en.pdf

8. Silvennoinen K, Heikkilä L, Katajajuuri JM, Reinikainen A. Food waste volume and origin: case studies in the Finnish food service sector. *Waste Manag*. (2015) 46:140–5. doi: 10.1016/J.WASMAN.2015.09.010

9. Lyndhurst B. (2007). Food behaviour consumer research: quantitative phase. Retail Programme-food waste: final report. *WRAP* Available at: https://wrap.org.uk/sites/default/files/2020-12/Food-behaviour-consumer-research-quantitative-phase.pdf. Accessed 17/5/2023

10. Van der Werf P, Seabrook JA, Gilliland JA. Food for naught: using the theory of planned behaviour to better understand household food wasting behaviour. *The Canadian Geographer/Le Géographe Canadien*. (2019) 63:478–93. doi: 10.1111/cag.12519

11. De Laurentiis V, Corrado S, Sala S. Quantifying household waste of fresh fruit and vegetables in the EU. *Waste Manag*. (2018) 77:238–51. doi: 10.1016/J.WASMAN.2018.04.001

12. Scalvedi ML, Rossi L. Comprehensive measurement of Italian domestic food waste in a European framework. *Sustainability*. (2021) 13:1492. doi: 10.3390/su13031492

13. Herzberg R, Schmidt TG, Schneider F. Characteristics and determinants of domestic food waste: a representative diary study across Germany. *Sustainability (Switzerland)*. (2020) 12. doi: 10.3390/su12114702

14. Parizeau K, von Massow M, Martin R. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. *Waste Manag*. (2015) 35:207–17. doi: 10.1016/J.WASMAN.2014.09.019

15. Visschers VHM, Wickli N, Siegrist M. Sorting out food waste behaviour: a survey on the motivators and barriers of self-reported amounts of food waste in households. *J Environ Psychol*. (2016) 45:66–78. doi: 10.1016/J.JENVP.2015.11.007

16. Von Massow M, Parizeau K, Gallant M, Wickson M, Haines J, Ma DWL, et al. Valuing the multiple impacts of household food waste. *Front Nutr*. (2019) 6. doi: 10.3389/fnut.2019.00143

17. Principato L, Secondi L, Pratesi CA. Reducing food waste: an investigation on the behaviour of Italian youths. *Br Food J*. (2015) 117:731–48. doi: 10.1108/BFJ-10-2013-0314

18. Kansal M, Ananda J, Mitsis A, Karunasena GG, Pearson D. Food waste in households: children as quiet powerhouses. *Food Qual Prefer*. (2022) 98:104524. doi: 10.1016/J.FOODQUAL.2021.104524

19. Damen FWM, Luning PA, Fogliano V, Steenbekkers BLPA. What influences mothers' snack choices for their children aged 2–7? *Food Qual Prefer*. (2019) 74:10–20. doi: 10.1016/J.FOODQUAL.2018.12.012

20. Graham-Rowe E, Jessop DC, Sparks P. Identifying motivations and barriers to minimising household food waste. *Resour Conserv Recycl*. (2014) 84:15–23. doi: 10.1016/J.RESCONREC.2013.12.005

21. Evans D. Blaming the consumer – once again: the social and material contexts of everyday food waste practices in some English households. *Crit Public Health*. (2012) 21:429–40. doi: 10.1080/09581596.2011.608797

22. Xue L., Liu G. (2019). *Introduction to global food losses and food waste. Saving food: Production, supply chain, food waste and food consumption*.

23. Boulet M, Hoek A, Raven R. Towards a multi-level framework of household food waste and consumer behaviour: untangling spaghetti soup. *Appetite*. (2021) 156:104856. doi: 10.1016/j.appet.2020.104856

24. Vittuari M, Garcia Herrero L, Masotti M. (2023) How to reduce consumer food waste at household level: a literature review on drivers and levers for behavioural change. *Sustainable Production and Consumption*, 38, 104–114. ISSN 2352-5509

25. Teeny JD, Siev JJ, Briñol P, Petty RE. A review and conceptual framework for understanding personalized matching effects in persuasion. *J. Consum. Psychol.* (2021) 31:382–414. doi: 10.1002/jcpy.1198

26. Abeliotis K, Lasaridi K, Chroni C. Attitudes and behaviour of Greek households regarding food waste prevention. *Waste Manag Res*. (2014) 32:237–40. doi: 10.1177/0734242X14521681

27. Falasconi L, Cicatiello C, Franco S, Segrè A, Setti M, Vittuari M. Such a shame! A study on self-perception of household food waste. *Sustainability*. (2019) 11:270. doi: 10.3390/su11010270

28. Grasso AC, Olthof MR, Boevé AJ, van Dooren C, Lähteenmäki L, Brouwer IA. Socio-demographic predictors of food waste behavior in Denmark and Spain. *Sustainability*. (2019) 11:3244. doi: 10.3390/su11123244

29. IDESCAT (Institut d'Estadística de Catalunya). (2022a). *Municipality in figures*. Avaialable at: https://www.idescat.cat/emex/?id=082665&lang=en. Accessed 15/5/2023.

30. MAGRAMA (Ministerio de agricultura, alimentación y medioambiente). (2021). Report on food consumption in Spain. Madrid: Secretaría general Técnica centro publicaciones. Available at: https://www.mapa.gob.es/es/alimentacion/temas/consumo-tendencias/informe-consumo-alimentario-2021-baja-res_tcm30-624017.pdf Accessed 10/5/2023

31. WMA (World Medical Association). World medical association declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. (2013) 310:2191–4. doi: 10.1001/jama.2013.281053

32. HLPE High-Level Panel of Experts on Food Security and Nutrition. Food losses and waste in the context of sustainable food systems. *A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome*. (2014) 2014

33. Van Herpen E, van Geffen L, Nijenhuis-de Vries M, Holthuysen N, van der Lans I, Quested T. A validated survey to measure household food waste. *Methods X*. (2019) 6:2767–75. doi: 10.1016/j.mex.2019.10.029

34. IDESCAT (Institut d'Estadística de Catalunya. (2022b). *Average annual net income of households*. Avaialable at: https://www.idescat.cat/indicadors/?id=aec&n=15392&lang=en. Accessed 15/5/2023.

35. MAGRAMA (Ministerio de agricultura, alimentación y medioambiente) (2022). Household food waste data. Available at: https://www.mapa.gob.es/es/alimentacion/temas/desperdicio/desperdicio-alimentario-hogares/

36. Giordano C, Alboni F, Falasconi L. Quantities, determinants, and awareness of households' food waste in Italy: a comparison between diary and questionnaires quantities'. *Sustainability*. (2019) 11:3381. doi: 10.3390/su11123381

37. Quested TE, Marsh E, Stunell D, Parry AD. Spaghetti soup: the complex world of food waste behaviours. *Resour Conserv Recycl*. (2013) 79:43–51. doi: 10.1016/J.RESCONREC.2013.04.011

38. WRAP (Waste and Resource Action Program). (2012). *Household food and drink waste in the United Kingdom 2012*. Available at: www.wrap.org.uk

39. Gaiani S, Caldeira S, Adorno V, Segrè A, Vittuari M. Food wasters: profiling consumers' attitude to waste food in Italy. *Waste Manag*. (2018) 72:17–24. doi: 10.1016/j.wasman.2017.11.012

40. Jörissen J, Priefer C, Bräutigam KR. Food waste generation at household level: results of a survey among employees of two European research centers in Italy and Germany. *Sustainability*. (2015) 7:2695–715. doi: 10.3390/su7032695

41. Koivupuro HK, Hartikainen H, Silvennoinen K, Katajajuuri JM, Heikintalo N, Reinikainen A, et al. Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. *Int J Consum Stud*. (2012) 36:183–91. doi: 10.1111/j.1470-6431.2011.01080.x

42. Carroll N, Wallace A, Jewell K, Darlington G, Ma DWL, Duncan AM, et al. Association between diet quality and food waste in Canadian families: a cross-sectional study. *Nutr J*. (2020) 19:54. doi: 10.1186/s12937-020-00571-7

43. Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, Jahns L. Relationship between food waste, diet quality, and environmental sustainability. *PLoS One*. (2018) 13. doi: 10.1371/journal.pone.0195405

44. Altintzoglou T, Skuland AV, Carlehög M, Sone I, Heide M, Honkanen P. Providing a food choice option increases children's liking of fish as part of a meal. *Food Qual Prefer*. (2015) 39:117–23. doi: 10.1016/J.FOODQUAL.2014.06.013

45. Secondi L, Principato L, Laureti T. Household food waste behaviour in EU-27 countries: a multilevel analysis. *Food Policy*. (2015) 56:25–40. doi: 10.1016/j.foodpol.2015.07.007

46. Bellini S, Cardinali MG, Grandi B. A structural equation model of impulse buying behaviour in grocery retailing. *J Retail Consum Serv*. (2017) 36:164–71. doi: 10.1016/j.jretconser.2017.02.001

47. Stancu V, Haugaard P, Lähteenmäki L. Determinants of consumer food waste behaviour: two routes to food waste. *Appetite*. (2016) 96:7–17. doi: 10.1016/j.appet.2015.08.025

48. Farr-Wharton G, Foth M, Choi JHJ. Identifying factors that promote consumer behaviours causing expired domestic food waste. *J Consum Behav*. (2014) 13:393–402. doi: 10.1002/cb.1488

49. Yildirim H, Capone R, Karanlik A, Bottalico F, Debs P, Bilali H. Food wastage in Turkey: an exploratory survey on household food waste. *J. Food Nutrition Res*. (2016) 4:483–9. doi: 10.12691/jfnr-4-8-1,el

50. Ilyuk V. Like throwing a piece of me away: how online and in-store grocery purchase channels affect consumers' food waste. *J Retail Consum Serv*. (2018) 41:20–30. doi: 10.1016/J.JRETCONSER.2017.11.003

51. Reales-Moreno M, Tonini P, Escorihuela RM, Solanas M, Fernández-Barrés S, Romaguera D, et al. Ultra-processed foods and drinks consumption is associated with psychosocial functioning in adolescents. *Nutrients*. (2022) 14. doi: 10.3390/nu14224831

52. Chen X, Kassas B, Gao Z. Impulsive purchasing in grocery shopping: do the shopping companions matter? *J Retail Consum Serv*. (2021) 60:102495. doi: 10.1016/J.JRETCONSER.2021.102495

53. Haselhoff V, Faupel U, Holzmüller HH. Strategies of children and parents during shopping for groceries. *Young Consum*. (2014) 15:17–36. doi: 10.1108/YC-03-2013-00366

54. Tucker CA, Farrelly A. Household food waste: the implications of consumer choice in food from purchase to disposal. *Local Environ*. (2016) 21:682–706. doi: 10.1080/13549839.2015.1015972

55. Setti M, Falasconi L, Segrè A, Cusano I, Vittuari M. Italian consumers' income and food waste behavior. *Br Food J*. (2016) 118:1731–46. doi: 10.1108/BFJ-11-2015-0427

56. Bos Verma M, de Vreede L, Achterbosch T, Rutten MM. Consumers discard a lot more food than widely believed: estimates of global food waste using an energy gap approach and affluence elasticity of food waste. *PLoS One*. (2020) 15. doi: 10.1371/journal.pone.0228369

57. Parfitt J, Barthel M, Macnaughton S. Food waste within food supply chains: quantification and potential for change to 2050. Philosophical transactions of the Royal Society of London. *Series B, Biological sciences*. (2010) 365:3065–81. doi: 10.1098/rstb.2010.0126

58. Segrè A. (2014). *Background paper on the economics of food loss and waste working paper global initiative on food loss and waste reduction SAVE FOOD: Global initiative on food loss and waste reduction background paper on the economics of food loss and waste working paper*. Available at: www.fao.org/publications

59. Kim J, Knox K, Rundle-Thiele S. Theory application in food waste behaviour programs: a systematic literature review. *Australasian J. Environ. Manag.* (2022) 29:344–67. doi: 10.1080/14486563.2022.2140211

60. Akin M, Eyduran SP, Eyduran E, Reed BM. Analysis of macro nutrient related growth responses using multivariate adaptive regression splines. Plant cell. *Tissue and Organ Culture (PCTOC)*. (2020) 140:661–70. doi: 10.1007/s11240-019-01763-8

61. Akin M, Hand C, Eyduran E, Reed BM. Predicting minor nutrient requirements of hazelnut shoot cultures using regression trees. Plant cell. *Tissue and Organ Culture (PCTOC)*. (2018) 132:545–59. doi: 10.1007/s11240-017-1353-x

62. Iori E, Masotti M, Falasconi L, Risso E, Segrè A, Vittuari M. Tell me what you waste and I'll tell you who you are: an eight-country comparison of consumers' food waste habits. *Sustainability*. (2022) 15:430. doi: 10.3390/su15010430

63. Mondéjar-Jiménez J, Ferrari G, Secondi L, Principato L. From the table to waste: an exploratory study on behaviour towards food waste of Spanish and Italian youths. Journal of cleaner production. Vol. 138. *Part*. (2016) 138:8–18. doi: 10.1016/j.jclepro.2016.06.018

64. Secondi L. Expiry dates, consumer behavior, and food waste: how would Italian consumers react if there were no longer "best before" labels? *Sustainability*. (2019) 11:6821. doi: 10.3390/su11236821

65. Corrado S, Caldeira C, Eriksson M, Hanssen OJ, Hauser HE, van Holsteijn F, et al. Food waste accounting methodologies: challenges, opportunities, and further advancements. *Glob Food Sec*. (2019) 20:93–100. doi: 10.1016/J.GFS.2019.01.002

66. Lebersorger S, Schneider F. Discussion on the methodology for determining food waste in household waste composition studies. *Waste Manag*. (2011) 31:1924–33. doi: 10.1016/j.wasman.2011.05.023

