Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Green and Sustainable Chemistry

Circular and inclusive utilization of alternative proteins: A European and Mediterranean perspective

C. G. Athanassiou[1], S. Smetana[2,3], D. Pleissner[4,5], A. Tassoni[6], L. Gasco[7], F. Gai[8], A. Shpigelman[9], M. Bravo Cadena[10], M. Gastli[11], L. E. C. Conceição[12], E. Gronich[13], S. Paolacci[14], V. Chalkidis[15], M. Kuthy[16], R. E. Stolzenberger[17], A. El Yaacoubi[18], C. Mehlhose[19], J.-I. Petrusán[2] and C. I. Rumbos[1]

Abstract
Current European, and particularly Mediterranean, agricultural production systems heavily depend on protein imports to cover the nutritional needs of farmed animals and fish. To increase their resilience, the EU is in search of efficient, sustainable, and locally produced alternative proteins. Insects and algae have recently gained much attention due to their ability to bioconvert agro-industrial side-streams into valuable resources. Legumes are known for their high protein content; however, certain species, such as lupins and fava beans, have been overlooked and underused as food and feed. Additionally, microbial fermentation can be used in parallel with insects, algae, and legumes, to efficiently transform them into food and feed. This contribution describes the challenges and chances associated with the utilization of these alternative protein sources for food and feed applications.

Addresses
[1] University of Thessaly, Laboratory of Entomology and Agricultural Zoology, Greece
[2] Deutsches Institut für Lebensmitteltechnik e.V., Germany
[3] Institute of Food Quality and Food Safety, University of Veterinary Medicine Hannover, Foundation, Hannover, Germany
[4] Institut für Lebensmittel- und Umweltforschung e.V., Germany
[5] Institute of Sustainable Chemistry, Leuphana University Lüneburg, Germany
[6] Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum-University of Bologna, Italy
[7] University of Turin, Italy
[8] Italian National Research Council, Italy
[9] Technion - Israel Institute of Technology, Israel
[10] AE Agribiologicals S.L., Spain
[11] nextProtein, Tunisia
[12] SPAROS Lda, Portugal
[13] Flying Spark LTD, Israel
[14] AquaBioTech Group, Malta
[15] ELVIZ S.A., Greece
[16] RTD TALOS Ltd, Cyprus
[17] Stolzenberger Bäckerei, Germany
[18] Green Development and Innovation Association, Morocco
[19] University of Göttingen, Germany

Corresponding author: Athanassiou, C.G. (athanassiou@uth.gr)

Given the role as Guest Editor, Daniel Pleissner, Sergiy Smetana had no involvement in the peer review of the article and has no access to information regarding its peer-review. Full responsibility for the editorial process of this article was delegated to Klaus Kümmerer.

Current Opinion in Green and Sustainable Chemistry 2024, **46:**100892

This review comes from a themed issue on **Waste-to-nutrition (2023)**

Edited by **Daniel Pleissner** and **Sergiy Smetana**

Available online 9 February 2024

For complete overview of the section, please refer the article collection - Waste-to-nutrition (2023)

https://doi.org/10.1016/j.cogsc.2024.100892

Keywords
Alternative proteins, Insects for food and feed, Microalgae, Legumes, Fermentation, Mediterranean basin.

Introduction

The need for an increase in protein production for food and feed is a highly emerging global issue [1]. Given that the human population is expected to exceed 10 billion people in 2050 [2], any increase in food availability is disproportionally developed, at least in comparison with global demands [3]. At the same time, especially after the pandemic of COVID-19 and the more recent food crisis, there are major concerns regarding food safety, which should be the first priority in any effort to assure food security. Most agricultural farming systems produce a huge amount of livestock and crop residues, as well as a wide variety of side-streams. It is estimated that 37% of our agricultural production is lost yearly, which corresponds to 2.6 billion tons on a global basis [4], valued at 750 billion US$ annually [5]. Similarly, one-third of all food produced for human consumption is either lost or wasted [6]. Additionally, on-farm food loss and waste is estimated to be 16% of the total agricultural-related greenhouse gas emissions globally, and reductions in these emissions have the potential to have a significant impact on climate change [7]. These losses represent a big pool of untapped and underrated resources.

