TYPE Mini Review
PUBLISHED 24 January 2024
DOI 10.3389/frfst.2024.1354391

Check for updates

OPEN ACCESS

EDITED BY
Silvani Verruck,
Federal University of Santa Catarina, Brazil

REVIEWED BY
Vidisha Tomer,
VIT University, India

*CORRESPONDENCE
Charles Stephen Brennan,
charles.brennan@rmit.edu.au

RECEIVED 12 December 2023
ACCEPTED 15 January 2024
PUBLISHED 24 January 2024

CITATION
Brennan CS (2024), The role of valorised plant proteins and phenolic compounds on the digestibility of foods: a short review of recent trends and future opportunities in addressing sustainability issues.
Front. Food. Sci. Technol. 4:1354391.
doi: 10.3389/frfst.2024.1354391

The role of valorised plant proteins and phenolic compounds on the digestibility of foods: a short review of recent trends and future opportunities in addressing sustainability issues

Charles Stephen Brennan*

School of Science, RMIT University, Melbourne, Australia

During the last 2–3 decades there has been increasing attention from academics, professionals and consumers about how phenolic compounds from plant based foods could enhance the nutritional quality of foods. This mini-review evaluates the focus given to the interactions phenolics have on the metabolic functions in foods and how these phenolic compounds can manipulate digestibility of both carbohydrates and proteins, and how this in turn can modulate metabolic disorders as well as microbiota. With an emphasis on research published in the last decade, the article also examines the potential of valorisation strategies to reutilise fractions which may have traditionally been lost in the food production operations. The reason for this focus is related to the pressing requirements of sustainability within the resource hungry food industry, and how we can create a culture of regenerative food innovation within the sectors.

KEYWORDS

nutrition, sensory, phenolic, carbohydrate, protein, digestibility, sustainability, regenerative food innovation

Why the attention on valorisation of food by-products?

Attention both in academic circles and in social media have been directed to the critical issues of sustainability in the agriculture and food systems. Numerous research publications have mentioned significant losses of food throughout the supply chain of the food industry, and beyond. Table 1 identifies 5 key references which are of interest when considering the recent focus of the role of phenolic compounds in manipulating enzymatic reactions.

The recent trends in food valorisation from waste products highlights the possibility of utilising compounds derived from waste by-products during processing and production for human health. Certainly when we discuss the large amount of food loss from the hospitality and consumer end of the sector. Huang et al. (2020) discussed the global paradigm of both having a surplus of foods and yet extensive waste within the food industry, noting that this would have significant effects on the environmental pressures surrounding sustainability, as well as the security of foods for the consumer. There is an urgent need to build a global agreement of strategies establishing resilience within the food industry so that national and regional challenges of nutritional security are understood (Martindale et al., 2020).

GRAPHICAL ABSTRACT
A simplified pictorial representation of food innovation using sustainable sources for phenolic materials.

Indeed Martindale et al. (2023) expanded on this requirement to enhance the resilience for the delivery of sustainability goals in their most recent review of possible solutions to be employed. Jagtap et al. (2023) advanced the call for action in their recent portfolio of articles addressing food security and sustainability in the face of global climate change and sustainability crises (Graphical Abstract). An obvious opportunity is in the recovery of bioactive rich material from waste materials and, by careful selection of the components, use these recovered products to enhance the nutritional quality of foods for the consumer (Villacís-Chiriboga et al., 2020). As these researchers indicated, there is potential in the recovery of active ingredients from waste streams in the production of foods, for instance the fruit sector (Leichtweis et al., 2021; Bhatkar et al., 2022a; Bhatkar et al., 2022b; Romano et al., 2022).

Bioactive compounds in valorised ingredients

Valorization of plant foods for phenolic compounds involves optimizing extraction methods, maximizing utilization of plant by-products, and exploring diverse applications in food, pharmaceuticals, and cosmetics. There is no doubt that innovation in extraction techniques, sustainability practices, and exploring novel sources of phenolics will drive future advancements in this field and that there is a need to address the challenges related to cost, scalability, and safety considerations will pave the way for the widespread utilization of phenolic compounds derived from plant sources, contributing to various industries and promoting sustainable practices in agriculture and food production.

Recently, recovery of these ingredients from waste streams has focused mainly on the ability of processes to extract phenolic compounds from waste streams such as coffee (Beltran- Medina et al., 2020), wine (Panzella et al., 2020), and vegetables and fruit pomaces in general (Dehghan-Shoar et al., 2011; Guo et al., 2017; Mnisi et al., 2022). These pomace materials are also a rich source of phytochemicals and dietary fibre compounds (Hui et al., 2020; Pop et al., 2021). And can be seen to health benefits when applied to commonly consumed food materials (Wu, et al., 2021). Developing innovative delivery systems to enhance the stability and bioavailability of phenolic compounds and fibres in various applications for the food industry will involve an understanding of their functionality as ingredients as well as their role in altering the physiological nutritional status of individuals.