67. Benvenuti L, De Santis A, Santesarti F, Tocca L. An optimal plan for food consumption with minimal environmental impact: the case of school lunch menús. *J Clean Prod*. (2016) 129:704–13. doi: 10.1016/j.jclepro.2016.03.051

68. Šimanskienė L, Paužuolienė J, Fiore M, Župerkienė E. Responsible consumption: society habits in time of crisis In: D Vrontis, A Thrassou, Y Weber, SMR Shams, E Tsoukatos and L Efthymiou, editors. *Business under crisis, volume III. Palgrave studies in cross-disciplinary business research, in association with euro med academy of business*. Cham: Palgrave Macmillan (2022)

69. ListOn (2022). Naladex Available at: . https://play.google.com/store/apps/details?id=shopping.list.free.lista.compra.gratis.liston&hl=en&gl=US

70. Outof Milk (2022), *Out of Milk app*. Available at: https://www.outofmilk.com/ Accessed 12/5/2023

71. Svuota Frigo (2022). *Svuota Frigo App*. Available at: https://play.google.com/store/apps/details?id=com.apphost.ricette&hl=en&gl=US

72. Recipe for Change Campaigns (2023). *United nation program against food waste, UNEP*. Available at: https://www.unep.org/recipe-change-campaign Accessed 18/5/2023

73. Adamashvili N., Chiara F., Fiore M. (2019), *Food loss and waste a global responsibility?! In "ECONOMIA AGRO-ALIMENTARE", pp 825–846*

74. Paužuolienė J, Šimanskienė L, Fiore M. What about responsible consumption? A survey focused on food waste and consumer habits In: *Sustainability, 14 (14), 8509*, vol. *14*. MDPI: AG. Retrieved from (2022) doi: 10.3390/su14148509

75. Fiore M, Pellegrini G, La Sala P, Conte A, Liu B. Attitude toward food waste reduction: the case of Italian consumers. *International J. Global. Small Business*. (2017) 9:185–201. doi: 10.1504/IJGSB.2017.088921

76. Zhu J, Luo Z, Sun T, Li W, Zhou W, Wang X, et al. Cradle-to-grave emissions from food loss and waste represent half of total greenhouse gas emissions from food systems. *Nature Food*. (2023) 4:247–56. doi: 10.1038/s43016-023-00710-3

77. Wang Y, Levis JW, Barlaz MA. An assessment of the dynamic global warming impact associated with long-term emissions from landfills. *Environ Sci Technol*. (2020) 54:1304–13. doi: 10.1021/acs.est.9b04066

frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 09 January 2024
DOI 10.3389/fsufs.2023.1285883

OPEN ACCESS

EDITED BY
Elena Velickova,
Saints Cyril and Methodius University of Skopje, North Macedonia

REVIEWED BY
Seydi Yıkmış,
Namik Kemal University, Türkiye
Catarina Possidónio,
Lusofona University, Portugal

*CORRESPONDENCE
Alexandru Rusu
✉ rusu@biozoon.de

RECEIVED 30 August 2023
ACCEPTED 14 December 2023
PUBLISHED 09 January 2024

CITATION
Gärtner A-K, Matullat I, Genuttis D, Engelhardt S, Sveinsdóttir K, Niimi J and Rusu A (2024) Vegan spread applications of alternative protein from torula yeast: product development and consumer perception. *Front. Sustain. Food Syst.* 7:1285883. doi: 10.3389/fsufs.2023.1285883

Vegan spread applications of alternative protein from torula yeast: product development and consumer perception

Ann-Kristin Gärtner[1], Imke Matullat[2], Darleen Genuttis[1], Sarah Engelhardt[1], Kolbrún Sveinsdóttir[3,4], Jun Niimi[5] and Alexandru Rusu[1]*

[1]R&D Department, Biozoon GmbH, Bremerhaven, Germany, [2]ttz Bremerhaven, Sensory and Consumer Sciences, Bremerhaven, Germany, [3]Matís ohf. Icelandic Food and Biotech R&D, Reykjavík, Iceland, [4]Faculty of Food Science and Nutrition, University of Iceland, Reykjavik, Iceland, [5]Department of Material and Surface Design, RISE, Research Institutes of Sweden, Bioeconomy and Health, Göteborg, Sweden

Alternative protein sources are gaining attraction in food industry and consumers. Proteins obtained by single-cell organisms, such as torula yeast, are of enormous interest, as they are highly scalable, efficient, and sustainable, and the production costs are comparably low. Nevertheless, proteins obtained from yeasts are still mostly known and studied for feed applications, despite their nutritional, functional, and sensory benefits for various food applications. Testing consumer acceptance of products, especially products containing alternative proteins provides insights into, e.g., market success, consumer perception, and optimization potential. In this study, the development of two vegan spread powders, high in protein and containing torula yeast as an alternative protein source, is introduced. The result of food product development using torula yeast were "Leberwurst"-style (14.7% protein) and a "Balkan"-style (9.7% protein) spreads both meeting the criteria "at least 20% kcal from proteins of total product kcal" and thus claimable as "high-protein." The application of the alternative protein from torula yeast within the final products was studied by a consumer acceptance test ($n = 123$) within three different countries (Germany, Iceland, and Sweden). Consumers also rated their trust in food production actors, the food industry in particular, and their willingness to try new foods. Overall, both spreads received acceptance values in the range of "like slightly." It is noticeable that the consumers liked the spread "Balkan style" more than "Leberwurst"-style. The background variables revealed higher neophobic characteristics of Icelandic consumers compared with Swedish or German consumers. However, German consumers felt transparency, and communication was missing, but Icelandic consumers, in general, had more trust in the overall food value chain. This knowledge allows for the development of strategies that address cultural-specific barriers and capitalize on cultural values that promote openness to culinary innovation. The identification of cultural variations in consumer preferences emphasizes the need for customized approaches to product development and marketing. These findings could have implications for businesses and policymakers in understanding and catering to the preferences and concerns of consumers in these respective countries. Businesses might benefit from emphasizing transparency and improving communication strategies. This could involve providing clear information about the sourcing, production, and other aspects of the food value chain.

KEYWORDS

alternative proteins, single-cell protein, torula yeast, product development, consumer acceptance, meat alternative, food neophobia

1 Introduction

By 2050, the world population is expected to reach up to 9.8 billion people accompanied by debate about carbon footprint reduction, sustainable and biodiverse food systems, and the sufficient protein supply in future (Ismail et al., 2020; Grossmann and Weiss, 2021; Jach et al., 2022; Di Lena et al., 2023). Alternative protein interest and their use in different food products are not only steadily increasing and gaining huge market share but are also one of the most discussed food science topics (Grossmann and Weiss, 2021; Banach et al., 2022; Verstringe et al., 2023).

Alternative protein attraction by the consumer can be divided into plant-based proteins, single-cell organisms, aquatic organisms, and insects (Sawicka et al., 2020). As the global population continues to grow, alternative protein sources can help address food security challenges by providing efficient and scalable sources of protein (Henchion et al., 2017; Rusu et al., 2020). The alternative protein market exceeded 50 billion USD in the year 2020 and is estimated to grow up to 155 billion USD by 2027. These numbers are a result of the growth of concerns about the environment, the increasing demand for alternative protein products, and the growing number of vegans, vegetarians, and flexitarians worldwide (Ahuja and Bayas, 2021). The people who belong to these three dietary groups helped expedite the use of alternative proteins in common food products, while also the food industry observed the benefit of the commercialization of products using such protein sources (Ismail et al., 2020). The development of alternative protein sources is ongoing, influenced by factors such as flavor, texture, cultural perceptions, and technological advancements. As consumers become more conscious of their dietary choices and their impact on the planet, the demand for diverse and sustainable protein sources is likely to continue to increase (Banach et al., 2022).

Single-cell organisms, such as yeasts in particular, are of interest, as single-cell proteins have the advantage of being highly scalable and efficient in terms of resource utilization. In addition to the low-cost biomass production with low environmental footprint (as well as the possible cultivation of side-stream products from various agro-industries), single-cell proteins show nutritional advantages, especially with regard to high protein content with a well-balanced amino acid profile, enzymes, trace minerals, and vitamins (Bekatorou et al., 2006; Jach et al., 2022).

Torula yeast (as well as most of the other yeast types) is mostly known and studied for feed applications so far, e.g., in fish diets (Olvera-Novoa et al., 2002; Leeper et al., 2022) and broilers (Lezcano and Herrera, 2013), shrimp (Mbuto, 2017). However, in the context of the growing population, the importance of food grade that produced yeasts is steadily increasing (Bekatorou et al., 2006). Jach et al. (2022) reported the useful integration of yeast biomass into food as emulsifiers, flavor enhancers, and vitamin carriers. Beyond that, Bekatorou et al. (2006) specified the use of yeast proteins as an ingredient within meat alternatives, seasonings, sauces, soups, and dips. This is of particular interest for providing products for flexitarian consumers, who prefer to reduce meat-based products in their diets and are looking for corresponding meat alternatives that resemble appearance, flavor, texture, and price of meat products (Joseph et al., 2020). The use of alternative proteins in food products is essentially accompanied by consumer acceptance, assuring market success and thus comprising interest in consumer perception of these products (Aschemann-Witzel et al., 2020).

Consumer attraction to alternative proteins in food is multifaceted and influenced by health, sustainability, ethics, culture, taste, and price. Aspects, influencing consumer acceptance, can be divided into three main categories, namely, product-related characteristics, psychological factors, and external environments such as trust and social environment, also covering food neophobia aspects (the unwillingness to eat and the habit of avoiding novel food products; Onwezen et al., 2021; De Kock et al., 2022). Different studies revealed that consumer acceptance of products including alternative proteins depends on the expected (Michel et al., 2021) or experienced sensory properties (especially. taste) of the products (Dietrich et al., 2016; Grahl et al., 2020).

In this study, analysis of the sensory acceptance by consumers from three different countries (Germany, Iceland, and Sweden) of two developed vegan spreads (Leberwurst and "Balkan"-style) containing alternative proteins from torula yeast as an ingredient has been performed. In addition, additional information on the general acceptance of the protein concepts and consumer confidence is discussed.

2 Materials and methods

2.1 Vegan spreads

Two types of vegan spreads based on different spices were developed. The final spreads were developed to be a "ready-to-use"-powder. Thus, the end-user of the products, namely, the consumer, is required to add vegetable oil and boiling water, enabling the highest possibilities of convenience and easy and long-term storage opportunities. Torula yeast powder (ARBIOM, Paris, France) was evaluated within the NextGenProteins EU project, which had high potential for use based on its sensory characteristics (such as umami and meat-like characteristics) in food application.

The first variant of spread developed resembled a meat-like product in accordance with the German "Leberwurst" (liver sausage). Leberwurst is a type of sausage that originates from Germany, which has a distinctive smooth and spreadable texture, and is commonly consumed as a spread on bread or crackers. Leberwurst generally has a rich and savory characteristic, though it can vary in flavor depending on the specific recipe and region. Thus, the goal was to achieve a meat-like and savory flavor, accompanied by a reddish to brown color, a spreadable texture that translates to soft and smooth mouthfeel, and finally meeting requirements for "high protein" claims (according to the Regulation (EG) 1924/2006).

The second spread was designed to have a smoked/rich paprika-flavored spread, called the "Balkan"-style. The Balkan cuisine has a rich culinary tradition characterized by a variety of flavors and ingredients, with influences from Mediterranean and Eastern European flavors. "Balkan"-style generally refers to the spices and herbs commonly used in the cuisine of the Balkan Peninsula, such as sweet and hot paprika, oregano, thyme, garlic, onion, and coriander. The goal was to achieve a smoked, savory, and paprika-spiced flavor and a reddish color. The Balkan spread was designed to have similar textural and mouthfeel properties to the "Leberwurst" spread and also meet the requirements of the "high protein" claim.

The following raw materials were additionally considered: broth, texturized vegetable proteins (TVP), seasonings, herbs, vegetable/onion plant powders and flavors for flavor development, caramel powder, fruit and vegetable powders for color development, pea protein and other (protein-rich) flours, and oil for texture and mouthfeel-optimization. For the composition of the final products, it was decided that at least 50% w/w of the powder should consist of protein- and texture-defining ingredients (proteins, flours), and flavoring/coloring ingredients should account for the remainder of the recipe.

Product development was performed under "trial-and-error"-conditions, starting with texture and mouthfeel-related raw materials and adding further flavoring and coloring compositions until a near optimal product formulation was attained. Final recipes were tasted and associated with nutritional calculations based on raw material nutritional values before consumer testing.

2.2 Consumer testing

2.2.1 Recruitment and questionnaire development

The target group was selected based on a screening questionnaire. Essential criteria were age (18–45 years) and certain openness toward new and innovative foods. The selection of the target group, comprising participants up to 45 years old with a specific level of openness toward new and innovative foods, is rooted in a strategic approach to capture a dynamic and influential demographic. The decision to focus on individuals of up to the age of 45 years is driven by the recognition that this age range represents a critical segment of the population characterized by a heightened receptivity to novel food experiences. The empirical evidence suggests that younger demographics, up to this age, tend to exhibit greater openness to experimentation with novel food items. Research indicates that individuals in this age bracket are more likely to adopt and adapt to innovative food products, making them a pivotal focus for understanding consumer preferences and potential market success. In addition, the incorporation of individuals with varying levels of openness and potential food neophobia enhances the robustness of our study, offering valuable insights into both the successful commercialization of innovative food products and the identification of potential obstacles in diverse consumer clusters.

Further questions were related to the education level the size of household, and known food allergies. Only participants who fulfilled the selection criteria were invited to the test.