There are numerous protein sources that have been so far evaluated; here, emphasis will be laid on three sources that have been prioritized by PRIMA (Partnership for Research and Innovation in the Mediterranean Area) through the funding of the CIPROMED (Circular and Inclusive utilisation of alternative PROteins in the MEDiterranean value chains; PRIMA Call 2022 Section 1) project: insects, algae and legumes. Among the three sources, insects and algae path the way to the utilization of nitrogenous compounds from agricultural production losses and to the coverage of future protein demand. Legumes, on the other hand, are known for nitrogen fixation and their high protein content, thus contributing first to the supply of proteins and second to reduced nitrogenous fertilizer use during cultivation. On the other hand, the efficient biorefinery processing of legume byproducts, residues, and wastes generated from agro-industrial and food processing and produced yearly in very large amounts may represent an interesting source of plant proteins contributing to satisfy the steadily increasing global protein demand [8].

Nitrogen recycling strategies

Insects have gained much attention during the last ten years due to their incontestable advantages as a waste management agent that can transform agricultural byproducts into valuable food and feed [9,10]. In recent years, the European Union (EU) has blazed a trail, giving the "green light" to authorize eight insect species for their utilization in feed, whereas four species are approved for food [11,12]. While the expansion of this authorization for other areas is a dynamic procedure that is still in progress with new entries (new species, other uses in agri-food, etc.), this development resulted in a rapid growth in research, with thousands of scientific publications annually on the subject, a subject that less than ten years ago was covered by less than one hundred publications annually [13]. At the same time, a new scientific journal was immediately launched on the subject, "Journal of Insects as Food and Feed," while other journals have already modified their aims and scope to attract submissions in this research area. These developments were run in parallel in the industrial sector, with the establishment and operation of numerous new companies that produce insects for food and feed in the vast majority of the EU countries. One of the key elements in developing the above areas is the utilization of side-streams or byproducts that cannot be utilized further in the agri-food chain, integrating circular economy attributes in practice, through the green transformation of "trash" to "gold".

In the same context, the use of microalgae (including cyanobacteria strains like *Arthrospira*) also works the same way in utilizing different byproducts in the agri-food value chain. Several microalgal species are widely used as important protein sources [14]. Certain legume species were overlooked for many decades, or their use was rather limited, even though they are rich in protein, such as lupins and fava beans [15]. Additionally, microbial fermentation can be used in parallel with insects, algae, and legumes, as it offers a highly applicable method that can transform an extremely large variety of substances into food and feed [16–18]. Apparently, none of the above techniques can serve as a standalone source for the complete substitution of the traditional protein sources; integration of more than one of these techniques simultaneously can constitute a viable solution for the production of proteins with environmentally compatible pathways. While microalgae could utilize several forms of water-soluble nitrogen in protein-rich biomass, many agricultural wastes would require pre-treatment steps so that nitrogen and other elements could be made available for microalgal consumption. In addition to nitrogen recovery, several microalgae could also produce other high-value metabolites (e.g. pigments, polyunsaturated fatty acids, etc.) using waste sources [19].

Alternative proteins in the European and Mediterranean value chains

Current European agricultural production systems are heavily dependent on protein imports to cover mainly the nutritional needs of livestock animals and farmed fish, but also additional needs for human consumption. Indicatively, the EU, together with Norway and Switzerland, is the second-largest importer of soy after China, with the most quantities to be imported from Brazil, Argentina, and the US [20]. The dependency of European agri-food systems on imports of the main protein sources renders them unstable and unprotected from major disruptions of the different channels in the supply chain, as has been proven during the pandemic crisis. This situation is especially critical for the Mediterranean region, where drought and ecological deficits are worsening the self-sufficiency of traditional protein supply chains [21]. Therefore, there is an urgent need for the EU, and particularly for the Mediterranean basin-based countries, for efficient, viable, and locally produced alternative protein sources, including the exploitation and valorization of agro-industrial side-streams and byproducts. In the Mediterranean—despite the above average consumer resistance—cultured, plant-based, and insect-based meat are emerging technologies for producing alternatives to meat-derived proteins, whose demand is growing. Thus, sustainable and smart intensification of farming systems with integrated biorefinery concepts (such as insect-based and algae-based) offers greenhouse gas mitigation options through nitrogen flow optimizations, overall improved biomass management, and higher conversion rates into accessible protein intermediates [22].