Many of the beneficial characteristics of bioactive ingredients, in terms of health and nutrition, stem from the connection between phenolic compounds and proteins. The connection between the secondary metabolites in plants, possessing diverse chemical structures with antioxidant and bioactive properties, and proteins rely on an understanding of the structure and function relationships of these compounds. For instance, Zhang et al. (2021) illustrated the significance of the role of dietary protein-phenolic interactions in altering the molecular configurations of bioactive ingredients and hence their mediating effects on nutrition and wellbeing from a cellular and a macro perspective. Part of these effects are related to both co-valent, and non-co-valent, bonding between the bioactive ingredients and the functional macromoelcules in foods (Chu et al., 2018).

Exemplifying this is the intense research on the role of dietary fiber in promoting the health of consumers in the opportunities to manipulate carbohydrate digestion (Tu et al., 2022; He et al., 2023; Tu et al., 2023), as well as the focus on the role of these compounds in altering the fermentation behaviour of gut microbiota (Ratanpaul et al., 2023). Tu et al. (2023) illustrated that polysaccharides from shitake mushrooms could act on a non-competitor manner in restricting alpha-glucosidase functionality and hence inhibited glucose transport of digested starch from Caco-2 cells monolayer.

What is of interest in terms of understanding the structure function relationships of foods is the structural alterations caused

TABLE 1 Illustrating key references investigating the specific interactions of food phenolic compounds and bioactivity.

Authors	Title	Main research points
Alves-Santos et al. (2020)	Prebiotic effect of dietary polyphenols: A systematic review	Prebiotics metabolized by hindgut microbiota, focus on polyphenols such as catechins and anthocynanins in stimulating population growth and production of short chain fatty acids
Ashaolu and Suttikhana (2023)	Plant-based bioactive peptides: a review of their relevant production strategies, *in vivo* bioactivities, action mechanisms and bioaccessibility	Plant based phytochemicals extracted from sustainable food sources to derive plant based bioactive peptides with biological activities including anti-hypertension, neuroprotection and cellular antioxidant manipulation
Guan et al. (2021)	Phenolic-protein interactions in foods and post ingestion: Switches empowering health outcomes	Secondary metabolites from plants interact with proteins and this phenolic-protein interaction continues during ingestion, digestion and metabolism. Focus on interactions between phenolic ingredients and dietary proteins, and functional proteins (such as enzymes, transporters, receptors and transcription factors (TFs)) inside the human body
Huang et al. (2022)	The influence of the fortification of red pitaya (*Hylocereus polyrhizus*) powder on the *in vitro* digestion, physical parameters, nutritional profile, polyphenols and antioxidant activity in the oat-wheat bread	Examined polyphenol profiles and antioxidant levels of material from pitaya fruit to illustrate significant reduction in glycaemic response and carbohydrate digestion
Luo et al. (2021)	Manipulating effects of fruits and vegetables on gut microbiota—a critical review	A comprehensive review of the functions of phenolic compounds in fruits and vegetables in manipulating gut microbiota and the effects on digestion and health
Noad et al. (2016)	Beneficial effect of a polyphenol-rich diet on cardiovascular risk: A randomised control trial	Polyphenol rich foods proven to be associated with reduction in cardiovascular disease. Subjects given fruit consumption and then chocolate and berries. Overall this treatment illustrates improvement in hypertension and cardiovascular management
Rocchetti et al. (2022)	Functional implications of bound phenolic compounds and phenolics–food interaction: A review	Phenolic rich foods are not only high in phenolic compounds but also may have co-passengers in the form of dietary fibers. The two health components may interrelate via noncovalent (reversible) and covalent (mostly irreversible) interactions. Fibre-bound, and unbound phenolic compounds, were reviewed in relation to functionality
Zhang et al. (2021)	Dietary protein-phenolic interactions: characterization, biochemical-physiological consequences, and potential food applications	The co-existence of protein and phenolic compounds creates complexes in processed and digested foods. These non-covalent or covalent processes, are closely associated with chemical structures of both compounds and the surrounding conditions, mainly temperature, pH, and the presence of phenolic oxidases

by the binding of phenolic compounds to protein components can affect the digestibility of the proteins and hence their accessibility in terms of cellular uptake. Phenolic compounds can also affect protein digestion by inhibiting proteolytic enzymes (for instance trypsin and pepsin), which plays an important role in altering protein breakdown in the digestive system. Some phenolic compounds, together with proteins, can serve as prebiotics, fostering the growth of beneficial gut bacteria and improving gut health. For instance catechins, anthocyanins, and proanthocyanidins have been shown to extert prebiotic effects (Alves-Santos et al., 2020). The researchers illustrated that phenolic compounds increased the levels of *Lactobacillus*, *Bifidobacterium*, *Akkermansia*, *Roseburia*, and *Faecalibacterium* spp., which in turn led to an increase production and release of secondary metabolites such as short-chain fatty acids (SCFA), including butyrate during fermentation. Associated with this observation is the research which clearly illustrates the potential of phenolic compounds to regulate cardiometabolic diseases as well as acting as reducing rates of inflammation (Noad et al., 2016; Paquette et al., 2017; Chai et al., 2019).