The questionnaire was developed and consisted of two parts. In the first part, the overall sensory acceptance of the products was measured without giving any additional information. Afterward, an open question was asked to specifically ask about product strengths and weaknesses. Second, the acceptance of the alternative proteins was asked again after providing information about the protein source used for the corresponding product. The questionnaire ended with the collection of background variables (trust in the stakeholders, trust in the food industry, food neophobia, and sociodemographic questions).

2.2.1.1 Acceptance

Acceptance of the consumers was analyzed using a 9-point hedonic scale starting from 1 = dislike very much up to 9 = like very much in constant distances, with 5 = neither like nor dislike as a neutral opinion. The results are collected per product with a comparison between the countries as a mean value. Within-country mean values were tested for significance using Student's t-test. The Kruskal–Wallis test was further used to compare the mean values between the countries.

2.2.1.2 Background variables

All background variables were presented in the distribution of the entries in %, and the distribution was tested by the means of Chi-square tests. All background variables were collected after testing.

Trust in stakeholders: The focus was on trust toward actors in the food value chain. A modified scale (Siegrist and Hartmann, 2020) was applied to measure respondents' trust in various actors (stakeholders) of the food chain. The query was carried out using selected actors on a scale from 1 = no trust at all to 5 = a high level of trust.

Trust in food industry: A scale after Mcready et al. (2020) was used for the measurement of trust in the food industry. The question construct contains 9 items, which were evaluated on a seven-point Likert scale from 1 (do not agree at all) to 7 (agree completely).

Food Neophobia: The tendency to avoid novel foods was measured by the alternative Food Neophobia Scale (FNS-A), which was recently developed by de Kock et al. (2022). Eight items were measured on a scale; answers were provided with seven-point scales ranging from 1 (do not agree at all) to 7 (agree completely).

The questionnaire was initially prepared in English and then translated into the language of each target country by the respective native-speaking authors.

The questionnaire data were collected using a computer/tablet program. In Germany, the data were collected using sensory software FIZZ (2.51) in Sweden and Iceland, and the online questionnaire from SoSciSurvey was used.

Table 1 shows the composition of the recruited target group for the spreads. A total of $n = 123$ test persons participated in the test, with 50 consumers from Germany, 48 from Sweden, and 25 from Iceland.

The distributions between the countries were very similar, but there were differences in the characteristics of gender, education level, and household status. While in Germany and Iceland, approximately 40% male and 60% female consumers participated, the ratio in Sweden was 30/70%. It is striking that, especially in Germany 60% of the participants have a secondary level of school education. This proportion is lower in the other countries, where more people with a university degree or higher participated in the test. While in Germany the majority (36%) of the participating consumers from this test live together with a partner, 36% of Icelandic participants still live at home with their parents and in Sweden almost half (48%) live alone.

TABLE 1 Composition of the target group for spreads per country.

	Germany	Sweden	Iceland
Total	$N = 50$	$N = 48$	$N = 25$
Gender	**%**	**%**	**%**
Male	40	29	40
Female	60	70	56
Diverse	0	1	4
Prefer not to say	0	0	0
Age	**%**	**%**	**%**
18–24 years	22	21	24
25–34 years	36	38	36
35–45 years	42	42	40
Education level	**%**	**%**	**%**
Basic education/elementary or lower	0	2	8
Secondary education (vocational qualification, high school)	60	35	28
University education (bachelor's degree)	34	25	32
University education (master's degree or higher; MA/MSc, PhD, MD)	4	25	28
Other, please specify	2	13	0
Prefer not to say	0	0	4
Household	**%**	**%**	**%**
I live at home with my parents	16	6	36
I live alone	22	48	8
I live alone with my child/children	0	4	12
I live with my spouse	36	19	8
I live with my spouse and child/children	18	15	28
I live with other adults (other than spouse or family members)	8	6	8
Prefer not to say	0	2	0
Basic dietary behavior	**%**	**%**	**%**
I regularly eat products of animal origin and non-animal origin (omnivorous)	68	71	84
I only eat meat sometimes (e.g., beef, pork, poultry, fish, seafood)	12	6	8
I avoid red meat (e.g., or pork, beef), but eat other meat products like chicken or fish	5	6	0
I do not eat meat (e.g., beef, pork or poultry), but I eat fish (I'm a pesco-vegetarian)	9	4	8
I do not eat meat (e.g., beef, pork, poultry or fish), but I eat other products of animal origin (e.g., eggs, cheese, milk) (I'm a lacto-ovo-vegetarian)	6	6	0
I do not eat any meat, eggs or dairy products (I'm a vegetarian)	1	2	0
I do not eat anything of animal origin (I'm a vegan)	0	4	0

2.2.2 Product preparation

The corresponding amount of vegan spread powder (22.2% w/v) was mixed with vegetable oil (11.1% w/v) and further homogenized after the addition of 66.7% w/v of boiling water. Both spreads are prepared 1 day in advance to cool down completely. The spreads were served by piping them on bread without a crust for consumer testing.

2.2.3 Test procedure

The consumer testing was conducted in three different countries (Germany, Iceland, and Sweden) as a central location test (CLT). Consumers neutralized their taste with water between the two samples. All consumers provided informed consent and privacy statement before the start of the test and provided signatures of written consent. The test was conducted as a semi-monadic test, and the samples were rotated.

2.2.4 Data analysis for consumer testing

2.2.4.1 Statistical analysis

Mean values per product and country were formed for the overall acceptance. The mean values were tested for differences using a non-parametric test, as the conditions for a normal distribution were not met. The mean values between the countries were tested using the Kruskall–Wallis test. Mean values were compared by the

Kruskal–Wallis test with a level of significance of alpha = 5%, displaying the significance by either using "*" or different letters. The null hypothesis is: There are no differences in the sensory acceptance of the overall impression in the countries tested (Germany, Sweden, and Iceland). The pairwise differences between the countries were tested by the multiple pair-wise comparisons using the Steel–Dwass–Critchlow–Fligner. The statistical analyses were carried out by using IBM SPSS 29 software.

3 Results

3.1 Vegan spread powder development

The recipes of both powder–based vegan spreads were composed of the base of pea protein, torula yeast powder, and different flours which are mainly responsible for the texture of the produced spreads and to achieve the "high protein" claim. In the case of the "Leberwurst"-style, spread crushed TVP, made up of pea protein and torula yeast powder, was added to the final recipe, as certain coarseness was expected for this product.

In terms of flavoring and coloring substances, the "Leberwurst"-style spread powder consisted of vegetable broth, onion and leek powder, caramel powder, dried chives, and beetroot powder. The taste was further complemented by marjoram, pepper, and citric acid.

The internal defined characteristics collected revealed a typical reddish to brownish color, accompanied by detectable onion and leek smell, connected with meat-like properties. The umami flavor and oily notes were recognizable followed by the taste of herbs and slightly caramel. The texture was further characterized as soft and spreadable.

The prepared vegan spread "Leberwurst"-style (with the addition of oil and water) resulted in 10.8% lipids, 3.0% carbohydrates, 1.5% fibers, and 14.7% protein, calculated by the used raw material nutritional values. With regard to the Regulation (EG) 1924/2006, the prepared spread can be legally claimed as "high protein" as 34% of the total energy is produced by the protein.

Flavoring and coloring substances selected for the final "Balkan"-style spread were tomato, mustard, onion, miso and leek powder, smoke flavor, vegetable broth, and raw cane sugar complemented by muscat, cardamom, salt, and paprika spice.

The spread was characterized as follows: A reddish, paprika-like color with visible herbs together with smoked paprika and a spicy smell connected with meat-like properties. The taste was summarized as spicy and fruity associated with "Balkan"-like characteristics supported by a soft, creamy, and spreadable texture.

The" Balkan"-style spread recipe occurs with 10.3% lipids, 2.3% carbohydrates 0.4% fibers, and 9.7% proteins, based on the information about raw materials. The benefit of "high protein" claim, according to the Regulation (EG) 1924/2006, is also applicable to this spread.

For the final application, in the case of both powder-based vegan spreads, 50 g of the spread powder was blended with 25 g of vegetable oil before pouring over 150 mL of boiled water under stirring. After cooling down to room temperature, the spreads could be used on the top of the bread. This easy preparation guarantees the highest convenience for the consumer. Furthermore, high-protein characteristics, both spreads resulted in vegan, including alternative proteins from single-cell protein (torula yeast). Figure 1 shows both vegan spreads on baguette bread.

FIGURE 1
Both vegan spreads containing torula yeast: "Balkan"-style spread without topping and "Leberwurst"-style spread with green topping.

3.2 Consumer acceptance

Figure 2 summarizes the spontaneous overall acceptance of both spreads.

The savory "Leberwurst"-style spread was equally well-received by consumers across three countries and is scored near 5 points on the scale (neither like nor dislike), which means they have a neutral opinion about the product. No significant differences are found between the mean liking values. The "Balkan"-type spread is rated significantly better in Germany and Sweden, with a mean score of 6.4, compared with Icelandic results with a score of 5.1. In detail, over 70% of responses from Sweden and Germany chose at least "like slightly," Icelandic results being slightly lower with nearly 40% in this range of likeliness. With regard to the "Leberwurst"-type spread, the countries differ: Icelandic participants show a higher acceptance within this type of spread compared with the "Balkan"-type and approximately 55% respond with "like slightly" or even higher. German (55%) and Swedish (45%) results are thus comparable to Icelandic responses but are rated generally lower compared with the "Balkan"-style spread.

In comparison, consumers were asked to rate acceptance at a later stage of the testing after giving some information about the alternative protein source, such as Torula.

3.3 Background variables

At the end of the test, consumers were asked to answer questions related to trust and in particular, trust toward stakeholders in the food value chain and the food industry in order to complement an insight about how consumers rate the whole food value chain.

3.3.1 Trust in stakeholders

First, the participants were asked to answer the question "How much do you trust the following food industry players?," using the Likert scale, as presented in Figure 3.

10.3389/fsufs.2023.1285883

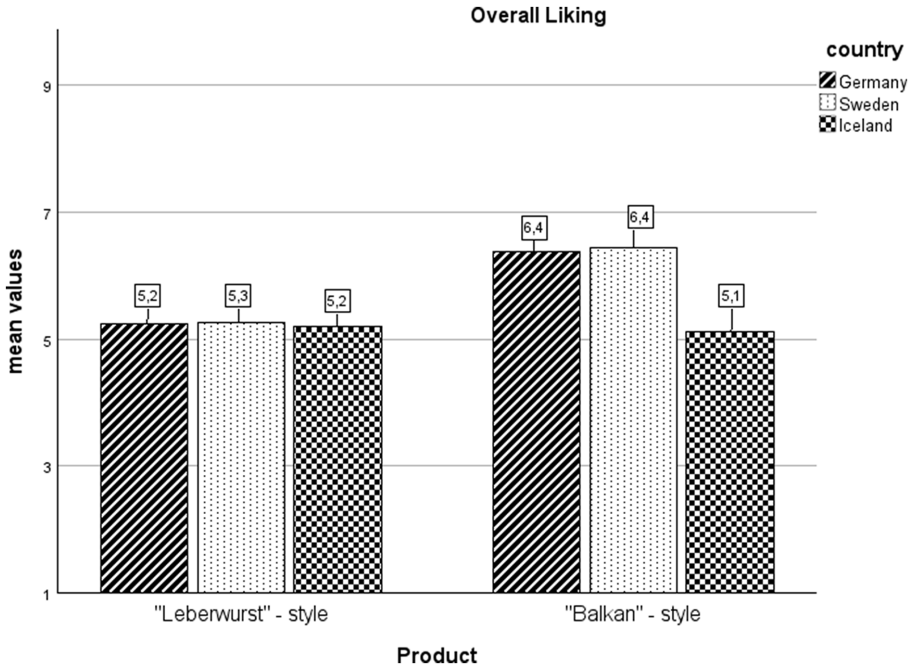


FIGURE 2
Spontaneous overall acceptance (1 = dislike very much, 9 = like very much) of both tested spread comparison of mean values by Kruskal–Wallis test; different letters show significant difference, alpha 0.05.

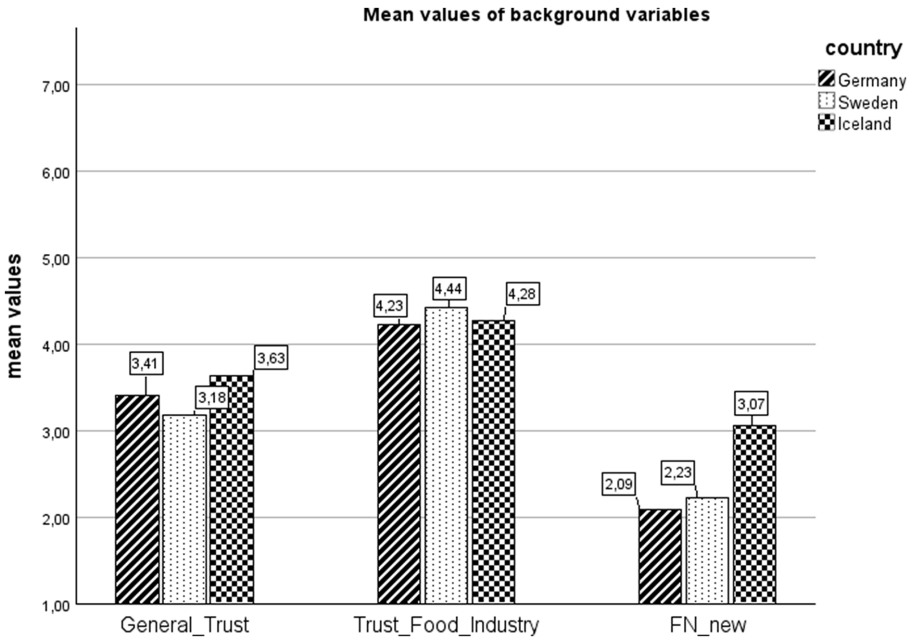


FIGURE 3
Mean values of the background variables tested by Kruskal–Wallis test; pairwise comparison with Steel–Dwass–Critchlow–Fligner procedure; *show significant difference, alpha 0.05.