The ability of agricultural production systems to rely on locally produced resources can increase their stability and resilience to adverse and unforeseen events that disrupt global supply chains. In this context, there is a need to reduce the risk for the Mediterranean countries from being dependent on imported protein sources, aiding them to rely more on locally produced nutrients. This can be achieved by adjusting novel protein production to the unique Mediterranean conditions, considering the establishment of new, socio-economically feasible, and environmentally sustainable alternative protein value chains and production systems. The exploitation of side-streams is of fundamental importance and can be based on the establishment of alternative protein production systems through local industrial adaptations that consider the unique characteristics of the Mediterranean basin. This should be done in conjunction with quantifying the perceptions and beliefs of the public in the Mediterranean region about novel protein production, using realistic case studies and paradigms with consumer and end-user cocreation of specific products. Recent studies indicate that there are positive perceptions in this region that further encourage research in this direction [23,24]. However, additional work is needed to integrate procedures to obtain high-quality protein ingredients, considering consumers' preferences and religious and cultural principles for these resources to be used daily.

One paradigm of the integration of local side-streams with the production of alternative proteins is the case of the so-called "fortified insects". In this case, the substrate for the mass rearing of insects is enriched with local agricultural byproducts of plant origin, such as residues of the processing of agricultural products, microalgae, or plants known to be rich in antioxidants and vitamins [25,26]. This enrichment has yielded in the production of insects that have all these desirable characteristics, as compared with insects that were fed only with conventional diets, e.g. bran [26].

Feed the future

The unique characteristics of the Mediterranean basin have resulted in unique feeding trials with targeted applications. For instance, seabass that was fed with aquafeed that contained the yellow mealworm, *Tenebrio molitor* L., was found to be superior to seabass that was fed with the standard aquafeed in terms of antiinflammatory and antiparasitic tolerance [27]. Similarly, seabream characteristics were not affected by the addition of *T. molitor*, the black soldier fly, *Hermetia illucens* L., and the housefly, *Musca domestica* L. [28]. Furthermore, substituting soybean meal with 50% and 100% black soldier fly larvae meal in guinea pig diets and its effects on meat quality (fatty acid profile, amino acid profile, water-holding capacity, pH, proximal composition, and color) have also been thoroughly investigated. The results showed no differences in the protein content and amino acid profile of meat nor in the n-6:n-3 and P/S ratios, but did show an increment in the desirable fats (mono- and poly-unsaturated fatty acids) in the guinea pigs fed with black soldier fly larvae meal [29]. Similar results have also been reported in the case of broilers that, when fed with *T. molitor*, had considerably better meat composition and welfare traits [30,31]. Similar data have also been reported in the case of pigs [32]. The same holds in the case of microalgae on different types of livestock and farmed fish [33–35]. All the above data clearly underline the importance of using side-streams through the alternative production chain, which, if translated further, is expected to have a considerable effect on the establishment of a green protein production industry.

Much more than just a protein: From extraction to bioconversion

One of the most noticeable characteristics that constitute the entire procedure unique is the fact that, although, in principle, the aim is novel protein extraction, there is a side procedure that takes place in parallel: bioconversion. Even before the intensified industrialization of the production of novel protein sources, certain agents, such as insects and algae, were valuable waste management agents for types of waste that could not be easily handled with conventional methods [36,37]. Hence, waste management thought these agents still remains an important and largely unexplored area, despite the fact that its potential is enormous for a wide range of waste materials [38–40]. In particular, legume residues are produced yearly in very large amounts and may represent an interesting source of plant proteins that contribute to satisfying the steadily increasing global protein demand. Innovative biorefinery extraction cascades may also enable the recovery of further bioactive molecules and fibers from these insufficiently tapped biomass streams [8].

With only a few exceptions, the evaluation of the "side" products of this procedure is now in its infancy, as many potential new products are positively evaluated and rapidly introduced into the market on an industrial scale. One such paradigm is insect frass, which was not known until recently. Insect frass is a byproduct of insect production units that has unique characteristics as a soil improvement agent and is now authorized in the EU for this purpose [41,42]. Recent works reported the positive effects of insect frass in different types of plant species [43,44]. As a "byproduct" of the insect rearing procedure, frass is expected to gain more ground as a commercial product very shortly, creating, if insects are fed on byproducts themselves, a never-ending circle of byproduct production and utilization in the agri-food chain. This list of side products is being continuously updated at regular intervals, with new discoveries or an update of a novel use of an already known substance. The list includes astaxanthin, which is an extremely strong antioxidant, insect oil, with characteristics that are comparable with those of some of the already existing oils that are used in food, gluten-free food, which is based on legumes, plant protection agents, that come from algae, and many more [45–48].