As mentioned before, the effects of phenolic compounds on digestibility of food components has been studied from a molecular basis, and that these effects are related to the interference of phenolic compounds on the degrading enzymes during digestion (Huang et al., 2022). Hui et al. (2020) illustrated that the phenolic compounds from blackcurrant materials could be incorporated into pastes rich in carbohydrates and affect the digestibility of these pastes by manipulating the activities against alpha amylase and alpha glucosidase. At the same time, blackcurrant phytochemicals have been shown to interact with dairy proteins such as whey material in cookies, thus manipulating the structure of the protein and phytochemical components in the food topography as well as altering the overall digestibility of the products. By understanding the molecular interactions between phenolic compounds and proteins and carbohydrates, researchers have been able to model inter and intra-molecular interactions which are a powerful knowledge resource for determining strategies for manipulating digestibility and fermentability of bioactive compounds from a range of plant based sources (Guan et al., 2021).

The research of Hao et al. (2022) illustrated this very clearly when discussing the role of the molecular conformation of polyphenols on their potential health benefits such as antioxidant activity and interaction with metabolic enzymes involved in food digestion post ingestion. Kuar et al. (2023) evaluated the impact of phenolic compounds on the digestibility of carbohydrate rich foods such as pasta, and how different processing operations could also manipulate the effect of the phenolic–compound interactions for overall health of individuals, especially when using whole grains. Similarly, Chang et al. (2023) evaluated the ability of the phenolic compounds from non-traditional cereals (in this case Millets) in regulating food digestibility and total nutrient recovery. This in itself built on the previous work of Kataria et al. (2022) who identified the relationship of phenolic compounds in teff, and in particular the role of thermal processing on altering the antioxidant and nutritional quality of foods from these compounds when considering the sensitivity of these materials to heat during processing. More recently Huang et al. (2023) evaluated the role of phenolic compounds in combination with traditionally regarded non-food components when investigating the bioactivity of mediated biosynthesis of gold nanoparticles on human health. This illustrates that the usefulness of phenolic compounds can go far beyond conventional food interactions.

How these phenolic compounds alter gut microbiota and their functionality is of interest when considering intestinal health and fermentation breakdown of products (Ashaolu and Suttikhana, 2023; Ibrahim et al., 2023). Loo et al. (2020) evaluated the modulation of the human gut microbiota by phenolics and phenolic fiber-rich foods. One of the issues around the role of phenolic compounds altering microbiota populations during digestion is the way that the phenolic compounds in plants tend to be intrinsically bound to the cellular components of fruits and seeds, and therefore their association with dietary fibres (Rocchetti et al., 2022). The binding affinity of these phenolic compounds to fibres and proteins may impart some of the properties in terms of ease of digestibility and fermentation. Matsumura et al. (2023) related this functionality to the concept of the gut brain axis and illustrated that phenolic compounds from tea for instance (and their metabolites during the digestion and fermentation processes) may exhibit antibacterial properties which protect the gut microbiota against pathogenic bacteria (*Clostridium perfringens*, *Escherichia coli*, *Salmonella*, and *Pseudomonas* for instance). This protection of the gut microbiota system could help with maintaining and improving the overall balance of intestinal microbes. In this way catechin compounds and their dimers such as theaflavins and theasinensins may be useful in altering the dynamic population within the gut. Similarly, the flavan-3-ols within caco products could have a direct effect on the distribution of gut microbiota throughout the intestine, which in turn would influence overall intestinal health and therefore go some way to explaining the observations that cocao phenolic compounds can ameliorate colonic inflammation and potentially attenuate diabetes, possibly by downregulate inflammation markers and suppress inflammation-related colon responses.