In most of the defined actors toward the food value chain, the trust, compared between the countries, is similar. Nevertheless, trust in primary food producers, food industry, and retailers is significantly higher among Icelandic consumers as compared with German and Swedish consumers.

3.3.2 Trust in the food industry

Moreover, consumers were confronted by different statements on trust toward the food industry, using the Likert scale as well. Table 2 includes all presented statements and the mean values of answers per country.

10.3389/fsufs.2023.1285883

TABLE 2 Trust in food industry (1 = no or very little trust; 5 = very much trust).

Country	… is doing a good job with regard to producing food	… is competent enough to deal with the production of food	… has necessarily skilled people to produce food	… is acting in the public interest with regard to producing food	… listens to concerns regarding food production raised by public	… listens to what ordinary people think about food production*	… provides all relevant information about food production to the public	… is honest about the production of food	… is sufficiently open about production of food
Germany	5.0	5.2	5.3	4.3	3.8	3.9[a]	3.8	3.6	4.1
Sweden	5.1	5.3	5.3	4.4	4.3	4.5	4.3	3.9	4.0
Iceland	4.6	5.2	4.9	4.0	4.0	4.0	4.0	3.8	4.0

[a]Significant different to Sweden; Kruskal–Wallis test; $p < 0.05$. Comparison of mean values by Kruskal–Wallis test, alpha 0.05.

There are no significant differences between the mean scores of the countries, although German consumers seem to be less able to agree with the statements, dealing with information and transparency of the food industry.

3.3.3 Food Neophobia

Last but not least, food neophobia was inquired according to the alternative scale by De Kock et al., 2022. The results are presented in Table 3.

Significant differences between the three countries were measured on six items. Considering the mean values, it was found that Icelandic consumers are more likely to show neophobic characteristics compared with Swedish or German consumers.

Finally, correlations between all background variables have been analyzed in order to find and discuss potential relationships toward the overall impression of the product. The results are presented in Table 4.

The possible influence of background variables and the overall liking are of interest. The table shows that there are no significant correlations between the overall liking of the products and the named background variables. However, the negative correlation of the tested datasets implies that an increase in one variable (e.g., food neophobia) is accompanied by a decrease in the other (e.g., overall liking). As correlations are no proof of causality, this can be observed as indication and tendency.

4 Discussion

The present study underlines the sensory acceptance of both developed vegan spreads in powder form, as they are one of a kind and contain novel proteins derived from Torula yeast. No comparable products on the market were identified at the time of writing this study, especially with regard to the use of torula yeast in foods. This shows the unicity of the torula yeast food application.

Two flavors were developed: a spicy "Balkan" style spread and a savory-type spread "imitating" German "Leberwurst."

Of the two tested products, the "Balkan"- style spread performed slightly better than the "Leberwurst"-style product based on sensory properties alone. In Germany and Sweden, the "Balkan"- style spread was rated significantly better than in Iceland.

The open questions from the blind tasting provide additional information about the optimization potential for both spread products. Essentially, the seasoning and the mouthfeel are characteristics, in which the "Balkan" - style product, in particular, can be optimized. Some consumers in all countries remark that the product tastes too spicy and in general too intense. In addition, sandy and slimy characteristics were identified. The "Leberwurst"-type spread was described as "not visually appealing" by the consumers, and the taste itself was not intense enough. In addition, some consumers noted a pappy aftertaste. An optimization of the products in terms of these characteristics could therefore be required to further increase the overall acceptance.

Both seasoning and mouthfeel are crucial factors that interact to create a holistic sensory experience when eating (Fiorentini et al., 2020). A well-seasoned dish with a pleasing mouthfeel can result in a more enjoyable and memorable dining experience. Seasoning refers to the use of various flavor-enhancing components and helps

TABLE 3 Alternative Food Neophobia scale, comparison of mean values (scale 1 = disagree strongly; 7 = agree strongly) by Kruskal–Wallis test; different letters show significant difference, alpha 0.05.

Country	New food eating experiences are important for me (R)	I am afraid to eat things I have never had before	I do not trust new foods	New foods mean an adventure for me (R)	I like to challange myself by trying new foods (R)	It is exciting to try new foods when travelling (R)	Foods from other cultures look too weird to eat	Foods that look strange scare me
Germany	1.7[a]	2.2	2.5	3.1	2.4	2.1	2.4	2.4[e]
Sweden	2.0	2.0	2.4	2.3[c]	2.3[d]	1.9	2.0	3.1[f]
Iceland	2.7	3.4[b]	2.8	3.1	3.2	2.6	2.6	4.1[g]

[a,c]Significant different to Iceland. [b]Significant different to Sweden and Germany. [d]Significant different to Sweden and Iceland. [e,f]Significant different to Germany and Iceland; all comparisons by Kruskal–Wallis test; $p < 0.05$.

TABLE 4 Pairwise correlation (Pearson correlation) of background variables and overall liking of consumers (*N* = number of datasets).

		Overall liking	General trust	Trust in food industry	Food Neophobia
Overall liking	Pearson correlation	1	−0.013	−0.006	−0.138
	Sig. (2-tailed)		0.889	0.947	0.129
	N	246	123	123	123
General trust	Pearson correlation	−0.013	1	0.440**	0.047
	Sig. (2-tailed)	0.889		<0.001	0.604
	N	123	123	123	123
Trust in the food industry	Pearson correlation	−0.006	0.440**	1	0.002
	Sig. (2-tailed)	0.947	<0.001		0.980
	N	123	123	123	123
Food Neophobia	Pearson correlation	−0.138	0.047	0.002	1
	Sig. (2-tailed)	0.129	0.604	0.980	
	N	123	123	123	123

**Correlation is significant at the 0.01 level (two-tailed).

to bring out the natural flavors of ingredients, balance out flavors, and create a harmonious and pleasing taste profile. Seasoning can vary greatly, depending on cultural preferences, regional cuisines, and individual tastes (Jeong and Lee, 2021). Proper seasoning can elevate a dish from being bland or one-dimensional to being rich and complex in flavor. Mouthfeel, on the other hand, refers to the tactile sensations that food creates in the mouth. It encompasses a range of sensations, such as texture, temperature, viscosity, and the physical sensations experienced while chewing and swallowing. The mouthfeel of food can greatly impact the overall eating experience (Suzuki et al., 2021).

The consumer tests showed that the spreads, both using the alternative protein from torula yeast, are accepted by consumers but still have the potential for sensory optimization. In principle, the torula yeast protein concept was rated positively. Interestingly, in this study, Icelanders seem to have more trust in food value chain actors than Swedes and Germans. In Germany, consumers rated the properties that measure transparency and communication in the food industry, as less expressed, these results being only evaluated as trends as they did not show significance. However, this could be an important signal for players in the German market that increasing attention should be given to communication and transparency to the consumer, considering especially marketing campaigns of developed products containing new alternative proteins (Kornher et al., 2019; Tso et al., 2021).

Early versions of some alternative protein products faced criticism for their taste and texture (Malek et al., 2019; Tso et al., 2021). However, manufacturers made significant strides in improving the taste and quality of these products, making them more palatable to consumers. Cultural preferences, habits, and regional differences can influence how quickly these options become mainstream. Ongoing research, development, and consumer education will likely continue to shape the trajectory of alternative protein acceptance in the years to come (FSA, 2022). In the German market, several trends and factors are gathering efforts to contribute to the growth of the alternative protein sector (Zollman Thomas and Bryant, 2021).

As a result, food neophobia appears to have a strong impact on acceptance within this study. When individuals experience food neophobia, they tend to stick to familiar foods and avoid trying new ones, which can limit their exposure to diverse nutrients and flavors. It has been shown that Icelanders have been more neophobic than Germans and Swedes, regardless of age. It is clear that neophobia can be influenced by cultural norms and social pressures. If certain foods are considered unusual or unfamiliar within a particular culture or social group, individuals may feel even more reluctant to try them (Costa et al., 2020). Neophobic individuals might miss out on

experiencing the richness and diversity of global cuisines (Hopkins et al., 2023). This can hinder their ability to appreciate different flavors and culinary traditions.

The analysis revealed a fascinating interconnection between consumer acceptance and food neophobia. Participants with lower levels of food neophobia exhibited a more positive response to the innovative food products. The statement suggests that individuals who have lower levels of food neophobia tend to show a more positive response to innovative food products. This implies that individuals with lower levels of food neophobia are more likely to embrace and enjoy innovative food products. This positive response may manifest in terms of willingness to try, liking the taste, or overall acceptance of the new food items. Overall, this observation highlights a connection between an individual's openness to trying new foods (lower food neophobia) and their receptiveness to innovative food products. It aligns with the idea that people with a more adventurous or less neophobic attitude toward food are generally more willing to explore and enjoy novel culinary experience. Unfortunately, neither a correlation of food neophobia, trust, and trust toward the food industry with the overall impression of the products nor a linear correlation was able to identify a direct significant relationship. This part emphasizes the difficulty in establishing a direct and significant relationship between various factors (food neophobia, trust, and trust toward the food industry) and the overall impression of the products. The attempts were made to correlate these variables, but none of these attempts revealed a clear and statistically significant connection. Additionally, the mention of linear correlation suggests that we explored whether there was a linear trend or relationship between these variables and overall impression, but this analysis did not yield significant results.

This aligns with previous research suggesting that individuals open to new culinary experiences are more likely to embrace and appreciate novel food items (Jaeger et al., 2021; Siddiqui et al., 2022). The findings highlight the pivotal role of food neophobia as a determinant of consumer acceptance, emphasizing the need for tailored marketing strategies and product positioning to address potential barriers associated with higher levels of food neophobia. The interplay between these background variables suggests a complex web of factors influencing consumer acceptance. For instance, individuals with high trust in stakeholders may be more inclined to overcome initial hesitancy associated with food neophobia (Siegrist and Hartmann, 2020). Additionally, aligning innovative products with specific diet preferences can capitalize on existing consumer habits and preferences, fostering a more positive reception. Therefore, a nuanced analysis of the interplay between consumer acceptance and background variables provides valuable insights into both practitioners and researchers. Recognizing the multifaceted nature of factors influencing consumer behavior allows for more informed product development, marketing strategies, and interventions aimed at overcoming potential barriers to successful commercialization (Šostar and Ristanović, 2023). By considering the holistic context in which consumer decisions are made, stakeholders in the food industry can better tailor their approaches to meet the diverse and evolving needs of their target audience.

Several studies have explored the relationship between personality traits, particularly openness to experience and food preferences (Esposito et al., 2021; Golestanbagh et al., 2021; Pristyna et al., 2022). Individuals with higher levels of openness are generally more adventurous and curious, making them more inclined to explore diverse cuisines and try unfamiliar foods. Cultural factors, exposure to different culinary traditions, and the influence of social and environmental factors also play a role in shaping attitudes of individuals toward new foods (Geuens, 2023). Additionally, positive or negative experiences with trying new foods in the past can impact the willingness of a person to experiment with novel culinary options.

5 Conclusion

Two vegan spread powders, namely a "Leberwurst"-style variant with 14.7% protein and a "Balkan"-style variant with 9.7% protein, have been developed, enriched with high protein content and featuring torula yeast as an innovative alternative protein source. The consumer acceptance test indicated that both spreads received favorable rating, falling within the "like slightly" range. Notably, the "Balkan-style" spread garnered higher consumer preference compared with the "Leberwurst"-style variant. Both products meet the criterion of providing "at least 20% kcal from proteins of total product kcal," qualifying them as "high-protein" and eligible for such claims. Proteins derived from torula yeast are gaining significant attention due to their immense appeal. These proteins boast attributes of being highly scalable, efficient, and sustainable, with production costs that are notably economical in comparison to other sources.

Analysis of background variables revealed that Icelandic consumers exhibit higher neophobic characteristics compared with Swedish and German consumers. Despite higher neophobic characteristics, Icelandic consumers, in general, express more trust in the overall food value chain. This implies that, despite being cautious about trying new things, Icelandic consumers have confidence in the transparency, quality, or reliability of the food supply chain. Additionally, German consumers feel that transparency and communication are lacking in the food value chain. This suggests that there might be concerns or dissatisfaction among German consumers regarding how information about food products is communicated to them. These findings could have implications for businesses and policymakers in understanding and catering to the preferences and concerns of consumers in these respective countries. Understanding the unique characteristics and preferences of consumers in each country can guide businesses and policymakers in developing targeted strategies that address specific concerns and build trust within the food value chain. This approach can contribute to more successful market penetration and improved consumer satisfaction.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethics approval was not required for this study, the research has been part of an EU-funded project and the European Commission

provides information on the main ethical aspects that may arise in research and indicates how each topic might be addressed to ensure compliance at: http://cordis.europa.eu/fp7/ethics_en.html. We followed the Ethics Review and Food-Related Research as mentioned in the official document of European Commission: Guidance Note for Research on Food Issues (europa.eu) (https://ec.europa.eu/research/participants/data/ref/fp7/89847/research-food_en.pdf). As document specified Informed Consent and Data Protection and Privacy were applied. Potentially vulnerable populations were not targeted within this study. Research activities supported have respected the fundamental ethical principles, including those reflected in the Charter of Fundamental Rights of the European Union and take into account opinions of the European Group on Ethics in Science and New Technologies.