Conclusions

Designing new recycling processes, products, and new uses of all the above is not an easy task, as such an effort requires a multidimensional approach involving a wide range of key players with simultaneous involvement. As such, any new products should be designed and developed to meet target group needs and expectations for preferences, nutritional value and satiety/satiation ability, healthy properties and sustainability, sensory appeal, a rewarding eating experience, and convenience, considering both individual and context-specific requirements. At the same time, any new developments should be based on a continuous update and harmonization with the EU legislation, providing adaptable and inclusive solutions that are likely to have industrial projections and agree with the local environmental indicators, especially in the case of dry areas such as the Mediterranean basin.

Author contributions

The manuscript was written through contributions of all authors. Each co-author has contributed significantly on a specific scientific level to this review manuscript. Conceptualization: ACG, SS, PD; Writing - original draft - Review & Editing: ACG, GM, GE, EYA and RCI (insects as nutrient source), SS (circularity and environmental impact of alternative proteins), PD and BCM (algae as nutrient source), TA (legumes as nutrient source), GL, CLEC, PS and CV (alternative protein-based feeds), GF and PJ-I (alternative protein-based foods and feeds), SA (fermentation of alternative proteins for innovative foods and feeds), KM (commercialization of alternative protein-based foods and feeds), SR (alternative protein-based foods) and MC (consumer acceptance of alternative protein-based foods and feeds); Funding acquisition: ACG, SS, PD, TA, GL, GF, SA, BCM, GM, CLEC, GE, PS, CV, KM, SR, EYA, MC, PJ-I and RCI. All authors have given approval to the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

Financial support for this paper has been provided by PRIMA, a program supported by the European Union, under grant agreement No 2231, project CIPROMED (PRIMA Call 2022 Section 1 Agri-food IA).

References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest
** of outstanding interest

1. Parisi G, Tulli F, Fortina R, Marino R, Bani P, Zotte AD, De Angelis A, Piccolo G, Pinotti L, Schiavone A, Terova G, Prandini A, Gasco L, Roncarati A, Danieli PP: **Protein hunger of the feed sector: the alternatives offered by the plant world**. *Ital. J. Anim. Sci.* 2020, **19**:1204–1225. https://doi.org/10.1080/1828051X.2020.1827993.

2. Ritchie H, Rodés-Guirao L, Mathieu E, Gerber M, Ortiz-Ospina E, Hasell J, Roser M: ***Population growth***. Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/population-growth. [Accessed 11 October 2023].

3. Beltran-Peña A, Rosa L, D' Odorico P: **Global food self-sufficiency in the 21st century under sustainable intensification of agriculture**. *Environ. Res. Lett.* 2020, **15**, 095004. https://doi.org/10.1088/1748-9326/ab9388.

4. FAO (Food and Agriculture Organization of the United Nations): *FAOSTAT database*. 2021. Available at: http://www.fao.org/faostat/en/#data. [Accessed 11 October 2023].

5. Sinha S, Tripathi P: **Trends and challenges in valorisation of food waste in developing economies: a case study of India**. *Case Stud. Chem. Environ. Eng.* 2021, **4**, 100162. https://doi.org/10.1016/j.cscee.2021.100162.

6. UNEP (United Nations Environment Programme): *Food waste index report 2021*. Nairobi. 2021. Available at:, https://www.unep.org/resources/report/unep-food-waste-index-report-2021. [Accessed 11 October 2023].

7. * O' Connor J, Skeaff S, Bremer P, Lucci G, Mirosa M: **A critical review of on-farm food loss and waste: future research and policy recommendations**. *Renew. Agric. Food Syst.* 2023, **38**: E24. https://doi.org/10.1017/S1742170523000169.

This paper gives an overview of on-farm food losses and wastes and suggests methods for their quantification, as well as management options.

8. Tassoni A, Tedeschi T, Zurlini C, Cigognini IM, Petrusan J-I, Rodríguez Ó, Neri S, Celli A, Sisti L, Cinelli P, *et al.*: **State-of-the-art production chains for peas, beans and chickpeas—valorization of agro-industrial residues and applications of derived extracts**. *Molecules* 2020, **25**:1383. https://doi.org/10.3390/molecules25061383.