These research findings, based on conventional use of plant ingredients, are important to consider when evaluating the potential benefits of valorised plant products from the foods industry (Luo et al., 2021). For instance, if the recovery of bioactive ingredients from production and processing wastes is going to achieve health benefits for future consumers, then the efficacy of these recovered biomolecules must be similar, or greater) than if they were present in native food systems. This quandary was discussed by Abou Chehade et al. (2018) when evaluating the possible recovery of functional biomolecules from waste streams in the tomato industry. Lycopene, has long been associated with a number of health promotion effects but can be susceptible to thermal degradation and is therefore a target for the use of non-thermal extraction processes to recover functional bioactives from waste streams (Dehghan-Shoar et al., 2010; Dehghan-Shoar et al., 2011; Anajran and Jouyban, 2017; Szabo et al., 2018; Madia et al., 2021). These techniques of using "environmentally friendly" extraction chemicals, as well as novel processes to improve structural recovery, can go some way in enabling the ecological benefits of waste valorisation from food industrial situations. The possibility of utilising multiple, targeted enzymes, in specific extraction processes of bioactives from waste streams is an area of intense future research (Lombardelli et al., 2020).

Biorefining for the future—where should we focus our attention?

The recovery of material from waste streams is no new phenomenon, and indeed one of our earlier papers on the lycopene and tomato nexus discussed the chemical and non-chemical extraction techniques, and benefits thereof, as well as the potential to include these products in commonly consumed foods such as extruded products (Dehghan-Shoar et al., 2011). Where the attention over the last few years has focused on is determining which food systems may present the best return on investment in terms of waste valorisation. This attention has put four industries into view, namely, the juice industry, oil processing, wine industry and more broadly the fermentation industry, as well as waste generated during vegetable preparation in the fresh fruit and vegetable processing lines. To that end, there has been considerable interest in citrus juice production streams and recovery of flavonoid and fibre components (Anticona et al., 2020; Russo et al., 2021; Romano et al., 2022). These have been used in a diverse food range such as extruded snack products, bakery, pasta and beverages in order to supplement the antioxidant capacity of processed foods, as well as manipulate their impact on metabolic functionality such as glycaemic impact. The excellent review of Andrade et al. (2022) sets out how the pectin, carotenoids and other natural compounds discovered in the peal and fleshy parts from citrus processing can be used in functional foods. More recently, researchers have concentrated on the oil industry and how the processing of botanical material for oil results in the production of large amounts of surplus pomace and pulp, rich sources of highly functional bioactive ingredients (Madureira et al., 2022) and how these products could be used to reduce obesity levels (Annunziata et al., 2018). In applied terms, this research has been related to the recovery of ingredients from oil producing species such as olives (Harzalli et al., 2022), cereals (Pestana-Bauer et al., 2023), and other seed crops (Yao et al., 2022). Baiano and Fiore (2023) have illustrated the great potential that grains have in supplying bioactive ingredients that can be recovered post primary processing, and explained how spent grains, for instance, can be a rich source of fibres, phenolics and proteins if harnessed appropriately. Certainly the phenolic compounds in the grains of oilseed plants allow for excellent recovery of phenolic compounds from waste streams post oilseed oil pressing (Yao et al., 2022). These compounds recovered from waste streams include isoflavones, ferulic acid, *p*-coumaric acid, chlorogenic acid, caffeic acid, syringic acid, vanillic acid, salicylic acid, protocatechuic acid, anthocyanins and associated polyphenolic compounds. All of these have been shown to have a value in terms of metabolic functionality in cellular function, and thus present themselves as potentially important valorised products from a human nutrition purpose.

Yu et al. (2022) using carrot by-products fed mice with fermented carrot pulp material (left over from juice manufacturing) and measured the microbial populations which developed following such interventions. The polyphenol and flavonoid contents of the pulp material had a direct effect on the population dynamics of the microbial communities within the intestines of the mice (observing an increase in *Bacteroidetes*, *Proteobacteria*, *Firmicutes*) and this enhanced absorption and utilization efficiency of the phenolic compounds. When challenged with antibiotics, those with the fermented pomace material containing the phenolic compounds, showed resilience to microbial reductions and maintained a diverse microecological balance. Research from Hui et al. (2021) illustrated that phenolic compounds from berry components enhanced *in vitro* antioxidant activity and reducing reactive oxygen species in lipopolysaccharide-stimulated Raw264.7 Macrophages and this could in turn be postulated to be related to alterations in microbial community and regulation of cellular activity. Similarly, Wang et al. (2020) illustrated the cellular activity of phenolic and fibre compounds found in mushroom materials and that gastric digestion of foods which are reinforced with phenolic compounds allow for increased cellular bioactivity. This may contribute to the mechanisms behind the phenolic interactions with proteins and carbohydrates which are obvious when investigating the effects of fibre and phenolic enhanced food products in terms of protein digestibility and glycaemic responses (Mu et al., 2022; Wang et al., 2022).

Conclusion

In order to achieve a circular economy with the food processing and production industry, the application of the knowledge we have generated over the last 2–3 decades will be of crucial importance. There is an undeniable potential to recover phenolic compounds, proteins and other functional ingredients from waste streams in the food processing arena, and that this would have considerable benefits in terms of responding to the multifaceted requirements of embracing sustainability initiatives. These ingredients could be central in the our innovation strategies for improving the nutritional quality of food products and enhancing the lifestyle and wellbeing of consumers across the globe. We therefore have the opportunity not only to redress the issues surrounding waste production, but innovate through technology to utilise these valorised components and create a future that is potentially better than the position we are at this moment. In other words, open the opportunity for regenerative food innovation strategies.