Author contributions

A-KG: Formal analysis, Investigation, Writing – original draft. IM: Formal analysis, Writing – review & editing. DG: Investigation, Writing – review & editing. SE: Data curation, Writing – review & editing. KS: Investigation, Writing – review & editing. JN: Formal analysis, Writing – review & editing. AR: Funding acquisition, Project administration, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was carried out in the frame of the NEXTGENPROTEINS project and SYLPLANT project, respectively. NEXTGENPROTEINS has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement no 862704 and SYLPLANT has received funding from the Circular Bio-based Europe Joint Undertaking and its members, under grant agreement no 101112555. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be responsible for them.

Acknowledgments

JN acknowledges Lisa-Maria Oberrauter and Elena Costa for assistance in consumer recruitment and data collection in Sweden.

Conflict of interest

A-KG, DG, SE, AR were employed by Biozoon.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ahuja, K., and Bayas, S. (2021). *Alternative Protein Market for Food Application Size by Source, by Application, Industry Analysis Report, Regional Outlook, Growth Potential, Application Potential, Price Trend, Competitive Market 2021–2027*. Global Market Insights (GMI) Report. Available at: https://www.gminsights.com/industry-analysis/alternative-protein-market-for-food-application

Aschemann-Witzel, J., Gantriis, R. F., Fraga, P., and Perez-Queto, F. J. A. (2020). Plant-based food and protein trend from a business perspective: markets, consumers, and the challenges and opportunities in the future. *Crit. Rev. Food Sci. Nutr.* 61, 3119–3128. doi: 10.1080/10408398.2020.1793730

Banach, J. L., van der Berg, J. P., Kleter, G., van Bokhorst-van de Veen, H., Bastiaan-Net, L., and van Asselt, E. D. (2022). Alternative proteins for meat and dairy replacers: food safety and future trends. *Crit. Rev. Food Sci. Nutr.* 63, 11063–11080. doi: 10.1080/10408398.2022.2089625

Bekatorou, A., Psarianos, C., and Koutinas, A. A. (2006). Production of food grade yeasts. *Food Technol Biotechnol* 44, 407–417.

Costa, A., Silva, C., and Oliveira, A. (2020). Food neophobia and its association with food preferences and dietary intake of adults. *Nutr. Diet.* 77, 542–549. doi: 10.1111/1747-0080.12587

De Kock, H. L., Nkhabutlane, P., Kobue-Lekalake, R. I., Kriek, J., Steyn, A., Purdon, L., et al. (2022). An alternative food neophobia scale (FNS-A) to quantify responses to new foods. *Food Qual. Prefer.* 101:104626. doi: 10.1016/j.foodqual.2022.104626

Di Lena, G., Schwarze, A., Lucarini, M., Gabrielli, P., Aguzzi, A., Caproni, R., et al. (2023). Application of rapeseed meal protein isolate as a supplement to texture-modified food for the elderly. *Foods* 12:1326. doi: 10.3390/foods12061326

Dietrich, T., Villaran Velasco, M. C., Echeverría, P. J., Pop, B., and Rusu, A. (2016). Crop and Plant Biomass as Valuable Material for BBB. Alternatives for Valorization of Green Wastes. In *Biotransformation of Agricultural Waste and By-Products: The Food, Feed, Fibre, Fuel (4F) Economy*. San Diego, CA, USA: Elsevier.

Esposito, C. M., Ceresa, A., and Buoli, M. (2021). The association between personality traits and dietary choices: a systematic review. *Adv. Nutr.* 12, 1149–1159. doi: 10.1093/advances/nmaa166

Fiorentini, M., Kinchla, A. J., and Nolden, A. A. (2020). Role of sensory evaluation in consumer acceptance of plant-based meat analogs and meat extenders: a scoping review. *Foods* 9:1334. doi: 10.3390/foods9091334

FSA (2022). *Alternative Proteins for Human Consumption*. Food Standards Agency.

Geuens, M. (2023). Research on influencing factors of food choice and food consumption. *Foods* 12:1306. doi: 10.3390/foods12061306

Golestanbagh, N., Miraghajani, M., Amani, R., Symonds, M. E., Neamatpour, S., and Haghighizadeh, M. H. (2021). Association of Personality Traits with dietary habits and food/taste preferences. *Int. J. Prev. Med.* 12:92. doi: 10.4103/ijpvm.IJPVM_19_19

Grahl, S., Strack, M., Mensching, A., and Mörlein, D. (2020). Alternative protein sources in Western diets: food product development and consumer acceptance of spirulina-filled pasta. *Food Qual. Prefer.* 84:103933. doi: 10.1016/j.foodqual.2020.103933

Grossmann, L., and Weiss, J. (2021). Alternative protein sources as techno functional food ingredients. *Annu. Rev. Food Sci. Technol.* 12, 93–117. doi: 10.1146/annurev-food-062520-093642

Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M., and Tiwari, B. (2017). Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. *Foods* 6:53. doi: 10.3390/foods6070053

Hopkins, I., Farahnaky, A., Gill, H., Danaher, J., and Newman, L. P. (2023). Food neophobia and its association with dietary choices and willingness to eat insects. *Front. Nutr.* 10:1150789. doi: 10.3389/fnut.2023.1150789

Ismail, B. P., Senaratne-Lenagala, L., Stube, A., and Brackenridge, A. (2020). Protein demand: review of plant and animal proteins used in alternative protein product development and production. *Anim. Front.* 10, 53–63. doi: 10.1093/af/vfaa040

Jach, M. E., Serefko, A., Ziaja, M., and Kieliszek, M. (2022). Yeast protein as an easily accessible food source. *Meta* 12:63. doi: 10.3390/metabo12010063

Jaeger, S. R., Chheang, S. L., and Prescott, J. (2021). Variations in the strength of association between food Neophobia and food and beverage acceptability: a data-driven exploratory study of an arousal hypothesis. *Nutrients* 13:3657. doi: 10.3390/nu13103657

Jeong, S., and Lee, J. (2021). Effects of cultural background on consumer perception and acceptability of foods and drinks: a review of latest cross-cultural studies. *Curr. Opin. Food Sci.* 42, 248–256. doi: 10.1016/j.cofs.2021.07.004

Joseph, P., Searing, A., Watson, C., and McKeague, J. (2020). Alternative proteins: market research on consumer trends and emerging landscape. *Meat Muscle Biol* 4, 1–11. doi: 10.22175/mmb.11225

Kornher, L., Schellhorn, M., and Vetter, S. (2019). Disgusting or innovative-consumer willingness to pay for insect based burger patties in Germany. *Sustainability* 11:1878. doi: 10.3390/su11071878

Leeper, A., Ekmay, R., Knobloch, S., Skírnisdóttir, S., Varunjikar, M., Dubois, M., et al. (2022). Torula yeast in the diet of Atlantic salmon Salmo salar and the impact on growth performance and gut microbiome. *Sci. Rep.* 12:567. doi: 10.1038/s41598-021-04413-2

Lezcano, P., and Herrera, M. (2013). Evaluation of torula yeast (*Candida utilis*) grown on distillery vinasse for broilers. *Cuban J Agric Sci* 47, 183–188.

Malek, L., Umberger, W. J., and Goddard, E. (2019). Committed vs. uncommitted meat eaters: understanding willingness to change protein consumption. *Appetite* 138, 115–126. doi: 10.1016/j.appet.2019.03.024

Mbuto, E. J. (2017). Influence of Torula Yeast (Candida utilis) as a Fishmeal Replacer on Rheological and Physical Qualities of Pelleted Shrimp Feed (Master's Thesis, Norwegian University of Life Sciences, Ås).

Mcready, A. L., Hieke, S., Klimczuk-Kochanska, M., Szumiat, S., Vranken, L., and Grunert, K. G. (2020). Consumer trust in the food value chain and its impact on consumer confidence: a model for assessing consumer trust and evidence from a 5-country study in Europe. *Food Policy* 92:101880. doi: 10.1016/j.foodpol.2020.101880

Michel, F., Knaapila, A., Hartmann, C., and Siegrist, M. (2021). A multi-national comparison of meat eaters' attitudes and expectations for burgers containing beef, pea or algae protein. *Food Qual. Prefer.* 91:104195. doi: 10.1016/j.foodqual.2021.104195

Olvera-Novoa, M. A., Martínez-Palacios, C. A., and Olivera-Castillo, L. (2002). Utilization of torula yeast (*Candida utilis*) as a protein source in diets for tilapia (*Oreochromis mossambicus* Peters) fry. *Aquac. Nutr.* 8, 257–264. doi: 10.1046/j.1365-2095.2002.00215.x

Onwezen, M. C., Bouwman, E. P., Reinders, M. J., and Dagevos, H. (2021). A systematic review on consumer acceptance of alternative proteins: pulses, algae, insects, plant-based meat alternatives, and cultured meat. *Appetite* 159:105058. doi: 10.1016/j.appet.2020.105058

Pristyna, G., Mahmudiono, T., Rifqi, M. A., and Indriani, D. (2022). The relationship between big five personality traits, eating habits, physical activity, and obesity in Indonesia based on analysis of the 5th wave Indonesia family life survey (2014). *Front. Psychol.* 13:881436. doi: 10.3389/fpsyg.2022.881436

Rusu, A., Randriambelonoro, M., Perrin, C., Valk, C., Álvarez, B., and Schwarze, A. K. (2020). Aspects influencing food intake and approaches towards personalising nutrition in the elderly. *J Popul Ageing* 13, 239–256. doi: 10.1007/s12062-019-09259-1

Sawicka, B., Umachandran, K., Nasir, N. A., and Skiba, D. (2020). "Alternative and new protein sources", in *Functional Foods and Nutraceuticals: Bioactive Components Formulations and Innovations*. eds. C. Egbuna, G. D. Tupas (Cham, Switzerland: Springer Nature Switzerland AG), 109–137.

Siddiqui, S. A., Zannou, O., Karim, I., Awad, N. M. H., Gołaszewski, J., Heinz, V., et al. (2022). Avoiding food Neophobia and increasing consumer acceptance of new food trends—a decade of research. *Sustainability* 14:10391. doi: 10.3390/su141610391

Siegrist, M., and Hartmann, C. (2020). Perceived naturalness, disgust, trust and food neophobia as predictors of cultured meat acceptance in ten countries. *Appetite* 155:104814. doi: 10.1016/j.appet.2020.104814

Šostar, M., and Ristanović, V. (2023). Assessment of influencing factors on consumer behavior using the AHP model. *Sustainability* 15:10341. doi: 10.3390/su151310341

Suzuki, Y., Narumi, T., Tanikawa, T., and Hirose, M. (2021). Taste in motion: the effect of projection mapping of a boiling effect on food expectation, food perception, and purchasing behavior. *Front. Comput. Sci.* 3:662824. doi: 10.3389/fcomp.2021.662824

Tso, R., Lim, A. J., and Forde, C. G. (2021). A critical appraisal of the evidence supporting consumer motivations for alternative proteins. *Foods* 10:24. doi: 10.3390/foods10010024

Verstringe, S., Vandercruyssen, R., Carmans, H., Rusu, A. V., Bruggeman, G., and Trif, M. (2023). "Alternative proteins for food and feed" in *Biodiversity, Functional Ecosystems and Sustainable Food Production*. ed. C. M. Galanakis (Cham: Springer)

Zollman Thomas, O., and Bryant, C. (2021). Don't have a cow, man: consumer acceptance of animal-free dairy products in five countries. *Front Sustain Food Syst* 5, 1–14. doi: 10.3389/fsufs.2021.678491

frontiers | Frontiers in Nutrition

TYPE Original Research
PUBLISHED 16 February 2024
DOI 10.3389/fnut.2024.1348275

OPEN ACCESS

EDITED BY
Laura Rossi,
Research Centre on Food and Nutrition, Italy

REVIEWED BY
Shemsu Kedir,
Werabe University, Ethiopia
Daniel Atlaw,
Madda Walabu University, Ethiopia

*CORRESPONDENCE
Wubetu Woyraw
✉ wubetu662@gmail.com

RECEIVED 02 December 2023
ACCEPTED 06 February 2024
PUBLISHED 16 February 2024

CITATION
Temesgen H, Woyraw W, Feleke FW, Mezgebu GS, Taye K and Awoke T (2024) Iron folic acid supplementation adherence level and its associated factors among pregnant women in Ethiopia: a multilevel complex data analysis of 2019 Ethiopian mini demographic and health survey data.
Front. Nutr. 11:1348275.
doi: 10.3389/fnut.2024.1348275

Iron folic acid supplementation adherence level and its associated factors among pregnant women in Ethiopia: a multilevel complex data analysis of 2019 Ethiopian mini demographic and health survey data

Habtamu Temesgen[1,2], Wubetu Woyraw[1,2]*, Fentaw Wassie Feleke[2,3], Getachew Sale Mezgebu[2], Kefyalew Taye[2,4] and Tadesse Awoke[5]

[1]Department of Nutrition, College of Health Science, Debre Markos University, Debre Marqos, Ethiopia, [2]School of Human Nutrition, College of Agriculture, Hawassa University, Hawassa, Ethiopia, [3]Department of Public Health, College of Health Science, Woldia University, Woldia, Ethiopia, [4]Department of Public Health, College of Health Science, Ambo University, Ambo, Ethiopia, [5]Institute of Public Health, College of Health Science, University of Gondar, Gondar, Ethiopia

Background: Iron and folic acid deficiency is a worldwide public health concern, particularly in low and middle-income countries. In Ethiopia, adherence to iron and folic acid supplements is still very low. Despite the fact that a number of studies on IFA supplementation have been conducted in Ethiopia, they do not indicate a nationwide problem and do not use advanced models to demonstrate clustering effects. The purpose of this study was to assess the level of non-adherence to iron folic acid supplementation and predictors among pregnant women in Ethiopia.

Objective: To assess iron folic acid supplementation adherence level and its associated factors among pregnant women in Ethiopia using data from the 2019 Mini-Ethiopian demographic health survey.