9. * Van Huis A, Gasco L: **Insects as feed for livestock production: insect farming for livestock feed has the potential to replace conventional feed**. *Science* 2023, **379**:138–139. https://doi.org/10.1126/science.adc9165.

This study gives an overview of the recent advances and challenges in the use of insects as feed.

10. Veldkamp T, Gasco L: **Insects as global opportunity**. *Animal Frontiers* 2023, **13**:3–5. https://doi.org/10.1093/af/vfad034.

11. *EU Commission Regulation 2017/893 of 24 May 2017 amending Annexes I and IV to regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to commission regulation (EU) No 142/2011 as regards the provisions on processed animal protein, OJEU 138*. 2017:92–116. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0893&from=EN. [Accessed 11 October 2023].

12. Commission Regulation (EC): *2021b/1372 of 17 August 2021b amending Annex IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council as regards the prohibition to feed nonruminant farmed animals, other than Fur animals, with*

protein derived from animals, OJEU 295. 2021:1–17. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2021:295:FULL&from=EN. [Accessed 11 October 2023].

13. Boukid F, Sogari G, Rosell CM: **Edible insects as foods: mapping scientific publications and product launches in the global market (1996-2021)**. *J. Insects Food Feed* 2022, **9**: 353–368. https://doi.org/10.3920/JIFF2022.0060.

14. * Amorim ML, Soares J, Coimbra JSR, Leite MO, Albino LFT, Martins MA: **Microalgae proteins: production, separation, isolation, quantification, and application in food and feed**. *Crit. Rev. Food Sci. Nutr.* 2021, **61**:1976–2002. https://doi.org/10.1080/10408398.2020.1768046.

This study describes the current state of the production of microalgae proteins for various applications.

15. Semba RD, Ramsing R, Rahman N, Kraemer K, Bloem MW: **Legumes as a sustainable source of protein in human diets**. *Glob. Food Sec.* 2021, **28**, 100520. https://doi.org/10.1016/j.gfs.2021.100520.

16. Garofalo C, Norici A, Mollo L, Osimani A, Aquilanti L: **Fermentation of microalgal biomass for innovative food production**. *Microorganisms* 2022, **10**:2069. https://doi.org/10.3390/microorganisms10102069.

17. Kewuyemi YO, Kesa H, Chinma CE, Adebo OA: **Fermented edible insects for promoting food security in Africa**. *Insects* 2020, **11**:283. https://doi.org/10.3390/insects11050283.

18. Cichońska P, Ziarno M: **Legumes and legume-based beverages fermented with lactic acid bacteria as a potential carrier of probiotics and prebiotics**. *Microorganisms* 2021, **10**:91. https://doi.org/10.3390/microorganisms10010091.

19. * Khan S, Das P, Thaher MI, Quadir MA, Mahata C, Al Jabri H: **Utilization of nitrogen-rich agricultural waste streams by microalgae for the production of protein and value-added compounds**. *Curr. Opin. Green Sustain. Chem.* 2023, **41**, 100797. https://doi.org/10.1016/j.cogsc.2023.100797.

This study describes the recent advances, challenges, and prospects of microalgal cultivation using agricultural wastes to produce biomass rich in protein and other value-added metabolites for food and feed applications.

20. IDH, European Soy Monitor: **Insights on the uptake of responsible and deforestation-free soy in 2019**. In *Prepared for IDH by Schuttelaar & Partners*. Utrecht, the Netherlands: IDH; 2021. Available at: https://www.idhsustainabletrade.com/uploaded/2021/06/2019-IDH-European-Soy-Monitor-report.pdf. [Accessed 11 October 2023].

21. Galli A, Iha K, Halle M, El Bilali H, Grunewald N, Eaton D, Capone R, Debs P, Bottalico F: **Mediterranean countries' food consumption and sourcing patterns: an ecological footprint viewpoint**. *Sci. Total Environ.* 2017, **578**:383–391. https://doi.org/10.1016/j.scitotenv.2016.10.191.

22. Mrabet R, Savé R, Toreti A, Caiola N, Chentouf M, Llasat MC, Mohamed AAA, Santeramo FG, Sanz-Cobena A, Tsikliras A, Food, Cramer W, Guiot J, Marini K, Eds., *Climate and environmental change in the Mediterranean basin – current situation and risks for the future. First Mediterranean assessment report, union for the Mediterranean, plan Bleu*. Marseille, France: UNEP/MAP; 2020:26. Available at: https://www.medecc.org/wp-content/uploads/2020/11/MedECC_MAR1_3_2_Food.pdf. [Accessed 11 October 2023].