Author contributions

CB: Conceptualization, Writing–original draft.

Funding

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

Conflict of interest

The author declares 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

Abou Chehade, L., Al Chami, Z., De Pascali, S. A., Cavoski, I., and Fanizzi, F. P. (2018). Biostimulants from food processing by-products: agronomic, quality and metabolic impacts on organic tomato (Solanum lycopersicum L.). *J. Sci. Food Agric.* 98, 1426–1436. doi:10.1002/jsfa.8610

Alves-Santos, A. M., Sugizaki, C. S. A., Lima, G. C., and Naves, M. M. V. (2020). Prebiotic effect of dietary polyphenols: a systematic review. *J. Funct. Foods* 74, 104169. doi:10.1016/j.jff.2020.104169

Anarjan, N., and Jouyban, A. (2017). Preparation of lycopene nanodispersions from tomato processing waste: effects of organic phase composition. *Food Bioprod. process.* 103, 104–113. doi:10.1016/j.fbp.2017.03.003

Andrade, M. A., Barbosa, C. H., Shah, M. A., Ahmad, N., Vilarinho, F., Khwaldia, K., et al. (2022). Citrus by-products: valuable source of bioactive compounds for food applications. *Antioxidants* 12, 38. doi:10.3390/antiox12010038

Annunziata, G., Maisto, M., Schisano, C., Barrea, L., Ciampaglia, R., Narciso, V., et al. (2018). Oleuropein as a novel anti-diabetic nutraceutical. An overview. *Archives Diabetes and Obes.* 1 (3), 54–58. doi:10.32474/ado.2018.01.000113

Anticona, M., Blesa, J., Frigola, A., and Esteve, M. J. (2020). High biological value compounds extraction from citrus waste with non-conventional methods. *Foods* 9, 811. doi:10.3390/foods9060811

Ashaolu, T. J., and Suttikhana, I. (2023). Plant-based bioactive peptides: a review of their relevant production strategies, *in vivo* bioactivities, action mechanisms and bioaccessibility. *Int. J. Food Sci. Technol.* 58, 2228–2235. doi:10.1111/ijfs.16384

Baiano, A., and Fiore, A. (2023). Sustainable food processing: single and interactive effects of type and quantity of brewers' spent grain and of type of sweetener on physicochemical and sensory characteristics of functional biscuits. *Int. J. Food Sci. Technol.* 58, 5757–5772. doi:10.1111/ijfs.16674

Beltrán-Medina, E. A., Guatemala-Morales, G. M., Padilla-Camberos, E., Corona-González, R. I., Mondragón-Cortez, P. M., and Arriola-Guevara, E. (2020). Evaluation of the use of a coffee industry by-product in a cereal-based extruded food product. *Foods* 9, 1008. doi:10.3390/foods9081008

Bhatkar, N. S., Shirkole, S. S., Brennan, C., and Thorat, B. N. (2022a). Pre-processed fruits as raw materials: part I – different forms, process conditions and applications. *Int. J. Food Sci. Technol.* 57, 4945–4962. doi:10.1111/ijfs.15891

Bhatkar, N. S., Shirkole, S. S., Brennan, C., and Thorat, B. N. (2022b). Pre-processed fruits as raw materials: part II—process conditions, demand and safety aspects. *Int. J. Food Sci. Technol.* 57, 4918–4935. doi:10.1111/ijfs.15887

Chai, S. C., Davis, K., Zhang, Z., Zha, L., and Kirschner, K. F. (2019). Effects of tart cherry juice on biomarkers of inflammation and oxidative stress in older adults. *Nutrients* 11, 228–310. doi:10.3390/nu11020228

Chang, L., Liu, Y., Niu, R., Yang, Q., Liang, J., Li, R., et al. (2023). Antioxidant activities, structure, physicochemical properties and *in vitro* digestibility of different millets (foxtail and proso). *Int. J. Food Sci. Technol.* 58, 5017–5026. doi:10.1111/ijfs.16597

Chu, Q., Bao, B., and Wu, W. (2018). Mechanism of interaction between phenolic compounds and proteins based on non-covalent and covalent interactions. *Med. Res.* 2, 180014. doi:10.21127/yaoyimr20180014

Dehghan-Shoar, Z., Hardacre, A., Meerdink, G., and Brennan, C. S. (2010). The physico-chemical characteristics of extruded snacks enriched with tomato lycopene. *Food Chem.* 12, 1117–1122. doi:10.1016/j.foodchem.2010.05.071