Methods: The Mini Ethiopian Demographic and Health Survey 2019 data were obtained from the official database website of the Demographic and Health Survey program (http://dhsprogram.com). The analysis included a sample of 2,356 weighted study participants. A multivariable multilevel mixed-effects logistic regression model was used Variables with *p*-values less than 5%) was reported as statistically significant variables in the multivariable analysis.

Results: The proportion of mothers who did not adhere to iron and folic acid supplements was 81.03% (95 %CI, 79.39, and 82.56). Birth interval less than 2years [AOR: 2.03; 95% CI: 1.12, 3.66], women ever born less than six children [AOR: 1.99; 95% CI: 1.09, 3.64], starting ANC visit during first trimester [AOR: 2.74; 95 %CI: 1.03, 7.30], region [AOR=0.24; 95% CI: 0.10], and having a high no ANC visit in the community [AOR=1.77; 95% CI: 1.08, 2.88] were statistically significant factors. There was Intra-Custer Correlation (ICC=17.72%), indicating that 17.72% variability in non-adherence levels was due to clusters.

Conclusion and recommendation: In Ethiopia, nearly four out of every five pregnant women did not receive iron folic acid supplementation for the

recommended periods. Birth intervals, number of children, timing of ANC visits, region, and community level no ANC service were significant factors for non-adherence IFAS. As a result, the community, govern metal and non-governmental sectors enacting on health should focus on reducing non-adherence through tailored interventions on factors that influence it.

KEYWORDS

non-adherence, iron folic acid supplementation, Mini-EDHS 2019, women, Ethiopia

Introduction

Iron and folic acid deficiency is a global public health concern, particularly in low and middle-income countries (1). Iron with folic acid is an important micronutrient for physiological function, growth, and development, as well as the mother's and her fetus's survival during pregnancy and later life. Similar to other nutrients, the demand for and scarcity of iron and folic acid increase during pregnancy to meet the daily requirement for the fetus's life development and growth (2).

The World Health Organization (WHO) estimates that iron deficiency is responsible for approximately 50% of all anemia cases (3). More than 56 million pregnant women suffer from anemia worldwide, with Africa accounting for two-thirds (17.2 million) (4) According to the Ethiopian Demographic and Health Survey (EDHS), the prevalence of anemia among women aged 15–49 years fell from 27 to 17% in 2011, but increased to 24% in 2016, with pregnant women accounting for 29% (5). Similarly, different studies conducted in Ethiopia show that the prevalence of anemia among pregnant women was between 21 and 54% (6–10).

A large population based study conducted among 22 Sub-Saharan African countries showed that only 28.7% of women took iron supplements for ≥90 days during pregnancy (11). The Ethiopian demographic health survey of 2016 reported that only 5% of pregnant women took an iron with a folic acid tablet for 90 days and 58% of pregnant women did not at all during their time of pregnancy (12). A meta-analysis studies done in 2019 and 2020 show that the pooled estimated prevalence of adherence to iron-folic acid supplementation among pregnant women in Ethiopia was 41.38 and 46.15% ranging from the lowest 17.1% to the highest 74.5%, respectively, (13, 14).

Findings from different literature shows that poor knowledge and awareness about anemia during pregnancy, inaccessibility of IFAS, fear of side effects, believed to be responsible for not conforming to the recommended IFAS during pregnancy, utilization of ANC services, inadequate supply of IFA tablets, poor counseling and lack of knowledge on anemia were the identified associated factors for poor adherence to IFAS (15–17).

Iron and folic acid supplementation (IFAS) with optimal adherence is the main cost-effective strategy for prevention and control of iron and folate deficiency anemia during pregnancy (18). IFAS during pregnancy was shown to reduce the risk of all types of maternal anemia by 70% and iron deficiency anemia by 57% (19).

World Health Organization recommends that all pregnant women receive a standard dose of 30–60 mg iron and 400-μg (0.4 mg) folic acid beginning as early as possible during gestation. Ideally, women should take 180 tablets before delivery; however, many countries, including, Ethiopia aim for women to receive 90+ tablets during pregnancy (20).

Reducing anemia is an important component of achieving women's and children's health. The second global nutrition targeted a 50% reduction of anemia in women of reproductive age in 2025 (21). Similarly, Ethiopia National Nutrition Program (NNP II) also set a key target to increase the number of women receiving iron-folic acid supplements for more than 90 days during pregnancy to 40% by 2020 (22).

Despite the fact that various studies have been conducted in Ethiopia to assess the magnitude and factors associated with iron supplementation adherence, these studies were conducted on a small number of participants and are therefore not representative of the general population. Furthermore, the majority of these studies were conducted on pregnant women receiving ANC services in health facilities, which may have inflated their findings. As a result, the current study used a two-stage multilevel mixed-effects logistic regression model with Mini-EDHS 2019 data to identify individual and community-level predictors of iron to folic acid supplementation during pregnancy.

Methods

Study area and data source

The data were retrieved from the Ethiopia Mini Demographic and Health Survey (DHS), 2019 program's official database website.[1] Ethiopia is a Federal Democratic Republic with 11 geographical regions where the two are city administrations. Regional states are divided into zones, and zones are subdivided into woredas, and woredas into kebeles, the lowest administrative units. The 2019 mini-DHS were conducted in all the geographic areas of the country from March 21, 2019, to June 28, 2019. In terms of its population size, Ethiopia is the second most populous nation in Africa with more than

Abbreviations: AOR, Adjusted Odds Ratio; ANC, Ante-Natal Care; CI, Confidence Interval; ICC, Intra-Cluster Correlation; IFAS, Iron Folic Acid Supplementation; MEDHS, Min-Ethiopian Demographic Health Survey; NNP, National Nutrition Program; WHO, World Health Organization.

1 https://dhsprogram.com/data/available-datasets.cfm

112 million people (56,010, 000 Females and 56, 069, 000 Males) in 2019. Women of reproductive ages (15–49 Years) represent 21% of the population in the country (MDHS, 2019).

Study participants

The Mini Ethiopian Demographic and Health Survey (MEHDS) was conducted to reproductive-age women. This study targeted women between the ages of 15 and 49 years who had their last child within the 5 years preceding the survey in Ethiopia, EMDHS 2019. A weighted 2,356 women who had received IFA supplements and were asked how many days they consumed IFA tablets/ syrup during their last pregnancy that occurred 5 years prior to the mini national survey were included in the sample, and the dataset we used was the maternal dataset.

Study variable

Dependent variable: The outcome variable of this study was IFA supplementation adherence level.

IFA adhered: Those mothers who took the supplement of IFA for the recommended periods which is 90 days or more.

Not adhered: mothers who took the IF supplement for less than the recommended periods (less than 90 days).

Independent variables: All the independent variables were classified into individual-level and community-level variables.

Individual-level variables: Maternal age, religion, wealth index, women's education level, parity, ANC visits, birth interval, number of children ever born marital status, head of the household and number of ANC visits.

Community-level variables: The two non-aggregate community-level factors were place of residence and region. Community women illiteracy, poverty, and no ANC visit were variables derived from aggregating individual-level variables. Based on the distribution of the average values calculated for each cluster, each aggregate variable was classified as "high" or "low." The median value was used for aggregate variables, and the median value was used as a cut off point for categorization. As a result, these variables were measured in the following manner.

Community women's illiteracy level

Low: The proportion of illiterate below the median of illiteracy level.

High: The proportion of illiterate higher than the median illiteracy level.

Proportion of no ANC at the community

Low: The proportion of no ANC visit in the clusters below the median level.

High: The proportion of no ANC visit in the clusters median and above level.

Community poverty level

Low: The proportion of poor below the median of poor wealth index.

High: The proportion of poor above the median of poor wealth index.

Data analysis

The analysis was carried out using Stata 17.0. The data were weighted using a primary sampling unit to restore representativeness and obtain a reliable estimate. The proportions and frequencies were estimated weighted for each variable. This was based on a thorough explanation of the mini-EDHS sample weighting procedure (23). Continuous variables were categorized and re-categorize using information obtained from various works of literature. The variables were described using descriptive statistics.

Due to the hierarchical nature of the 2019 EDHS data, a multilevel mixed effect binary logistic regression analysis was fitted in this study to estimate the effects of individual and community-level determinants of IFA supplementation non-adherence.

We have employed a complex multilevel data analysis technique (melogit [pweight = wt] || v001:) to adopt a comprehensive approach in examining intricate survey data through a multilevel logistic regression model. By utilizing this method, we effectively address the complexities of the survey design and ensure the provision of accurate statistical inferences.

To select potential variables for multivariable analysis, bivariable multilevel binary logistic regression analysis was performed on each independent individual and community level variable. Finally, multivariable multilevel analysis was performed, and variables that showed a significant association at p value less than 0.05 with adjusted odds ratio and 95% CI were reported as statistically significant factors for IFA supplementation non-adherence in Ethiopia.

Model building and selecting the best-fitted model

To identify the potential factors associated with non-adherence to iron folic acid supplementation, a multilevel mixed effect binary logistic regression was fitted. The null model (Model I) was fitted first. The variance of the random effect in this model was 0.71, indicating that there is significant variation across clusters. There was also Intra-Custer Correlation (ICC = 17.72%), indicating that 17.72% variability in non-adherence levels was due to clusters. Model II was fitted after bivariable analysis by adding individual level factors to the null model. Model III was then fitted by incorporating the community level variables into the null model. Finally, model IV was fitted by combining individual level and community level factors. The final model (Model IV) was appropriate to identify the individual and community level factors of non-adherence to iron folic acid supplementation in Ethiopia after checking the model fitness level using different post estimation methods (AIC, BIC, and loglikelihood) (Table 1). Variable Inflation Factors (VIF) and tolerance level were used to check for multicollinearity among independent variables, and there was no collinearity across variables.

10.3389/fnut.2024.1348275

TABLE 1 Variability at community-level and model comparison for iron folic acid supplementation adherence among women age 15–49 with a child born in the 5 years preceding the survey in Ethiopia, EMDHS 2019.

Parameters	Null model	Model II	Model III	Model IV
ICC	17.72%			
AIC	2198.684	2200.598	1547.79	1535.278
BIC	2210.171	2217.829	1613.219	1649.778
Log likelihood	−1097.342	−1097.299	−761.8949	−746.639

Results

Socio-demographic characteristics of women

The data were first weighted. The analysis included 2,356 women who were given/brought for supplementation during pregnancy out of a total of 3,927 women aged 15–49 with the last child born in the 5 years preceding the survey. Of the total respondents, 1,256 (53.33%) were between the age group of 25–34 years, nearly (42%) had no formal education, and the majority (94.1%) were currently in union. The majority of the mothers were Orthodox Christian (44.81%) followers, 46.96% of respondents were from the rich households, and 86.95% had 6 or more children ever born. From the total number of participants, 69.61% were from rural areas, and 867 (36.81%) were from Tigray and Amhara regions. Almost 1,100 women (46.69%) come from wealthy families, while 769 (32.66%) come from low-income families. Almost 86.95% of the households were headed by a man, and the majority of women (83.74%) had a birth interval of 2 years or more between the births of the index child (Table 2).

In terms of community educational level, 1,273 (54.03%) of women in the community had low literacy level, and 1,393.39 (59.15%) of the community had low poverty level (Table 2).

Women's characteristics related to maternal health service utilization

In this survey, 271 (11.49%) women were confirmed pregnant at the time of the survey, and 56.26 percent began ANC during the second trimester. The majority of the women (56.20%) was multiparous and had four or more ANC visits during their pregnancy (57.60%). One thousand three hundred thirty-seven (56.76%) of the women in the community have low proportion of not having ANC visits (Table 3).

The magnitude of adherence level to iron folic acid supplementation of pregnant women in Ethiopia

Iron folic acid supplements were given to 2,356 women (59.99%). Among those, 1,909 (81.03% (95% CI: 79.39, 82.56)) of women did not follow WHO recommendations for iron folic acid (IFA) supplementation, while 18.97% of women in Ethiopia adhered to iron folic supplementation in Ethiopia (Figure 1).

TABLE 2 Socio-demographic characteristics of Ethiopian women aged 15–49 with a child born in the 5 years preceding the survey, EMDHS 2019.

Variables	Category	Frequency	Percentage
Maternal age	15–24 years	625.5	26.55
	25–34 years	1,256.2	53.33
	35–39 years	308.9	13.11
	40–49 years	164.9	7.00
Maternal educational level	No education	986.9	41.89
	Primary	956.99	40.63
	Secondary and higher	411.71	17.48
Religion	Orthodox	1,055.5	44.81
	Muslim	700.2	29.73
	Protestant	571.5	24.26
	Others	28.35	1.20
Residence	Urban	715.77	30.39
	Rural	1,639.78	69.61
Region	Tigray_Amhara	866.99	36.81
	Oromia	832.5	35.34
	SNNPR	434.45	18.44
	Most urbans	114.84	4.88
	Eastern pastoralist	66.86	1.69
Marital status	Currently in union	2,216.3	94.1
	Currently not in union	139.3	5.9
Household wealth index	Poor	769.38	32.66
	Medium	486.27	20.64
	Rich	1,099.90	46.69
Community women education(illiterate)	Low	1,272.65	54.03
	High	1,082.91	45.97
Community poverty	Low	1,393.39	59.15
	High	962.16	40.85
Birth interval	Less than 2 years	289.67	16.26
	Two and more years	1,491.97	83.74
Number of children ever born	Less than 6	1,889.75	80.22
	6 and above	465.81	19.78
Head of the household	Male headed	2,048.07	86.95
	Female headed	307.49	13.05

Factors associated with non-adherence to iron folic acid supplementation

To identify the potential factors associated with non-adherence to iron folic acid supplementation, a multilevel mixed effect binary logistic regression was fitted. The final model (Model IV) was appropriate to identify the individual and community level factors of

10.3389/fnut.2024.1348275

TABLE 3 The characteristics of maternal health service utilization of women aged 15–49 who had a child in the 5 years preceding the MEDHS 2019.