23. Lafarga T, Pieroni C, D'Imporzano G, Maggioni L, Adani F, Acién G: **Consumer attitudes towards microalgae production and microalgae-based agricultural products: the cases of Almería (Spain) and Livorno (Italy)**. *ChemEngineering* 2021, **5**: 27. https://doi.org/10.3390/chemengineering5020027.

24. Rumbos CI, Mente E, Karapanagiotidis IT, Vlontzos G, Athanassiou CG: **Insect-based feed ingredients for aquaculture: a case study for their acceptance in Greece**. *Insects* 2021, **12**:586. https://doi.org/10.3390/insects12070586.

25. Ogidi CO, Ogunlade AO, Bodunde RS, Aladejana OM: **Evaluation of nutrient contents and antioxidant activity of wheat cookies fortified with mushroom (*Termitomyces robustus*) and edible insects**. *J. Food Sci. Technol.* 2023. https://doi.org/10.1080/15428052.2023.2181253. in press.

26. Kotsou K, Chatzimitakos T, Athanasiadis V, Bozinou E, Adamaki-Sotiraki C, Rumbos CI, Athanassiou CG, Lalas SI: **Waste orange peels as a feed additive for the enhancement of the nutritional value of *Tenebrio molitor***. *Foods* 2023, **12**:783. https://doi.org/10.3390/foods12040783.

27. Henry MA, Gasco L, Chatzifotis S, Piccolo G: **Does dietary insect meal affect the fish immune system? The case of mealworm, *Tenebrio molitor* on European sea bass, *Dicentrarchus labrax***. *Dev. Comp. Immunol.* 2018, **81**:204–209. https://doi.org/10.1016/j.dci.2017.12.002.

28. Mastoraki M, Ferrándiz PM, Vardali SC, Kontodimas DC, Kotzamanis YP, Gasco L, Chatzifotis S, Antonopoulou E: **A comparative study on the effect of fish meal substitution with three different insect meals on growth, body composition and metabolism of European sea bass (*Dicentrarchus labrax* L.)**. *Aquaculture* 2020, **528**, 735511. https://doi.org/10.1016/j.aquaculture.2020.735511.

29. Herrera E, Petrusan J-I, Salvá-Ruiz B, Novak A, Cavalcanti K, Aguilar V, Heinz V, Smetana S: **Meat quality of Guinea pig (*Cavia porcellus*) fed with black soldier fly larvae meal (*Hermetia illucens*) as a protein source**. *Sustainability* 2022, **14**: 1292. https://doi.org/10.3390/su14031292.

30. Andrade JMM, Pereira RT, de Paula VRC, Moreira Junior H, Menten JFM: ***Tenebrio* meal as a functional ingredient modulates immune response and improves growth performance of broiler chickens**. *J. Appl. Poult. Res.* 2023, **32**, 100346. https://doi.org/10.1016/j.japr.2023.100346.

31. Vasilopoulos S, Giannenas I, Savvidou S, Bonos E, Rumbos CI, Papadopoulos E, Fortomaris P, Athanassiou CG: **Growth performance, welfare traits and meat characteristics of broilers fed diets partly replaced with whole *Tenebrio molitor* larvae**. *Animal Nutrition* 2023, **13**:90–100. https://doi.org/10.1016/j.aninu.2022.12.002.

32. Veldkamp T, Vernooij AG: **Use of insect products in pig diets**. *J. Insects Food Feed* 2021, **7**:781–793. https://doi.org/10.3920/JIFF2020.0091.

33. Shah MR, Lutzu GA, Alam A, Sarker P, Chowdhury MAK, Parsaeimehr A, Liang Y, Daroch M: **Microalgae in aquafeeds for a sustainable aquaculture industry**. *J. Appl. Phycol.* 2018, **30**: 197–213. https://doi.org/10.1007/s10811-017-1234-z.

34. El-Bahr S, Shousha S, Shehab A, Khattab W, Ahmed-Farid O, Sabike I, El-Garhy O, Albokhadaim I, Albosadah K: **Effect of dietary microalgae on growth performance, profiles of amino and fatty acids, antioxidant status, and meat quality of broiler chickens**. *Animals* 2020, **10**:761. https://doi.org/10.3390/ani10050761.

35. Chaves AAM, Martins CF, Carvalho DFP, Ribeiro DM, Lordelo M, Freire JPB, de Almeida AM: **A viewpoint on the use of microalgae as an alternative feedstuff in the context of pig and poultry feeding—a special emphasis on tropical regions**. *Trop. Anim. Health Prod.* 2021, **53**:396. https://doi.org/10.1007/s11250-021-02800-5.

36. Ojha S, Bußler S, Schlüter OK: **Food waste valorisation and circular economy concepts in insect production and processing**. *Waste Management* 2020, **118**:600–609. https://doi.org/10.1016/j.wasman.2020.09.010.

37. Ramli NM, Verreth JAJ, Yusoff FM, Nurulhuda K, Nagao N, Verdegem MCJ: **Integration of algae to improve nitrogenous waste management in recirculating aquaculture systems: a review**. *Front. Bioeng. Biotechnol.* 2020, **8**:1004. https://doi.org/10.3389/fbioe.2020.01004.

38. Valentino F, Moretto G, Gottardo M, Pavan P, Bolzonella D, Majone M: **Novel routes for urban bio-waste management: a combined acidic fermentation and anaerobic digestion process for platform chemicals and biogas production**. *J. Clean. Prod.* 2019, **220**:368–375. https://doi.org/10.1016/j.jclepro.2019.02.102.

39. Gasco L, Biancarosa I, Liland NS: **From waste to feed: a review of recent knowledge on insects as producers of protein and fat for animal feeds**. *Curr. Opin. Green Sustain. Chem.* 2020, **23**: 67–79. https://doi.org/10.1016/j.cogsc.2020.03.003.

40. Smetana S: **Circularity and environmental impact of edible insects**. *J. Insects Food Feed* 2023, **9**:1111–1114. https://doi.org/10.3920/JIFF2023.x004.

41. Poveda J: **Insect frass in the development of sustainable agriculture. A review**. *Agron. Sustain. Dev.* 2021, **41**:5. https://doi.org/10.1007/s13593-020-00656-x.

42. ** Barragán-Fonseca KY, Nurfikari A, van de Zande EM, Wantulla M, van Loon JVA, de Boer W, Dicke M: **Insect frass and exuviae to promote plant growth and health**. *Trends Plant Sci.* 2022, **27**:646–654. https://doi.org/10.1016/j.tplants.2022.01.007.
This study describes the potential of insect residual streams derived from the production of insects as food and feed to promote plant growth and health.

43. Quilliam RS, Nuku-Adeku C, Maquart P, Little D, Newton R, Murray F: **Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems**. *J. Insects Food Feed* 2020, **6**:315–322. https://doi.org/10.3920/JIFF2019.0049.

44. Hodge S, Conway J: **The effects of insect frass fertilizer and biochar on the shoot growth of chicory and plantain, two forage herbs commonly used in multispecies swards**. *Agronomy* 2022, **12**:2459. https://doi.org/10.3390/agronomy12102459.

45. Laroche M, Perreault V, Marciniak A, Gravel A, Chamberland J, Doyen A: **Comparison of conventional and sustainable lipid extraction methods for the production of oil and protein isolate from edible insect meal**. *Foods* 2019, **8**:572. https://doi.org/10.3390/foods8110572.

46. Costa JAV, Freitas BCB, Cruz CG, Silveira J, Morais MG: **Potential of microalgae as biopesticides to contribute to sustainable agriculture and environmental development**. *J. Environ. Sci. Health* 2019, **54**:366–375. https://doi.org/10.1080/03601234.2019.1571366.

47. Al-Othman H, Maghaydah S, Abughoush M, Olaimat AN, Al-Holy MA, Ajo R, Al Khalaileh NI, Choudhury IH, Angor M: **Development and characterization of nutritious gluten-free doughnuts with lupin and inulin flours**. *Foods* 2022, **11**:3237. https://doi.org/10.3390/foods11203237.

48. Honda M, Hirota K, Zhang Y, Hayashi Y, Sygahara R: **Effect of astaxanthin isomer supplementation on their accumulation in edible orthopterans: migratory locusts and two-spotted crickets**. *J. Insects Food Feed* 2023, **9**:955–964. https://doi.org/10.3920/JIFF2022.0129.