Dehghan-Shoar, Z., Hardacre, A. K., Meerdink, G., and Brennan, C. S. (2011). Lycopene extraction from extruded products containing tomato skin. *Int. J. Food Sci. Technol.* 46, 365–371. doi:10.1111/j.1365-2621.2010.02491.x

Guan, H., Zhang, W., Sun-Waterhouse, D., Jiang, Y., Li, F., Waterhouse, G. I. N., et al. (2021). Phenolic-protein interactions in foods and post ingestion: switches empowering health outcomes. *Trends Food S ci Technol.* 118, 71–86. doi:10.1016/j.tifs.2021.08.033

Guo, R., Chang, X., Guo, X., Brennan, C. S., Li, T., Fu, X., et al. (2017). Phenolic compounds, antioxidant activity, antiproliferative activity and bioaccessibility of Sea buckthorn (Hippophaë rhamnoides L.) berries as affected by *in vitro* digestion. *Food and Funct.* 8, 4229–4240. doi:10.1039/C7FO00917H

Hao, L., Sun, J., Pei, M., Zhang, G., Li, C., Li, C., et al. (2022). Impact of non-covalent bound polyphenols on conformational, functional properties and *in vitro* digestibility of pea protein. *Food Chem.* 383, 132623. doi:10.1016/j.foodchem.2022.132623

Harzalli, Z., Willenberg, I., Medfai, W., Matthäus, B., Mhamdi, R., and Oueslati, I. (2022). Potential use of the bioactive compounds of the olive mill wastewater: monitoring the aldehydes, phenolic compounds, and polymerized triacylglycerols in sunflower and olive oil during frying. *J. Food Process. Preserv.* 46, e17006. doi:10.1111/jfpp.17006

He, M., Condict, L., Richardson, S. J., Brennan, C. S., and Kasapis, S. (2023). Molecular characterization of interactions between lectin - a protein from common edible mushroom (Agaricus bisporus) - and dietary carbohydrates. *Food Hydrocoll.* 146, 109253. doi:10.1016/j.foodhyd.2023.109253

Huang, C.-H., Liu, S.-M., and Hsu, N.-Y. (2020). Understanding global food surplus and food waste to tackle economic and environmental sustainability. *Sustainability* 12, 2892. doi:10.3390/su12072892

Huang, X., Devi, S., Bordiga, M., Brennan, C. S., and Xu, B. (2023). Phenolic compounds mediated biosynthesis of gold nanoparticles and evaluation of their bioactivities: a review. *Int. J. Food Sci. Technol.* 58, 1673–1694. doi:10.1111/ijfs.16346

Huang, Y., He, M., Kasapis, S., Brennan, M., and Brennan, C. (2022). The influence of the fortification of red pitaya (Hylocereus polyrhizus) powder on the *in vitro* digestion, physical parameters, nutritional profile, polyphenols and antioxidant activity in the oat-wheat bread. *Int. J. Food Sci. Technol.* 57, 2729–2738. doi:10.1111/ijfs.15530

Hui, X., Wu, G., Han, D., Stipkovits, L., Wu, X., Tang, S., et al. (2020). The effects of bioactive compounds from blueberry and blackcurrant powders on the inhibitory activities of oat bran pastes against α-amylase and α-glucosidase linked to type 2 diabetes. *Food Res. Int.* 138, 109756. doi:10.1016/j.foodres.2020.109756

Hui, X. D., Wu, G., Han, D., Gong, X., Wu, X. Y., Tang, S. Z., et al. (2021). The effects of bioactive compounds from blueberry and blackcurrant powder on oat bran pastes: enhancing *in vitro* antioxidant activity and reducing reactive oxygen species in lipopolysaccharide-stimulated Raw264.7 Macrophages. *Antioxidants, þ* 1, 388. Article Number: 388. doi:10.3390/antiox10030388

Ibrahim, S. A., Yeboah, P. J., Ayivi, R. D., Eddin, A. S., Wijemanna, N. D., Paidari, S., et al. (2023). A review and comparative perspective on health benefits of probiotic and fermented foods. *Int. J. Food Sci. Technol.* 58, 4948–4964. doi:10.1111/ijfs.16619

Jagtap, S., Litos, L., Raut, R., Gupta, S., and Grover, A. (2023). Ensuring food security and sustainability in the face of crises. *Int. J. Food Sci. Technol.* 58, 5430–5432. doi:10.1111/ijfs.16630

Kataria, A., Sharma, S., and Dar, B. N. (2022). Changes in phenolic compounds, antioxidant potential and antinutritional factors of Teff (Eragrostis tef) during different thermal processing methods. *Int. J. Food Sci. Technol.* 57, 6893–6902. doi:10.1111/ijfs.15210