Variables	Category	Frequency	Percentage
Parity	uni para	565.94	24.03
	Multi para	1,323.81	56.20
	Grand multipara	465.81	19.78
Currently pregnancy	no or unsure	2,084.99	88.51
	Yes	270.56	11.49
Timing of first ANC visit	First trimester	853.33	36.23
	Second trimester	1,325.20	56.26
	Third trimester	177.02	7.52
Number of ANC visit during pregnancy	No ANC visit	106.11	4.50
	1–3 ANC visit	892.73	37.90
	4 and above ANC visit	1,356.72	57.60
Proportion of no ANC in the community	Low	1,337.04	56.76
	High	1,018.52	43.24

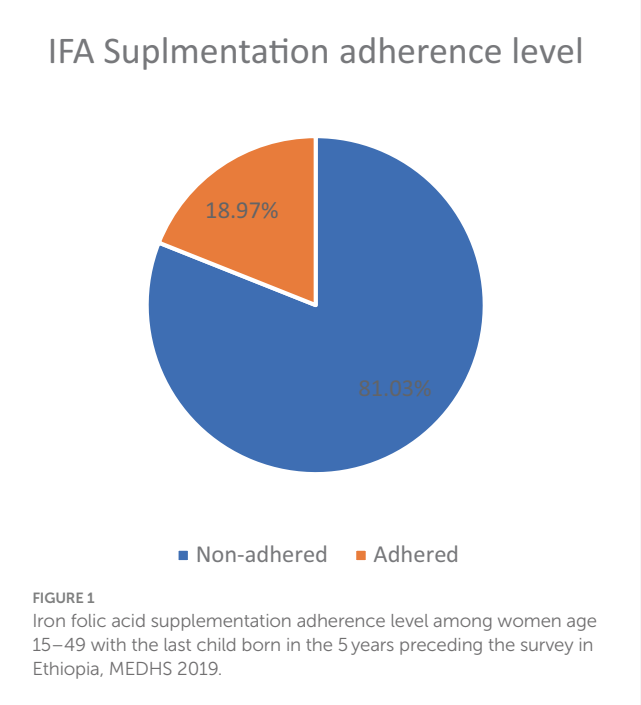


FIGURE 1
Iron folic acid supplementation adherence level among women age 15–49 with the last child born in the 5 years preceding the survey in Ethiopia, MEDHS 2019.

non-adherence to iron folic acid supplementation in Ethiopia after checking the model fitness level using different post estimation methods (AIC and loglikelihood) (Table 1). According to the multilevel multivariable analysis results Birth interval, the number of children ever born, timing of First ANC visit, region, and proportion of no ANC in the community were statistically significant factors of non-adherence to iron folic acid supplementation in Ethiopia (Table 4).

The odds of non-adherence to iron folic acid supplementation of pregnant women having birth interval less than 2 years were 2times higher than having two and above years birth interval [AOR: 2.03; 95%CI: 1.12,3.66; at $p < 0.05$]. The odds of non-adherence to iron to folic acid supplementation of pregnant women ever born less than 6 children were also 1.99 times higher than whoever born 6 and more children [AOR: 1.99; 95% CI: 1.09, 3.64 at $p < 0.05$]. The timing of first ANC visit was also significant factor for non-adherence. Those mothers who started there ANC visit during first trimester were 2.74 times more likely become non-adherence to iron folic acid supplementation when compared to who started in third trimester [AOR: 2.74; 95% CI: 1.03, 7.30 at $p < 0.05$].

On the other hand, mothers from SNNPR were decreases the non-adherence to IFA supplementation by 76% when compared to Tigray Amhara region [AOR = 0.24; 95%CI: 0.10, 0.61 at $p < 0.01$]. The odds of non-adherence to iron folic acid supplementation also were 1.77 times higher among higher Proportion of no ANC in the community than counter parts [AOR = 1.77; 95%CI: 1.08, 2.88 at $p < 0.05$] (Table 4).

Variability at community level and model comparison to select the appropriate model

Variability at community-level and Model comparison for iron folic acid supplementation adherence among women age 15–49 with a child born in the 5 years preceding the survey in Ethiopia, EMDHS 2019 as shown in Table 4.

Discussion

Iron folic acid supplementation is critical in the prevention and treatment of iron deficiency anemia, especially in pregnant women whose iron requirements increase due to fetal and maternal needs (24). Thus, the purpose of this study was to assess the level of non-adherence to iron folic acid supplementation during pregnancy and its associated factors among Ethiopian women aged 15–49 years who had the last child in the previous 5 years using MEDHS 2019. The overall magnitude of non-adherence to iron folic acid supplementation was high in Ethiopia. Birth interval, number of children ever born, and time of ANC visit were individual level factors that were significantly associated with non-adherence to iron folic acid supplementation during pregnancy in Ethiopia, whereas region and proportion of community no ANC visit were community level factors.

In Ethiopia, the overall magnitude of non-adherence to iron folic acid supplementation during perinatal periods was 81.03% among women aged 15–49 years. This finding is higher than the meta-analysis study conducted in Ethiopia (53.85, 58.62%) (13, 14), different single study reports in Ethiopia (24–27), 22 African countries DHS data (71.3%) (11), DHS data report of Haiti (68%) and Malawi (65%) (28), meta-analysis in SSA (60.8%) (29) and the study done in Kenya (30). The magnitude of non-adherence in this study was also slightly lower than the magnitude of non-adherence to iron folic acid supplementation reported in Ethiopia using EDHS 2016 (86.6%) (31, 32) and the magnitude of non-adherence in northern Ethiopia (89.5%) (33). Furthermore, according to the EDHS 2016, 95% of pregnant women took iron folic acid for less than 90 days. The difference could be due to the study design, as the current study used a large-scale survey, whereas the others used meta-analysis and a

10.3389/fnut.2024.1348275

TABLE 4 Individual and community level factors associated with iron folic acid supplementation adherence among women age 15–49 with the last child born in the 5 years preceding the survey in Ethiopia, MEDHS 2019.

Variables		IFA supplantation adherence level		COR at 95% CI	AOR at 95% CI
		Non adhered	Adhered		
Age of the women	15–24 years	485.36	140.14	1	1
	25–34 years	1,023.09	233.10	0.70(0.46, 1.07)	1.14(0.52, 2.48)
	35–49 years	400.14	73.74	0.57(0.34, 0.95)*	1.44(0.60, 3.45)
Religion	Orthodox	865.26	190.26	1	1
	Muslim	542.72	157.49	1.40(0.90, 2.14)	1.70(0.91, 3.19)
	Protestant	476.11	95.36	0.95(0.52, 1.74)	1.68(0.73, 3.82)
	Others	24.49	3.85	0.53(0.054,5.25)	1.22(0.08, 17.48)
Birth interval	Less than 2 years	217.57	72.10	1.71(0.93, 3.14)*	2.03(1.12,3.66)*
	Two and more years	1,249.69	242.28	1	1
Number of children ever born	Less than 6	1,504.81	384.94	1.96(1.17, 3.29)*	1.99(1.09, 3.64)*
	6 and above	403.79	62.03	1	1
Timing of first ANC visit	First trimester	636.41	216.93	3.80(1.47, 9.80)*	2.74(1.03, 7.30)*
	Second trimester	1,112.37	212.83	2.06(0.79, 5.344)	1.61(0.59, 4.39)
	Third trimester	159.81	17.21	1	1
Household head	Male	1,648.90	399.17	1	1
	Female	259.69	47.80	0.64(0.44, 0.92)*	0.64(0.36, 1.15)
Region	Tigray_ Amhara	705.27	161.73	1	1
	Oromia	633.66	198.83	1.5(0.96, 2.35)	1.23(0.61, 2.49)
	SNNPR	399.66	34.79	0.37(0.21, 0.67)*	0.24(0.10, 0.61)*
	Most urbans	81.49	33.35	2.02(1.38, 2.95)*	1.44(0.73, 2.84)
	Eastern pastoralist	57.87	8.99	0.72(0.38, 1.35)	0.49(0.19,1.29)
	Western semi-pastoralist	30.65	9.27	1.42(0.87, 2.30)	1.53(0.69,3.39)
Residence	Urban	567.28	148.49	1	1
	Rural	1,341.31	1,639.78	0.73(0.50, 1.06)	1.16(0.61, 2.20)
Community illiteracy level	Low	1,008.38	264.26	1	1
	High	900.21	182.70	0.91(0.64, 1.30)	0.99(0.51, 1.90)
Community poverty	Low	1,103.67	289.72	1	1
	High	804.92	157.25	0.74(0.52,1.05)	0.68(0.39, 1.18)
Proportion of no ANC in the community	Low	1,076.53	260.51	1	1
	High	832.06	186.46	0.95(0.66, 1.36)	1.77(1.08, 2.88)*

*Indicates variable which have association with outcome variable.

single survey in a limited area. Another explanation for the variation could be recall bias for EDHS data, which increases non-adherence while most individual studies are conducted at the institution level during the time of ANC follow up. Furthermore, this finding was lower than the EDHS, 2016 different reports, and this is due to various interventions made between 2016 and 2019. Another reason for the variation could be due to study periods and location.

In this study, pregnant women with birth intervals of less than 2 years had twice the odds of not taking IFA supplements as compared with birth intervals of 2 years or more. This finding is consistent with the findings of a study on Folic Acid Supplementation and Interpregnancy Interval in Norway (34) and a study in Tanzania (35). The shorter birth intervals were primarily due to a lower proportion of planned pregnancies (34). Because of the unplanned pregnancy, the iron folic acid supplementation is not taken as recommended.

Mothers who have had fewer than six children are more likely to have poor adherence for IFA supplementation than mothers who have had six or more children.

Mothers with less than six children are more prone to non-adherence to iron and folic acid (IFA) supplementation due to several justifiable reasons. Firstly, mothers with fewer children often have a relatively younger age, which can be associated with a lack of experience and knowledge regarding the importance of IFA supplementation during pregnancy. They may be less aware of the potential risks and benefits of IFA supplementation, leading to a higher likelihood of non-adherence.

Secondly, mothers with six or more children tend to have a higher level of experience and familiarity with pregnancy and maternal health practices. They have likely received more exposure to healthcare information and interventions, including IFA supplementation, throughout their previous pregnancies. This accumulated experience and knowledge may contribute to a higher level of adherence among this group. Therefore, the higher level of adherence among mothers with six or more children can be attributed to a combination of factors, including increased awareness, experience, knowledge, and support. Timing of the first ANC visit was one of the significant factors for non-adherence to IFA supplementation during pregnancy. This study found that mothers who started their ANC in the first trimester were 2.7 times more likely to be non-compliant than mothers who started in the third trimester. This finding contradicts the findings of a study conducted in Gondar and Debre Tabor hospitals, which found that beginning the first ANC visit increases IFA supplementation adherence (25, 27) and Ethiopian ANC strategy which demonstrated that initiating the first ANC visit actually increased adherence to IFA supplementation. During pregnancy, it is best to begin iron and folic acid supplementation as soon as possible. Most Ethiopian women do not begin iron folic acid supplementation during the first trimester of pregnancy because the majority of them discover their pregnancy after the first trimester and begin ANC during the second half of pregnancy (36).

This delay in starting IFA supplementation is often attributed to late pregnancy detection, as many women only discover their pregnancy after the first trimester and subsequently initiate ANC visits.

Interestingly, when women do begin ANC visits in the first trimester, they may also commence IFA supplementation during this time. However, this early initiation of IFA supplementation can lead to physiological disturbances, particularly gastrointestinal discomfort, which commonly occurs during the first trimester. Consequently, some women may discontinue taking IFA due to these adverse effects. This initial negative reaction to IFA tablets during the first trimester can have a lasting impact on adherence to IFA supplementation in subsequent months of pregnancy, ultimately resulting in non-compliance with the World Health Organization's (WHO) recommendations.

It is recommended to start IFA supplementation early in pregnancy, the timing of the first ANC visit plays a significant role in adherence to IFA supplementation. The contradictory findings between studies emphasize the need for further research and tailored interventions to ensure optimal adherence to IFA supplementation throughout pregnancy, taking into account the specific context and challenges faced by pregnant women.

We found that IFA supplement non-adherence is associated with clusters with a higher proportion of no ANC in the community. Non-adherence to iron folic acid supplementation was also 1.77 times higher in communities with a higher proportion of no ANC than in others. This finding is consistent with Ethiopian studies (32, 37), Haiti and Malawi (28). This could be because an ANC visit is the entry point for utilizing maternal health care services such as IFA supplementation. This fosters in the community positive compliance behavior in the use of IFA supplements.

The findings also revealed that there is variation in IFA supplement adherence across regions, which is treated as a community level variable. Women in SNNPR had higher levels of adherence than women in northern Ethiopia (Amhara-Tigray). Mothers residing in the SNNPR region exhibited a significantly lower rate of non-adherence to IFA supplementation, with a reduction of 76% compared to mothers residing in the Tigray Amhara region. This finding contradicts previous research findings in Ethiopia (13). The observed variation in non-adherence to IFA supplementation between the SNNPR and Tigray Amhara regions can be attributed to intensified intervention efforts by governmental and non-governmental organizations. These interventions were implemented in response to previous studies reporting inadequate adherence and supplement utilization in the SNNPR region. It is possible that this discrepancy reflects the regional and federal government's commitment to enhancing intervention strategies, particularly in maternal services, with a specific focus on improving adherence to IFA supplementation. In this study; we tried to investigate individual and community-level factors associated with non-adherence to IFA supplementation in Ethiopia. As a result, it is more representative, and policymakers and other stakeholders can use the study's findings to plan and implement effective strategies and interventions. This study, however, has some limitations. Because the outcome variable was assessed based on the maternal report within the 5 years preceding the survey, the study was subject to recall bias. Furthermore, some of the data was incomplete and difficult to analyze.