Kaur, H., Bobade, H., Sharma, R., and Sharma, S. (2023). Influence of extruded whole wheat flour addition on quality characteristics of pasta. *Int. J. Food Sci. Technol.* 59, 1129–1137. doi:10.1111/ijfs.16697

Leichtweis, M. G., Oliveira, M. B. P. P., Ferreira, I. C. F. R., Pereira, C., and Barros, L. (2021). Sustainable recovery of preservative and bioactive compounds from food industry bioresidues. *Antioxidants* 10, 1827. doi:10.3390/antiox10111827

Lombardelli, C., Liburdi, K., Benucci, I., and Esti, M. (2020). Tailored and synergistic enzyme-assisted extraction of carotenoid-containing chromoplasts from tomatoes. *Food Bioprod. process.* 121, 43–53. doi:10.1016/j.fbp.2020.01.014

Loo, Y. T., Howell, K., Chan, M., Zhang, P., and Ng, K. (2020). Modulation of the human gut microbiota by phenolics and phenolic fiber-rich foods. *Compr. Rev. Food Sci. Food Saf.* 19, 1268–1298. doi:10.1111/1541-4337.12563

Luo, J., Lin, X., Bordiga, M., Brennan, C., and Xu, B. (2021). Manipulating effects of fruits and vegetables on gut microbiota – a critical review. *Int. J. Food Sci. Technol.* 56, 2055–2067. doi:10.1111/ijfs.14927

Madia, V. N., De Vita, D., Ialongo, D., Tudino, V., De Leo, A., Scipione, L., et al. (2021). Recent advances in recovery of lycopene from tomato waste: a potent antioxidant with endless benefits. *Molecules* 26, 4495. doi:10.3390/molecules26154495

Madureira, J., Margaça, F. M. A., Santos-Buelga, C., Ferreira, I. C. F. R., Cabo Verde, S., and Barros, L. (2022). Applications of bioactive compounds extracted from olive industry wastes: a review. *Compr. Rev. Food Sci. Food Saf.* 21, 453–476. doi:10.1111/1541-4337.12861

Martindale, W., Hollands, T. Æ., Jagtap, S., Hebishy, E., and Duong, L. (2023). Turn-key research in food processing and manufacturing for reducing the impact of climate change. *Int. J. Food Sci. Technol.* 58, 5568–5577. doi:10.1111/ijfs.16543

Martindale, W., Swainson, M., and Choudhary, S. (2020). The impact of resource and nutritional resilience on the global food supply system. *Sustainability* 12, 751. doi:10.3390/su12020751

Matsumura, Y., Kitabatake, M., Kayano, S-I., and Ito, T. (2023). Dietary phenolic compounds: their health benefits and association with the gut microbiota. *Antioxid.* 12, 880. doi:10.3390/antiox12040880

Mnisi, C. M., Mhlongo, G., and Manyeula, F. (2022). Fruit pomaces as functional ingredients in poultry nutrition: a review. *Front. Animal Sci.* 3. doi:10.3389/fanim.2022.883988

Mu, J., Wang, L., Lv, W., Chen, Z., Brennan, M., Ma, Q., et al. (2022). Phenolics from sea buckthorn (Hippophae rhamnoides L.) modulate starch digestibility through physicochemical modifications brought about by starch – phenolic molecular interactions. *LWT* 165, 113682. doi:10.1016/j.lwt.2022.113682

Noad, R. L., Rooney, C., McCall, D., Young, I. S., McCance, D., McKinley, M. C., et al. (2016). Beneficial effect of a polyphenol-rich diet on cardiovascular risk: a randomised control trial. *Heart* 102 (17), 1371–1379. doi:10.1136/heartjnl-2015-309218

Panzella, L., Federica, M., Rita, N., Stefania, M., Luisella, V., and Alessandra, N. (2020). Bioactive phenolic compounds from agri-food wastes: an update on green and sustainable extraction methodologies. *Front. Nutr.* 7, 60. doi:10.3389/fnut.2020.00060

Paquette, M., Larqué, A. S. M., Weisnagel, S. J., Desjardins, Y., Marois, J., Pilon, G., et al. (2017). Strawberry and cranberry polyphenols improve insulin sensitivity in insulin-resistant, non-diabetic adults: a parallel, double-blind, controlled and randomised clinical trial. *Br. J. Nutr.* 117 (4), 519–531. doi:10.1017/S0007114517000393

Pestana-Bauer, V. R., Mendonça, C. R., Bruscatto, M. H., Krumreich, F. D., Otero, D. M., Costa, I. H., et al. (2023). Fatty acid distillation residues from rice oil bran refining as a source of phytochemicals. *Int. J. Food Sci. Technol.* 58, 4627–4637. doi:10.1111/ijfs.16567

Pop, C., Suharoschi, R., and Pop, O. L. (2021). Dietary fiber and prebiotic compounds in fruits and vegetables food waste. *Sustainability* 13, 7219. doi:10.3390/su13137219

Ratanpaul, V., Stanley, R., Brennan, C., and Eri, R. (2023). Manipulating the kinetics and site of colonic fermentation with different fibre combinations – a review. *Int. J. Food Sci. Technol.* 58, 2216–2227. doi:10.1111/ijfs.16373

Rocchetti, G., Gregorio, R. P., Lorenzo, J. M., Barba, F. J., Oliveira, P. G., Prieto, M. A., et al. (2022). Functional implications of bound phenolic compounds and phenolics–food interaction: a review. *Compr. Rev. Food Sci. Food Saf.* 21, 811–842. doi:10.1111/1541-4337.12921

Romano, R., De Luca, L., Aiello, A., Rossi, D., Pizzolongo, F., and Masi, P. (2022). Bioactive compounds extracted by liquid and supercritical carbon dioxide from citrus peels. *Int. J. Food Sci. Technol.* 57, 3826–3837. doi:10.1111/ijfs.15712

Russo, C., Maugeri, A., Lombardo, G. E., Musumeci, L., Barreca, D., Rapisarda, A., et al. (2021). The second life of citrus fruit waste: a valuable source of bioactive compounds. *Molecules* 26, 5991. doi:10.3390/molecules26195991

Szabo, K., Cătoi, A.-F., and Vodnar, D. C. (2018). Bioactive compounds extracted from tomato processing by-products as a source of valuable nutrients. *Plant. Foods Hum. Nutr.* 73, 268–277. doi:10.1007/s11130-018-0691-0

Tu, J., Brennan, M. A., Hui, X., Wang, R., Peressini, D., Bai, W., et al. (2022). Utilisation of dried shiitake, black ear and silver ear mushrooms into sorghum biscuits manipulates the predictive glycaemic response in relation to variations in biscuit physical characteristics. *Int. J. Food Sci. Technol.* 57, 2715–2728. doi:10.1111/ijfs.15500

Tu, J. C., Adhikari, B., Brennan, M. A., Cheng, P., Bai, W. D., and Brennan, C. S. (2023). Shiitake polysaccharides acted as a non-competitive inhibitor to α-glucosidase and inhibited glucose transport of digested starch from Caco-2 cells monolayer. *Food Res. Int.* 173, 113268. doi:10.1016/j.foodres.2023.113268

Villacís-Chiriboga, J., Elst, K., Van Camp, J., Vera, E., and Ruales, J. (2020). Valorization of byproducts from tropical fruits: extraction methodologies, applications, environmental and economic assessment – a Review (Part 1: general overview of the byproducts, traditional biorefinery practices and possible applications). *Compr. Rev. Food Sci. Food Saf.* 19, 405–447. doi:10.1111/1541-4337.12542

Wang, L., Zhao, H., Brennan, M. A., Guan, W., Liu, J., Wang, L., et al. (2020). *In vitro* gastric digestion antioxidant and cellular radical scavenging activities of wheat-shiitake noodles. *Food Chem.* 330, 127214. doi:10.1016/j.foodchem.2020.127214

Wang, R., Li, M., Wu, G., Hui, X., Tu, J., Brennan, M. A., et al. (2022). Inhibition of phenolics on the *in vitro* digestion of noodles from the view of phenolics release. *Int. J. Food Sci. Technol.* 57, 1208–1217. doi:10.1111/ijfs.15502

Wu, G., Hui, X., Stipkovits, L., Rachman, A., Tu, J., Brennan, M. A., et al. (2021). Whey protein-blackcurrant concentrate particles obtained by spray-drying and freeze-drying for delivering structural and health benefits of cookies. *Innovative Food Sci. Emerg. Technol.* 68, 102606. doi:10.1016/j.ifset.2021.102606

Yao, Z., Huaming, X., Xin, L., Dan, W., Hong, C., and Fang, W. (2022). Comprehensive review of composition distribution and advances in profiling of phenolic compounds in oilseeds. *Front. Nutr.* 9, 1044871. doi:10.3389/fnut.2022.1044871

Yu, C., Liu, Y., Xuemei, Z., Ma, A., Jianxin, T., and Yiling, T. (2022). Fermented carrot pulp regulates the dysfunction of murine intestinal microbiota. *Oxidative Med. Cell. Longev.* 2022, 2479956. doi:10.1155/2022/2479956

Zhang, Q., Cheng, Z., Wang, Y., and Fu, L. (2021). Dietary protein-phenolic interactions: characterization, biochemical-physiological consequences, and potential food applications. *Crit. Rev. Food Sci. Nutr.* 61, 3589–3615. doi:10.1080/10408398.2020.1803199