Conclusion and recommendations

In Ethiopia, nearly four out of every five pregnant women did not receive iron folic acid supplementation for the recommended periods. Birth intervals of less than 2 years, women having fewer than six children, and beginning ANC visits during the first trimester were individual level factors that increase the non-adherence to iron folic acid supplementations. Non-adherence to iron folic acid supplementation in Ethiopia was also influenced by region and community level on ANC service. Thus, the following recommendations are important.

Promote birth spacing: Encourage women to have a birth interval of at least 2 years between pregnancies. This can be done through family planning programs and education on the importance of birth spacing for maternal and child health.

Enhance maternal health services: Focus on women who have had fewer than six children, as they were found to have a higher likelihood of non-adherence. Strengthen antenatal care (ANC) services by ensuring early initiation of ANC visits during the first trimester. This can be achieved through awareness campaigns and improving access to quality ANC services.

Regional interventions: Consider regional variations in non-adherence rates and tailor interventions accordingly. Identify regions with higher non-adherence rates and implement targeted strategies to address the specific challenges and barriers faced in those areas.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

Authorization to download and use the Mini EHDS, 2019 dataset for this study was obtained from the DHS Program/ICF International following the request made by the Investigators. The data obtained for this study has no personal level identifiers and hence there is no way those respondents' privacy and confidentiality of the information be broken.

Author contributions

HT: Data curation, Software, Validation, Writing – original draft, Writing – review & editing. WW: Conceptualization, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. FF: Data curation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. GM: Methodology, Software, Writing – review & editing. KT: Methodology, Software, Writing – review & editing. TA: Methodology, Validation, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

We would like thank ICF International, a global consulting services company, that manages the Demographic and Health Survey (DHS) program for the authorization provided to us to use the datasets of the Ethiopian Demographic and Health Survey. We would like to extend our gratitude to Hawassa University offering such an opportunity.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Rogers LM, Cordero AM, Pfeiffer CM, Hausman DB, Tsang BL, De-Regil LM, et al. Global folate status in women of reproductive age: a systematic review with emphasis on methodological issues. *Ann N Y Acad Sci*. (2018) 1431:35–57. doi: 10.1111/nyas.13963

2. World Health Organization. *WHO recommendations on antenatal care for a positive pregnancy experience*. World Health Organization (2016).

3. Heidkamp RA, Piwoz E, Gillespie S, Keats EC, D'Alimonte MR, Menon P, et al. Mobilising evidence, data, and resources to achieve global maternal and child undernutrition targets and the sustainable development goals: an agenda for action. *Lancet*. (2021) 397:1400–18. doi: 10.1016/S0140-6736(21)00568-7

4. DAA FJL, Sununtnasuk C. A simple method for making a rapid, initial assessment of the consumption and distribution of Iron-folic acid supplements among pregnant women in developing countries In: *USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project*. Arlington, VA: JSI Research and Training Institute, Inc. (2014)

5. Central Statistical Agency. *EDHS: Ethiopia Demographic and Health Survey 2016*. Maryland, USA: CSA and ICF (2016).

6. Kefiyalew F, Zemene E, Asres Y, Gedefaw L. Anemia among pregnant women in Southeast Ethiopia: prevalence, severity and associated risk factors. *BMC Res Notes*. (2014) 7:1–8. doi: 10.1186/1756-0500-7-771

7. Getachew M, Yewhalaw D, Tafess K, Getachew Y, Zeynudin A. Anaemia and associated risk factors among pregnant women in Gilgel gibe dam area, Southwest Ethiopia. *Parasit Vectors*. (2012) 5:1–8. doi: 10.1186/1756-3305-5-296

8. Alem M, Enawgaw B, Gelaw A, Kena T, Seid M, Olkeba Y. Prevalence of anemia and associated risk factors among pregnant women attending antenatal care in Azezo health center Gondar town, Northwest Ethiopia. *J Interdiscipl Histopathol*. (2013) 1:137–44. doi: 10.5455/jihp.20130122042052

9. Hailu T, Kassa S, Abera B, Mulu W, Genanew A. Determinant factors of anaemia among pregnant women attending antenatal care clinic in Northwest Ethiopia. *Trop Dis Travel Med Vaccines*. (2019) 5:13–7. doi: 10.1186/s40794-019-0088-6

10. Getahun W, Belachew T, Wolide AD. Burden and associated factors of anemia among pregnant women attending antenatal care in southern Ethiopia: cross sectional study. *BMC Res Notes*. (2017) 10:276–7. doi: 10.1186/s13104-017-2605-x

11. Ba DM, Ssentongo P, Kjerulff KH, Na M, Liu G, Gao X, et al. Adherence to iron supplementation in 22 sub-Saharan African countries and associated factors among pregnant women: a large population-based study. *Curr Dev Nutr*. (2019) 3:nzz120. doi: 10.1093/cdn/nzz120

12. Lakew Y, Reda AA, Tamene H, Benedict S, Deribe K. Geographical variation and factors influencing modern contraceptive use among married women in Ethiopia: evidence from a national population based survey. *Reprod Health*. (2013) 10:1–10. doi: 10.1186/1742-4755-10-52

13. Desta M, Kassie B, Chanie H, Mulugeta H, Yirga T, Temesgen H, et al. Adherence of iron and folic acid supplementation and determinants among pregnant women in Ethiopia: a systematic review and meta-analysis. *Reprod Health*. (2019) 16:182–14. doi: 10.1186/s12978-019-0848-9

14. Sendeku FW, Azeze GG, Fenta SL. Adherence to iron-folic acid supplementation among pregnant women in Ethiopia: a systematic review and meta-analysis. *BMC Pregnancy Childbirth*. (2020) 20:138–9. doi: 10.1186/s12884-020-2835-0

15. Balarajan Y, Ramakrishnan U, Özaltin E, Shankar AH, Subramanian S. Anaemia in low-income and middle-income countries. *Lancet*. (2011) 378:2123–35. doi: 10.1016/S0140-6736(10)62304-5

16. Lacerte P, Pradipasen M, Temcharoen P, Imamee N, Vorapongsathorn T. Determinants of adherence to iron/folate supplementation during pregnancy in two provinces in Cambodia. *Asia Pac J Public Health*. (2011) 23:315–23. doi: 10.1177/1010539511403133

17. Fiedler JL, D'Agostino A: *A rapid initial assessment of the distribution and consumption of iron-folic acid tablets through antenatal care in Honduras*. JSI Research and Training Institute (2015).

18. Yusrawati Y, Defrin D, Karmia HR. Neonatal growth, Neurotrophine, zinc, and ferritin concentration in Normal and Iron Deficience pregnancy: an observational Analitic study. *Open Access Maced J Med Sci*. (2019) 7:1114–8. doi: 10.3889/oamjms.2019.202

19. Organization WH. *Guideline: Daily iron and folic acid supplementation in pregnant women*. Geneva: World Health Organization (2012).

20. Fiedler JL, D'Agostino A. *A simple method for making a rapid, initial assessment of the consumption and distribution of iron-folic acid supplements among pregnant women in developing countries*. Arlington, VA: USAID (2015).

21. Organization WH. *Global nutrition targets 2025: Stunting policy brief*. Geneva, Switzerland: World Health Organization (2014).

22. FDRE. National Nutrition Program 2016–2020. Addis Ababa; (2016). Available at: http://www.fao.org/faolex/results/details/en/c/LEX-FAOC190946/2016.

23. Ethiopian Public Health Institute - EPHI, Federal Ministry of Health - FMoH, ICF. *Ethiopia Mini demographic and health survey 2019*. Addis Ababa, Ethiopia: EPHI/FMoH/ICF (2021).

24. Assefa H, Abebe SM, Sisay M. Magnitude and factors associated with adherence to Iron and folic acid supplementation among pregnant women in Aykel town. *BMC Pregnancy Childbirth*. (2019) 19:1–8. doi: 10.1186/s12884-019-2422-4

25. Birhanu TM, Birarra MK, Mekonnen FA. Compliance to iron and folic acid supplementation in pregnancy. *BMC Res Notes*. (2018) 11:1–5. doi: 10.1186/s13104-018-3433-3

26. Gebre A, Mulugeta A, Etana B. Assessment of factors associated with adherence to iron-folic acid supplementation among urban and rural pregnant women in North Western zone of Tigray, Ethiopia: comparative study. *Int J Food Sci Nutr*. (2015) 4:161. doi: 10.11648/j.ijnfs.20150402.16

27. Gebremariam AD, Tiruneh SA, Abate BA, Engidaw MT, Asnakew DT. Adherence to iron with folic acid supplementation and its associated factors among pregnant women attending antenatal care follow up at Debre Tabor general hospital, Ethiopia, 2017. *PLoS One*. (2019) 14:e0210086. doi: 10.1371/journal.pone.0210086

28. WenJuan W, Benedict R, Mallick L. The role of health facilities in supporting adherence to iron-folic acid supplementation during pregnancy: a case study using DHS and SPA data in Haiti and Malawi. *DHS Working Papers*. (2019) 160

29. Fite MB, Roba KT, Oljira L, Tura AK, Yadeta TA. Compliance with Iron and folic acid supplementation (IFAS) and associated factors among pregnant women in sub-Saharan Africa: a systematic review and meta-analysis. *PLoS One*. (2021) 16:e0249789. doi: 10.1371/journal.pone.0249789

30. Bahati F, Kairu-Wanyoike S, Nzioki JM. Adherence to iron and folic acid supplementation during pregnancy among postnatal mothers seeking maternal and child healthcare at Kakamega level 5 hospital in Kenya: a cross-sectional study. *Wellcome Open Res*. (2021) 6:80. doi: 10.12688/wellcomeopenres.16699.2

31. Biru YB, Lemelem GA, Mezen MK. Magnitude and determinants of adherence to iron supplementation among Ethiopian pregnant women: a cross-sectional study from a National Survey. *Prim. Health Care*. (2021) 11:1–5.

32. Tadesse AW, Aychiluhm SB, Mare KU. Individual and community-level determinants of Iron-folic acid intake for the recommended period among pregnant women in Ethiopia: a multilevel analysis. *Heliyon*. (2021) 7:e07521. doi: 10.1016/j.heliyon.2021.e07521

33. Gebremichael TG, Haftu H, Gereziher TA. Time to start and adherence to iron-folate supplement for pregnant women in antenatal care follow up Northern Ethiopia. *Patient Prefer Adherence*. (2019) 13:1057–63. doi: 10.2147/PPA.S184168

34. Nilsen RM, Mastroiacovo P, Gunnes N, Alsaker ER, Bjørke-Monsen AL, Eussen SJ, et al. Folic acid supplementation and interpregnancy interval. *Paediatr Perinat Epidemiol*. (2014) 28:270–4. doi: 10.1111/ppe.12111

35. Exavery A, Mrema S, Shamte A, Bietsch K, Mosha D, Mbaruku G, et al. Levels and correlates of non-adherence to WHO recommended inter-birth intervals in Rufiji, Tanzania. *BMC Pregnancy Childbirth*. (2012) 12:1–8. doi: 10.1186/1471-2393-12-152

36. Alene AG, Olayemi OO, Berhane Y. Timing and factors associated with early antenatal visits among pregnant women in west Gojjam, Northwest Ethiopia. *Afr J Midwifery Womens Health*. (2021) 15:1–11. doi: 10.12968/ajmw.2020.0023

37. Tamirat KS, Kebede FB, Gonete TZ, Tessema GA, Tessema ZT. Geographical variations and determinants of iron and folic acid supplementation during pregnancy in Ethiopia: analysis of 2019 mini demographic and health survey. *BMC Pregnancy Childbirth*. (2022) 22:127–11. doi: 10.1186/s12884-022-04461-0

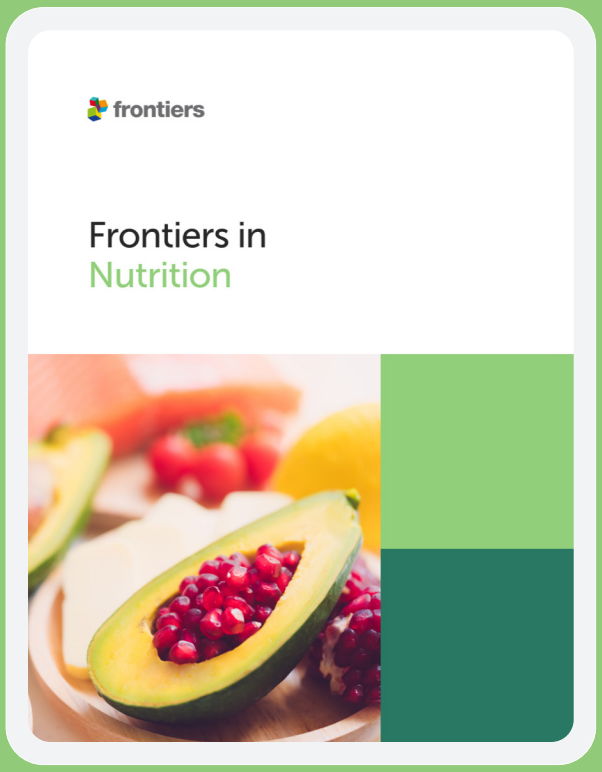
Frontiers in Nutrition

Explores what and how we eat in the context of health, sustainability and 21st century food science

A multidisciplinary journal that integrates research on dietary behavior, agronomy and 21st century food science with a focus on human health.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact