EDIBLE INSECTS AS SUSTAINABLE AND NUTRIENT-RICH FOOD SOURCES: EXPLORING INNOVATIONS AND ADVANCEMENTS FOR FUTURE FOOD PRACTICES–A COMPREHENSIVE REVIEW

Salgado-Ramos, M., Castagnini, J. M., Dar, B. N., Gharibzahedi, S. M. T., Phimolsiripol, Y., Rimac-Brnčić, S., Martínez-Culebras, P. V., Altintas, Z., Barba, F. J.

Edible Insects as Sustainable and Nutrient-Rich Food Sources: Exploring Innovations and Advancements for Future Food Practices – A Comprehensive Review

Manuel Salgado-Ramos[a], Juan Manuel Castagnini[a*], Basharat N. Dar[b*], Seyed Mohammad Taghi Gharibzahedi[c,d], Yuthana Phimolsiripol[e,f], Suzana Rimac-Brnčić[g], Pedro V. Martínez-Culebras[a*], Zeynep Altintas[c,d,h], and Francisco J. Barba[a]

Author affiliation(s)

[a] Research group in Innovative Technologies for Sustainable Food (ALISOST), Department of Preventive Medicine and Public Health, Food Science, Toxicology and Forensic Medicine, Faculty of Pharmacy, Universitat de València, Avda. Vicent Andrés Estellés s/n, Burjassot, 46100 València, Spain

[b] Department of Food Technology, Islamic University of Science and Technology, 192122 Kashmir, India

[c] Institute of Chemistry, Faculty of Natural Sciences and Maths, Technical University of Berlin, Straße des 17. Juni 124, 10623 Berlin, Germany

[d] Institute of Materials Science, Faculty of Engineering, Kiel University, 24143 Kiel, Germany

[e] Faculty of Agro-Industry, Chiang Mai University, Chiang Mai 50100, Thailand

[f] Cluster of Agro Bio-Circular-Green Industry, Chiang Mai University, Chiang Mai 50100, Thailand

[g] Faculty of Food Technology and Biotechnology, University of Zagreb, Pierottijeva 6, 10000 Zagreb, Croatia

[h] Kiel Nano, Surface and Interface Science (KiNSIS), Kiel University, 24118 Kiel, Germany

Corresponding authors

Juan Manuel Castagnini[a], juan.castagnini@uv.es

Pedro V. Martínez-Culebras[a], pedro.martinez@uv.es

Basharat N. Dar, darnabi@gmail.com

ABSTRACT: The utilization of edible insects (EIs) as an alternative source of nutrients and functional foods has gained substantial recognition in recent years, opening doors to sustainable food production, improved dietary health, and unique food experiences. EIs are rich in bioactive compounds (BACs) encompassing proteins, peptides, PUFA, vitamins, and antioxidants. These BACs have a wide array of health-enhancing qualities, from antioxidant, anti-inflammatory, antimicrobial and immune system-modulating effects. Furthermore, the potential of EIs extends to the management or mitigation of health conditions like obesity, diabetes, cardiovascular diseases, and malnutrition. The incorporation of EIs into food systems has evolved beyond traditional consumption, with applications in the development of functional foods, dietary supplements, and food ingredients. In this context, this critical review aims to amalgamate the most recent developments in the realm of EIs-based food products, in addition to elucidating the most efficient process intensification procedures for the extraction and recovery of these BACs. The sustainable utilization of EIs calls for a careful examination of several crucial considerations, including consumer acceptance or allergenicity. In this respect, intensified technologies have emerged to maximize the potential of BACs derived from EIs, while simultaneously enhancing their functionality, stability, and regulatory approval within the ambit of food products.

Keywords: Edible Insects; Nutrition; Bioactive Compounds; Innovations; Sustainability

1. Introduction

The global population is anticipated to reach 8.5 billion individuals by the year 2030, with a further projected increase to 9.7 billion by 2050, thereby precipitating a substantial surge in worldwide food demand [1]. The prevailing evidence unequivocally underscores the unsustainable nature of contemporary food systems. These systems are responsible for a significant portion of global greenhouse gas emissions, exacerbate the ongoing loss of biodiversity, and stand as major consumers of freshwater resources. Moreover, there exists a pressing imperative to champion the promotion of healthful dietary patterns while simultaneously averting malnutrition in all its multifaceted forms. This encompasses addressing issues such as undernourishment, stunting, wasting, and micronutrient deficiencies, as well as tackling the burgeoning concerns of overweight and obesity [2]. Furthermore, these dietary factors are intricately linked to a range of non-communicable diseases, including diabetes, cardiovascular diseases, and certain types of cancer

[3]. In light of this multifaceted challenge, the global food production system is compelled to respond by generating an adequate supply of high-quality sustenance, capable of catering to the nutritional requirements of an expanding global populace while inflicting minimal ecological harm [4].

The current scenario has ignited renewed global interest in the consumption of edible insects (EIs) [5] (**Figure 1**). The production of EIs as a source of both food and feed has garnered attention due to its considerably lower land and water requirements, as well as reduced greenhouse gas emissions when compared to conventional livestock farming [6] (Toviho & Péter, 2020). Therefore, EIs play a pivotal role in enhancing the sustainability of food supply chains [7, 8]. It is worth noting that the consumption of EIs by humans is far from a recent trend; rather, it has a long historical legacy dating back to ancient times. In the contemporary context, insect consumption remains an integral component of the daily diet in numerous Asian, African, and South American countries [7,9]. Although insects have traditionally been absent from Western culinary traditions, the EIs industry is rapidly evolving to meet the growing demand for insects as a culinary ingredient. This trend is also gaining traction in Western nations [10-12]. An additional compelling aspect in favour of EIs is their remarkable versatility. EIs can be consumed in various forms, including whole or processed into protein powder, flour, or other ingredients. They find application in a wide spectrum of dishes, ranging from snacks to main courses, offering a mild, nutty flavour profile that complements a variety of ingredients [13].

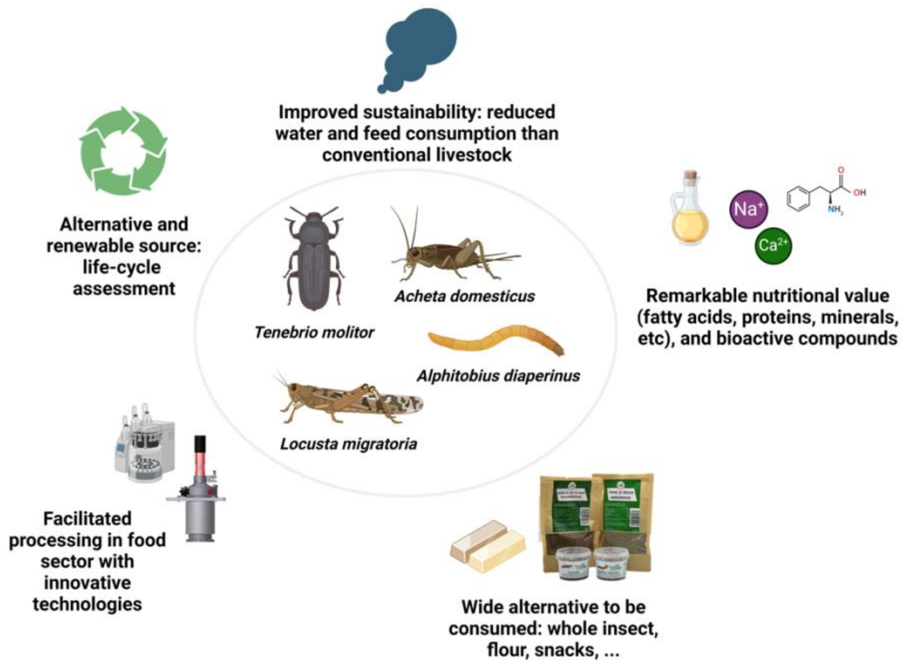

Figure 1. Summary of the main benefits of consuming EIs. Created with biorender.com.

As per the Food and Agriculture Organization [5], the most commonly consumed insects include beetles (Coleoptera, 31 %), caterpillars (Lepidoptera, 18%), bees, wasps, and ants (Hymenoptera, 14%), grasshoppers, locusts, and crickets (Orthoptera, 13%), cicadas, fulgoromorphs, jumpers, mealybugs, and bedbugs (Hemiptera, 10%), termites (Isoptera, 3%), dragonflies (Odonata, 3%), flies (Diptera, 2%), and others (5%) [14]. The European Union has made it obligatory to implement the new European Regulation (EU) 2015/2283 concerning "novel foods", which encompasses insects and arthropods. This regulation came into effect in the EU at the commencement of 2018 [15, 16]. In light of the pressing need for alternative sources of proteins, lipids, or bioactive compounds (BACs), it is noteworthy that four distinct insect species, namely yellow mealworm (*Tenebrio molitor*), migratory locust (*Locusta migratoria*), house cricket (*Acheta domesticus*), and lesser mealworm (*Alphitobius diaperinus*), received recent approvals through various EU regulations. These approvals permit their marketing as snacks or as ingredients for the development of innovative food products.

From a nutritional perspective, EIs stand out as a notable source of energy, high-quality protein, and mono- (MUFAs) and poly- (PUFAs) unsaturated fatty acids, as well as a diverse array of readily accessible vitamins and minerals [17,18,19,20] (**Figure 1; Table 1**). The elevated protein content and the presence of essential amino acids (EAAs) make EIs a compelling alternative to traditional protein sources like meats, fish, and cereal crops, particularly when considering future dietary trends [20, 21]. Although insect proteins may exhibit higher levels of threonine and lysine and comparatively lower levels of methionine or tryptophan, the overall EAAs score in insects falls between 46% and 96%. This range surpasses the minimum recommended level for human diets, which stands at more than 40%. EIs boast even higher quantities of these EAAs than commonly found in plants and animals. Furthermore, insect proteins demonstrate superior digestibility in comparison to plant proteins while maintaining lower digestibility than animal proteins [16,22]. In addition to proteins, EIs are rich in lipids, fibers (including chitin in their exoskeleton), water- and fat-soluble vitamins (e.g., B-groups, C, A, etc.), and minerals (e.g., potassium (K), calcium (Ca), iron (Fe), phosphorus (P), magnesium (Mg), zinc (Zn), etc.) (**Table 1**). However, it is important to note that the potential of EIs to meet recommended daily intake (RDI) values for macro- and micro-nutrients varies according to the specific insect species [18].

Table 1. Nutritional composition of EIs

Nutrients	Composition	References
Protein	50-60 g/100g dry weight. Highly digestible and with essential amino acids (EAAs)	[22]
EAAs	Arginine (Arg), Cysteine (Cys), Glycine (Gly), Glutamine (Glu), Proline (Pro), Tyrosine (Tyr)	[23]
Lipids	20-30 g/dry weight	[24]
Fatty acids	C14:0, C16:0, C18:0, C18:1, C18:2	[23]
Carbohydrates and fibers	6-10 g/dry weight	[25]
Vitamins	B1, B2, B3, B6, B12, C, A, D, E, K	[8, 24, 26]
Minerals	Ca, Zn, Fe, Mg, Cu, Na, K, Ca, P, Mn, I	[24, 27]

In addition to their intrinsic nutritional value, EIs also introduce an innovative dimension through their abundance of BACs and their role as functional foods. These foods are defined as foods that provide health benefits extending beyond basic nutrition [18, 28] (**Figure 2, Table 2**). EIs are particularly rich sources of EAAs, PUFAs, antioxidant vitamins, carotenoid pigments, and phenolic compounds. These components play a pivotal role in significantly reducing or preventing the occurrence of chronic diseases and disorders due to their anti-cardiovascular, anti-inflammatory, antioxidant, and anticancer properties [8, 29-30] (**Table 2**). Certain EIs, such as mealworms and crickets, are rich sources of PUFAs, including omega-3 and omega-6 fatty acids, which play vital roles in promoting cardiovascular health and cognitive function [29]. The antioxidant properties of EIs are closely linked to the presence of various BACs, including phenols, vitamins, flavonoids, and carotenoids [31]. Both *in vitro* and *in vivo* studies provide substantial support for the antioxidant activity of EIs and suggest that their consumption may bolster the body's antioxidant defence mechanisms, thus conferring protection against oxidative damage [31, 32]. Moreover, EIs have recently emerged as a promising source of natural compounds endowed with anti-inflammatory properties [33, 34]. These beneficial properties can be attributed to the presence of various BACs, including peptides, polyphenols, and fatty acids [35]. Consequently, supplementation with insect-based products has demonstrated the ability to reduce inflammatory markers, including nuclear factor-kappa B (NF-κB) and C-reactive protein (CRP), and to ameliorate conditions associated with inflammation, such as colitis and arthritis [36]. Furthermore, these same or similar BACs have exhibited promising anti-cancer properties, affecting mechanisms such as cell cycle arrest, induction of apoptosis, and the reduction of tumor cell migration [37,38, 39].

Moreover, research has revealed that the inclusion of insect-based diets can effectively inhibit tumor growth, reduce tumor size, and enhance the effectiveness of chemotherapy drugs [22]. It is worth noting that the BACs present in EIs, including peptides, enzymes, and fatty acids, yield a multitude of health benefits related to the modulation of the microbiota, cholesterol-lowering effects, antimutagenic properties, antimicrobial activity, immunomodulation, and antihypertensive effects [17, 40, 41, 42] (**Figure 2**).

Table 2. A summary of major BACs of EIs

	Metabolites	Properties	References
Biologically active compounds	Chitin / chitosan	Antimicrobial, antioxidant and immunostimulatory. Wound healing and drug delivery system	[40]
	Antimicrobial peptides	Defense mechanism against fungi, viruses and bacteria	[43]
	Polyunsaturated fatty acids (PUFAs; oemga-3 and omega-6)	Brain development, cardiovascular benefit, and anti-inflammatory effects	[29]
	Phenolics (catechin, quercetin, gallic acid)	Antioxidant by scavenging free radicals and protect against oxidative stress	[44]
	Bioactive peptides from collagen	Antioxidant, antimicrobial, antihypertensive, or anticancer properties	[39]

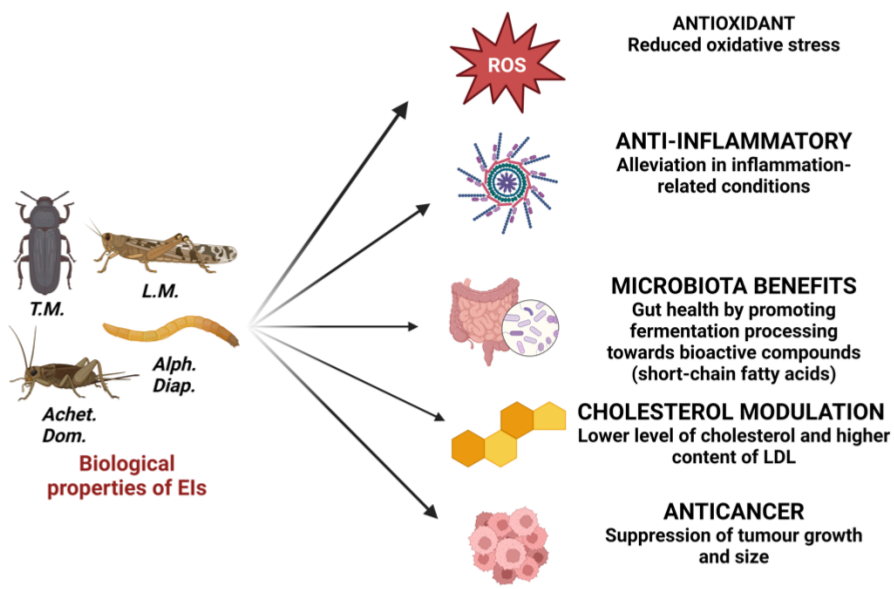

Figure 2. A concise overview of the principal biological properties and health advantages linked to the consumption of EIs. Abbreviations: T.M.: *Tenebrio molitor*; L.M.: *Locusta migratoria*; *Achet. Dom..*: *Acheta domesticus*; *Alph. Diap..*: *Alphitobius diaperinus*. Created with biorender.com.

Hence, there is a pressing need for further research that delves into the content of BACs within EIs, offering additional insights that can build upon their already-established nutritional value. In this context, the continuous evolution of innovative thermal and non-thermal technologies within the food processing sector has brought about a revolution in the quality, safety, bio- and techno-functionality, and shelf life of processed food products. Besides, the application of these advanced technologies yields benefits such as reduced energy consumption, heightened operational efficiency, and the recovery of BACs from food waste and bio-products. Given that EIs contain heat-labile BACs that must be preserved within food products to elicit their health-promoting effects, the utilization of these cutting-edge technologies holds the potential to surmount the limitations associated with traditional heat treatment techniques [45, 46].

Taking into consideration all the aforementioned factors, this review is dedicated to exploring the latest advancements in processing EIs through the application of innovative and emerging technologies. The primary goal is to create novel functional products that can be integrated into both feed and food, enhancing nutritional value, quality, and safety. Furthermore, this review will assess the present and potential future applications of these functional insect-based products.

2. Innovative technologies in processing edible insects:

Indeed, recent progress in the food sector has been primarily oriented toward sustainable processing, aligning with the imperatives of environmental, social, and economic sustainability. To this end, the utilization of innovative technologies stands out as a promising avenue for enhancing the quality and safety of insect-based products [47, 48]. In this context, a crucial consideration involves food decontamination, which can effectively mitigate mycotoxins, allergens, pesticides, or other contaminants. Furthermore, it is worth emphasizing the extraction and isolation of nutraceutical BACs, mainly lipids and proteins, which are abundantly present in EIs. This process yields valuable materials that can be harnessed for the production of food products, both in the industrial sector and for home-made preparations [47, 48]. Additionally, bioactive peptides from insects have demonstrated a wide spectrum of biological properties, serving as antihypertensives, antioxidants, antidiabetics, antimicrobials, and more [16,39]. These innovative technologies offer a more environmentally friendly approach to extraction and mitigation compared to conventional methods. This is not only by reducing energy consumption or waste generation but also by introducing alternative solvents or chemicals. In essence, the mechanisms underlying these protocols enable the recovery of high-quality extracts and products (**Figure 3**), aligning with the principles of Green Chemistry [49, 50]. Several of these prominent technologies for processing EIs processing are comprehensively detailed. In addition, **Table 3** provides a summary of the key findings and reports that have contributed to the state of art in this field over recent years.

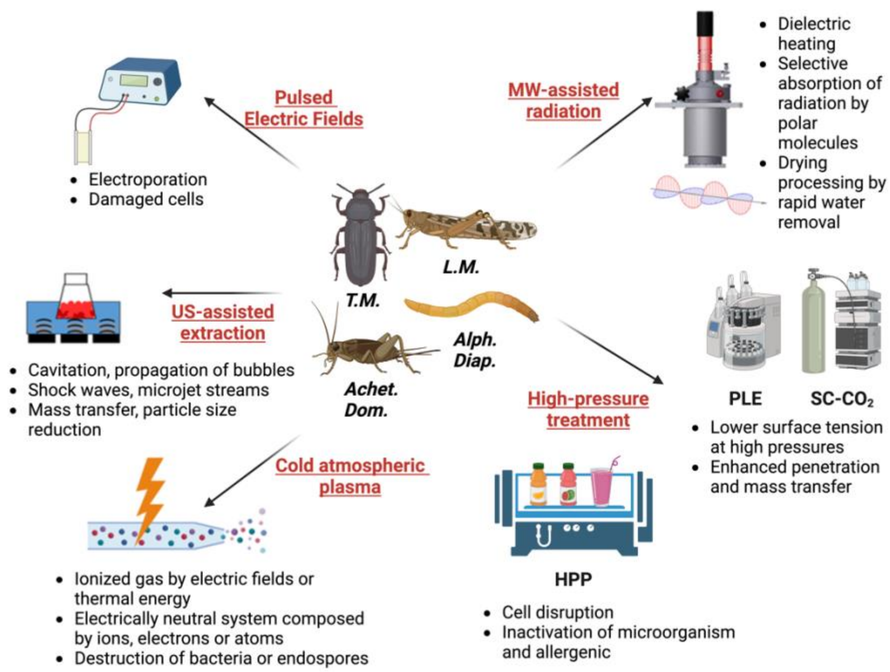

Figure 3. Key innovative technologies for processing EIs. Abbreviations: *T.M.*: *Tenebrio molitor*; *L.M.: Locusta migratoria*; *Achet. Dom.*: *Acheta domesticus*; *Alph. Diap.*: *Alphitobius diaperinus*; HPP: high hydrostatic pressures; PLE: pressurized liquid extraction; SC-CO_2: supercritical CO_2; MW: microwave; US: ultrasound. Created with biorender.com.

Table 3. Principal processing approaches for EIs utilizing intensified technologies.

EI type	Technology and processing conditions	Purpose and main findings	Reference
Lesser mealworm (*A. diaperinus*)	**UAE**, 35 kHz, 240 W. EtOH/isopropanol mixture, 22.64 min, 70ºC, 22.5 v/w solvent-to-solid ratio (RSM)	Oil extraction. Improved efficiency (60 %), TPC (4.306 mg GAE/g) and carotenoid (0.778 mg/g) contents; 88% extraction, 71% DPPH scavenging capacity	[30]
Yellow mealworm (*T. molitor)*	**UAE**, 60% sonication output, 20 kHz. EtOH/miliQ water (1:1, v/v). 15 min, 70ºC. Solvent-to-solid ratio 1:10	Bioactive extraction (lipids, amino acids, certain acids, sugars). Scavenging activity (80% DPPH), anti-inflammatory response, hypolipidemic potential (30% pancreatic lipase inhibition), and 56% reduction in cholesterol bioaccessibility	[51]
Yellow mealworm (*T. molitor*) and black soldier fly (*H. illucens*) larvae	**UAE**, 60% sonication output. 20 kHz. 15 min, 70ºC. Different solvent at 1:10 ratio to-solid	Bioactive extraction (lipids, amino acids, disaccharides, organic acids, sterols). Simultaneous antioxidant activity and lipase-inhibitory multibioactivity at $EtOH/H_2O$ 70% from defatted matrices	[52]
House cricket (*A. Domesticus*) and yellow mealworm (*T. molitor*)	**UAE**, 60% sonication output. 20 kHz. 15 min, 70ºC	TPC (5 g GAE/100g extract), antioxidant activity (86% DPPH), pancreatic lipase inhibition (0.50 mg/mL IC_{50}), cholesterol content (0.45g/100g extract), and lipidic profile of $EtOH/H_2O$ and EtOH extracts	[53-54]
House cricket (*A. Domesticus*)	**PEF**. 4.9-49.1 kJ/kg, 1.5 kV/cm, 20 Hz. 100-1000 pulses, 15 µs. Near rectangular form and bipolar	Enhanced extraction of proteins (18%) and fat (40 %), as well as improved oil binding (19.53%), emulsifying capacity (22%) and antioxidant activity (45.79%) after PEF (4.9 kJ/kg)	[55]
Black soldier fly (*H. illucens*) larvae	**PEF**. 5-20 kJ/kg, 2-3 kV/cm, 2 Hz. 40 µs. Monopolar pulse	Favoured drying of insects, oil extraction (35.1%), and enhanced recovery of free amino acids (5.74%)	[56]
House cricket (*A. domesticus*)	**MAE.** 40 ºC, 120 s+ 50 ºC, 300 s (900W)	Phenolic characterization and antioxidant activity. TPC (1.9 g GAE/100g extract), protein (43.88 g/100g, DPPH (0.275 mg/mL IC_{50}) and ABTS (0.09 mg/mL IC_{50})	[57]
Any species	**Microwave**	Drying processing	[58-59]

House cricket (*A. domesticus*) and yellow mealworm (*T. molitor*)	**PLE.** 120ºC, 15min, 100 bar, N_2	TPC (3.8 g GAE/100g extract), antioxidant activity (80-90% DPPH), pancreatitic lipase inhibition (0.15 mg/mL IC_{50}), cholesterol content (0.45g/100g extract), and lipidic profile of EtOH/H_2O and EtOH extracts	[53-54]
House cricket (*A. domesticus*) and yellow mealworm (*T. molitor*)	**SFE (SC-CO_2).** 325 bar, 55ºC, 75 min, 10 g/mL CO_2 flow	Defatting processing (yields of 11.9% for *AD* and 22.1% for *TM*). Subsequently favored protein extraction and high-pure-protein flour recovered (70.1 and 72.7% *vs*. 58.3 and 48.7% without defatting, respectively)	[60]
Black soldier fly (*H. illucens)* larvae	**SFE (SC-CO_2).** 450 bar, 60ºC, 190 min, 130 g/min CO_2 flow (scale-up)	Defatting processing (74.1-96.9%). High presence of lauric acid (50%). Peroxide index of SFE extracts 0.85-2.76 mEqO_2/kg) lower than hexane values (4.07-11.90 mEqO_2/kg)	[61]

Table 3. Principal processing approaches for EIs utilizing intensified technologies (cont.).

Edible insect type	Technology and processing conditions	Purpose and main findings	Reference
Black soldier fly (*H. illucens*) larvae	**SFE (SC-CO_2).** 450 bar, 60ºC, 100 g/min CO_2 flow (scale-up)	Defatting processing (~90%). Post defatting SC-CO_2 step and bioactivity assay: lipase inhibitory activity (50%) and antioxidant activity by DPPH. Mainly free amino acids and fatty acids	[62]
Yellow mealworm (*T. molitor*) and black soldier fly (*H. illucens*) larvae	**SFE (SC-CO_2).** 300 bar, 45ºC, 180 min, 18 kg/h CO_2 flow	Defatting yields of 86% and 93% for HI and TM, respectively. High protein content for the defatted matrix (64 and 79%). Evaluation of color, particle size distribution, flowability and floodability	[63]
Yellow mealworm (*T. molitor*)	**SFE (SC-CO_2) (pilot scale).** 400/250 bar, 45ºC, 105 min, 20 kg/h CO_2 flow	Maximal defatting of 95%. 72% unsaturated fatty acids, 42% oleic acid. Oil composition and acidity influenced by extraction parameters	[64]
Yellow mealworm (*T. molitor*)	**SFE (SC-CO_2).** 30 MPa, 50ºC and 8 MPa, 45ºC. 8 kg/h CO_2 flow	Immunomodulatory effects: carbon expurgation, phagocytosis, serum nitric oxide and hemolytic antibody content, and acid phosphatase and alkaline phosphatase activity higher than control	[65]

Yellow mealworm (*T. molitor*)	**HHP.** 70-600 MPa, 20ºC, 5 min; 100-500 MPa, 35ºC	Improved technical functional properties of EIs' proteins under high pressures by new aggregations	[66-67]
Yellow mealworm (*T. molitor*)	**HHP.** HHP-assisted enzymatic hydrolysis by Alcalase® (60ºC) or pepsin (40ºC). 380 MPa, 1 min	Increased in vitro digestion of specific allergenic proteins, lowering the immunoreactivity in food	[68]
House cricket (*A. domesticus*)	**HHP.** Acid and alkaline protein extraction + HHP at 500 MPa, 25ºC, 15 min	Isolation of insect proteins to food gels applications as novel foods: conventional protein extraction + HHP by adding 2% porcine gelatin to dispersions of protein fraction	[69]
Yellow mealworm (*T. molitor*) and house cricket (*A. domesticus*)	**HHP.** Conventional defatting with hexane + HHP at 500 MPa, 30-40ºC, 15 min	Improved functional properties for the post-extraction powders (mealworm and cricket) after HHP. Evaluation of crude (up to 72 and 79%) and soluble protein content (55-57 and 59-63%), water and oil binding capacity (180-202 and 132-157%, respectively), TPC (maximum 10.973 mg GAE/g), TAC by DPPH (2.629 mg Trolox/g) and gelation behavior by NMR relaxometry	[70]
House cricket (*A. domesticus*)	**SMD-CAPP.** 8.7-22.0 mW/cm^2, 5 min	Decontamination. Reducing the total microbial count by 1.6-1.9 $\log_{10}$.	[71]

Abbreviations: UAE: ultrasound-assisted extraction; MAE: microwave-assisted extraction; PLE: pressurized liquid extraction; PEF: pulsed electric fields; SFE: supercritical fluid extraction; SC-CO_2: supercritical CO_2; HPP: high hydrostatic pressures; SMD-CAPP: surface micro-discharge cold atmospheric pressure plasma; TM: *T. molitor;* AD: *A. domesticus;* HI: *H. illucens.*

2.1 ***Ultrasound:***

The preferred method for recovering BACs, known as ultrasound-assisted extraction (UAE), relies on the remarkable cavitation phenomena induced by ultrasound (US) power. In this process, the influence of the US leads to the formation of minuscule gaseous micro-bubbles within the liquid phase. These micro-bubbles expand until they reach a point of instability, where they suddenly and violently collapse. This implosion generates abrupt changes in temperature and pressure within the reaction medium, instigating shock waves, microjet streams, turbulence, and shear forces. These effects significantly enhance mass transfer through intensive mixing and heating, resulting in thorough surface cleaning, particle size reduction, and ultimately the breakdown of molecules into small constituents [72, 73]. The application of UAE is well-established for the extraction of BACs from diverse food matrices [74, 75, 76]. As well, it has been instrumental in reducing thawing times, thereby preventing product degradation.

Within the domain of EI processing, it is worth highlighting the significant study conducted by Gharibzahedi and Altintas (2022) [30] on *A. diaperinus*. Their research demonstrated a notable improvement in oil extraction efficiency. Specifically, through a relatively brief 22.64-min process at 70ºC, the utilization of UAE enhanced the extraction efficiency by a remarkable 60% when compared to the traditional extraction method using *n*-hexane solvent. Furthermore, this study revealed substantial antioxidant activity of lipids extracted from *A. diaperinus* by UAE including 71% inhibition of DPPH free radicals. This bioactivity was attributed to the high total phenolic (TPC; 4.306 mg/g), and carotenoid (0.778 mg/g) contents. Nonetheless, Navarro del Hierro et *al*. (2021, 2022) [51, 52] achieved a notable recovery of BACs from *Tenebrio molitor* and *Hermetia illucens* in a mere 15 min. Their method involved the use of EtOH/H_2O mixtures and operated at a frequency of 20 kHz. This further underscores the significance of the work of Gharibzahedi & Altintas (2022) [30] concerning environmental sustainability. Their work employed potentially harmful extracting solvents, such as isopropanol, and necessitated a higher energy consumption, involving a 22.64-min duration and a frequency of 35 kHz. Moreover, the bioactivity was significantly improved in terms of antiradical capacity (80% of DPPH-free radical inhibition), anti-inflammatory response, cholesterol bioaccessibility (56%), and the inhibition of pancreatic lipase (30%). Furthermore, in parallel studies by Navarro del Hierro [53] and Otero [54], the biological activities of *Acheta domesticus* and *T. molitor* were explored under consistent experimental conditions. Results analysis for the ethanol and ethanol/water extracts were: TPC (5g/100g extract), DPPH scavenging activity (86%), cholesterol content (0.27g/100g), and pancreatic lipase inhibition (0.91 mg/mL IC_{50}). These results underscore the reproducibility of bioactive properties in different EI species and their potential for diverse applications.

2.2 ***Pulsed electric fields:***

In the realm of electrical-disruption based processes, the utilization of pulsed electric fields (PEF) has garnered notable attention in recent years [77, 78, 79]. Briefly, when a matrix is situated between high-voltage electrodes, an electrical current is applied in the form of short pulses lasting from milliseconds to nanoseconds. Under these conditions, the cell walls of the matrix are damaged, resulting in the creation of numerous pores on the surface. The permanence or temporality of these pores depends on various factors, including the matrix's nature and the parameters applied, such as field strength (kV/cm), specific energy (kJ/kg), or frequency (Hz). The formation of these pores results in increased permeability of the cell membrane, facilitating the release of intracellular compounds. In the food sector, this approach can be particularly valuable for various purposes, such as the mitigation of mycotoxins in ready-to-eat foods like juices and smoothies [80, 81]. Concurrently, the disruption of cell walls could elevate the enzyme release/concentration ratio, potentially leading to the hydrolysis of allergens [48]

In a recent development, Psarianos et *al*. [55] reported notable improvements in the functional properties of house cricket (*A. domesticus*) as food material following PEF processing. Moreover, the study involved the extraction of essential nutrients found in EIs, specifically proteins and lipids, as well as the recovery of chitin, further showcasing the versatility and potential of PEF in enhancing the utility of EIs. In this regard, the application of PEF-assisted extraction at an energy input of 4.9 kJ/kg yielded a significant enhancement in the recovery of essential compounds compared to the control group, with improvements of over 18% for proteins and 40% for lipids. Additionally, a significant improvement in functional properties such as oil binding (28.10%), emulsifying capacity (64.88%), and antioxidant activity (58.20%) were also observed with an energy input of 24.53 kJ/kg. Nonetheless, when evaluating the sustainability and economic feasibility of the PEF process, the energy input of 4.9 kJ/kg was identified as the most suitable and efficient option. Nevertheless, even with the lower energy input of 4.9 kJ/kg, notable improvements of 19.53% for oil binding, 22.06% for emulsifying capacity, and 45.79% for antioxidant activity were still accomplished [55]. Alles et *al*. (2020) [56] applied PEF to *H. illucens* under various field strengths (2 and 3 kV/cm) and specific energies (5, 10, and 20 kJ/kg). A salient observation was the reduction in drying rate across all PEF protocols, which was accompanied by a modest yet significant improvement in oil extraction. Particularly, the oil yield at 3 kV/cm and 5 kJ/kg was increased up to 8% compared to the control. Furthermore, PEF treatment at 3 kV/cm and 20 kJ/kg led to a substantial release of free amino acids, marking a noteworthy increase ranging from 51.33% to 54.28% in comparison to the untreated control. Most intriguingly, the study reported a remarkable 63.5% increase in crude protein content within the press cake following PEF treatment at 2 kV/cm and 20 kJ/kg, thereby enhancing the overall quality of the food source compared to the untreated material.

2.3 *Microwave heating:*

Microwave (MW) radiation is harnessed for heat generation primarily through ionic conduction and dipole rotation mechanisms. Materials with the capacity to absorb MWs are those containing molecular dipoles, such as water or ethanol. This selective absorption of radiation by polar molecules results in even and uniform heating, differing from conventional treatments where temperature gradients typically form from the container's walls to the inner solution [82]. Therefore, the efficacy of metabolite extraction via MW-assisted extraction (MAE) is attributed to the heightened absorption of intracellular water, which induces cell expansion and subsequent rupture of plant tissues [50]. To the best of the authors' knowledge, there is a lack of literature on the extraction of BACs from EIs using MAE. However, a study by Nino et al.[57] focused on the recovery of bioactive phenolic compounds and assessed the antioxidant capacity of extracts derived from *A. domesticus*. In this study, commercially available Acheta (cricket species) treated with MAE showed a TPC of 1.9 g gallic acid equivalent (GAE)/100 g in the extracted material. Some of the main identified polyphenols included gallic and caffeic acid, quercetin, or kaempferol-3-glucoside. Notably, the total antioxidant capacity displayed promising results with IC_{50} values of 0.275 and 0.09 mg/mL when assessed using the DPPH and ABTS assays, respectively. Interestingly, the authors attributed this enhanced antioxidant capacity to the high protein (43.88%) content observed, despite the relatively low TPC found in the extracts. MW treatment is commonly employed for drying EIs due to its ability to efficiently remove water without causing crust formation or temperature gradients [58, 59]. Moreover, MW drying typically requires less processing time compared to freeze drying or oven drying. Nonetheless, it is important to consider that the application of high temperatures during MW drying can potentially lead to protein denaturation in EIs, which may result in alterations to the nutritional properties of these new ingredients.

2.4 *High-pressure-based processing:*

The use of compressed fluids offers an effective means for the recovery of metabolites from natural sources. This process is facilitated by the reduction in the solvent surface tension achieved through the application of high pressures. As a result, the solvent can penetrate the matrix more efficiently, leading to the disruption of the matrix and the transfer of analytes into the solvent [83]. Moreover, the increased pressure resulting from the compaction of fibres enhances the extraction efficiency of BACs. Under these conditions, the solvent can be maintained below its boiling point, enabling the use of higher working temperatures. This elevated temperature has a twofold effect: it increases the distribution coefficient, which aids in the transfer of metabolites, and it enhances the solubility of these compounds in the extraction medium [84]. Pressurized fluid extraction (PFE) is a notable technique used for the extraction of various compounds. In this approach, conventional solvents such as ethanol or hexane are employed in a pressurized system, which aids in the extraction of specific target compounds, as previously described. Nonetheless, it is important to highlight the use of water in pressurized hot water extraction (PHWE), also known as subcritical water extraction (SWE). This method is noteworthy because of its environmentally friendly processing, making it a more sustainable choice for extraction [85]. In addition to traditional solvent-based extraction methods, supercritical fluid extraction (SFE) offers an alternative approach. This technique utilizes alternative solvents such as supercritical carbon dioxide (SC-CO_2), which is particularly effective for the extraction of lipids and other compounds [86,88]. The wide fat content in EIs makes them particularly suitable for extraction using SC-CO_2. SC-CO_2 is an excellent solvent for lipids due to its low polarity, making it an efficient and eco-friendly method for extracting fats from EIs. Finally, high hydrostatic pressure (HPP) processing is another technique utilized in the food industry, involving ultra-high pressures in the range of 200-600 MPa with short holding times (5 min or less). This method is particularly effective for inactivating microorganisms and allergenic compounds in food products, as it disrupts microbial cells due to the applied extreme pressures. HPP can also improve the extraction of nutrients or oils from various sources, such as EIs, without compromising their biological properties [70].

Navarro del Hierro et *al*. and Otero et *al*. [53, 54] recently conducted studies in parallel to the UAE to recover BACs-rich fractions from *A. domesticus* and *T. molitor* via pressurized liquid extraction (PLE). Their extraction process utilized ethanol and ethanol-water mixture at a temperature of 120ºC for only 15 min. These studies reported several key findings, including a TPC with a maximum value of 3.8 g GAE/100 g extract, strong DPPH scavenging activity of 80-90%, effective inhibition of pancreatic lipase with an IC_{50} value up to 0.15 mg/mL, cholesterol content of 0.45 g/100 g, and an evaluation of the lipidic profile within these two insect species. The use of ethanol compared to the other solvent yielded extracts with higher cholesterol content and more effective pancreatic lipase inhibition. This result can be attributed to the application of high pressure, which reduces the solvent's polarity and, consequently, enhances the extraction of lipid fractions. Conversely, the ethanol-water mixture extracted bioactive fractions with higher TPC and DPPH scavenging activity. Hence, the choice of solvent and extraction conditions can be tailored to target specific BACs or functional properties of interest in these insect extracts. As previously mentioned, the defatting process, commonly carried out through SC-CO_2 extraction, plays a crucial role in the extraction of BACs and proteins from EIs. The work of Laroche et *al.* [60], while not included in prior reviews, is a noteworthy addition to the existing body of literature. In their study, the defatting process was performed at 325 bar, 55ºC, and 75 min for both *A. domesticus* and *T. molitor*. The defatting process resulted in moderate yields of 11.9% for *A. domesticus* and 22.1% for *T. molitor*. Despite these moderate yields, the post-protein extraction process benefited significantly from defatting compared to the non-defatted matrix. This led to the production of insect flours with high protein purity, reaching 70.1% for *A. domesticus* and 72.7% for *T. molitor*. These findings highlight the importance of defatting as a pre-processing step to obtain insect-based products with increased protein content and purity. Indeed, the effectiveness of supercritical extraction for defatting insect larvae has been further explored, as demonstrated in the recent work by Fornari et al. [61]. In their study, a pilot-scale supercritical extraction was conducted at 450 bar and 60ºC, with a CO_2 flow rate of 130 g/min during 190 min. The results revealed defatting yields ranging from 74.1% to 96.9% for different varieties of *H. illucens* larvae. In addition, the lipid-rich crudes obtained through SFE from *H. illucens* showed a high proportion of lauric acid and displayed peroxide index values lower than those obtained with hexane extraction (0.85-2.76 *vs.* 4.07-11.90 mEqO_2/kg, respectively). Besides, the same research group conducted various biological and antioxidant assays on the SC-CO_2 extracts from *H. illucens* crudes. The defatting yield was approximately 90%, and the extraction was performed under similar conditions as the previous study (450 bar, 60ºC, 100 g/min CO_2), providing valuable insights into the potential health benefits of insect-derived lipids [62]. In this study, a lipase inhibitory activity close to 50% was also found, and the antioxidant power was assessed using the DPPH assay. Additionally, a significant amount of free amino acids was detected in the crudes. For *T. molitor* and *H. illucens*, Laurent et *al.* [63] reported defatting yields of 86% and 93%, respectively, along with the recovery of high-protein-content flour after processing (64% and 79%). In this study, various parameters, including colour, particle size distribution, flowability, and floodability, were evaluated. The experimental conditions involved 300 bar, 45ºC, and 180 min of processing, with a CO_2 flow of 18 kg/h. Previous works by Purschke et *al*. [64] and Tang and Dai [65] also contribute to the understanding of *T. molitor*. Purschke et al. [64] conducted a pilot-scale extraction with a defatting yield of 95% at a CO_2 flow rate of 20 kg/h. Meanwhile, Tang and Dai [65] investigated the immunomodulatory activity of the SFE extracts from *T. molitor* through various biological assays, confirming the potential of these crudes to protect the immune system in mice.

HHP has shown its potential to enhance the safety of EIs [89]. This aspect is particularly relevant when considering the allergenic potential of these insects. The application of ultra-high pressure can induce structural modifications in insect proteins, including changes to intermolecular and intramolecular disulfide bonds. These alterations can lead to the formation of new protein structures with reduced allergenicity. Ultimately, this can result in the development of insect-based food products that are more acceptable for human consumption, addressing concerns related to allergenic reactions.

Recent research has explored the effects of HHP on various EIs, mainly in terms of improving the functional properties of insect flour after processing. In a couple of studies conducted by Boukil et *al*. [66] and Kim et *al*. [67], HHP was applied in the range of 70-600 MPa at temperatures of 20 and 25ºC, respectively. Several parameters, such as turbidity, particle-size distribution, surface hydrophobicity, pH, colour, emulsion capacity, and emulsion stability, were evaluated to confirm the positive impact of HHP. These findings provided evidence of structural modifications in *T. molitor* proteins induced by HHP, which enhanced the functional properties of the insect flour. Furthermore, Bolat et *al*. [70] conducted a comprehensive evaluation of specific parameters following the application of high pressures (500 MPa) for 15 min at temperatures between 30-40ºC, with a prior conventional defatting step. Their results indicated that up to 72% and 79% of crude protein was detected for *T. molitor* and *A. domesticus*, respectively, with a soluble protein content ranging from 55-57% for the former and 59-63% for the latter. In addition, they measured water and oil binding capacity, which fell within the range of 180-202% to 132-157%, respectively. Also, different antioxidant assays were performed, including TPC, with a maximum of 10.973 mg GAE/g for cricket at 40ºC, and DPPH, with 2.629 mg Trolox/g detected in the same cricket powder. These findings highlight the potential of HHP for enhancing the nutritional and functional properties of EIs.

Finally, the capacity of gelation was also determined by NMR relaxometry, acting $CaCl_2$ as a salting-out salt for mealworms, whereas it behaved as a salting-in salt in for cricket. Regarding the above, Urbina et *al*. [69] studied the potential of isolated proteins from *A. domesticus* for use in food gels applications as novel foods, using HHP treatment at 500 MPa, 25ºC, and a 15-min processing time. To enhance the gelling properties, 2% porcine gelatine was added to the dispersions of the recovered protein fraction. In another study, Boukil et al. [68] explored the *in vitro* digestion of specific allergenic proteins from *T. molitor* using HHP-assisted enzymatic hydrolysis with Alcalase® or pepsin at 380 MPa. This method significantly reduced the immunoreactivity in food products in just 1 min [68]. Overall, H"HP is a widely recognized and highly applied processing technique in the food sector, mainly for decontamination purposes.

2.5 *Cold atmospheric pressure plasma (CAPP):*

Cold plasma technology has been recognized in food decontamination [90-91]. It involves the generation of plasma via the application of electrical fields or thermal energy to a gas, typically air, O_2, N_2, or CO_2, resulting in ionization. This process generates an electrically neutral system comprising ions, electrons, atoms, unionized neutral molecules, and free radicals. These reactive species can interact with water on the surface of food products, leading to the formation of acidic compounds, which can disrupt cell structures, degrade extracellular polymeric material, and effectively target bacteria and endospores.

A recent study by Pina-Pérez et *al*. [71] has contributed to the current state of knowledge in this field. The authors found that low plasma density, at 8.7 mW/cm^2, was effective in reducing microbial counts in *A. domesticus*. This reduction amounted to 1.6 $\log_{10}$ for mesophilic bacteria and 1.9 $\log_{10}$ for *Enterobacteriaceae*. Importantly, this decontamination process did not result in the degradation of triglycerides or an increase in fatty free acids content. However, the study noted that a power density of 22.0 mW/cm^2 was not effective in destroying *Bacillus* strains.

3. Recent food applications of EIs:

EIs have found application in various food products, particularly in baked goods like breads, cakes, and cookies, as well as meat products. Beyond these, EIs are also being used in the development of cereal and protein bars, pasta products, and meat analogues, among others. The inclusion of insect powder as an ingredient is not only beneficial for enhancing the nutritional value of these products but can also play a significant role in improving consumer acceptance [92]. For instance, insect protein-based food products are aligning well with the preferences of Italian consumers who are increasingly seeking alternative protein sources [93]. EIs are particularly suited for incorporation into bakery and meat products due to their high protein content, fiber enrichment, and the presence of EAAs [94]. Recent research by Bartkiene et *al*. [95] has demonstrated that the inclusion of insect proteins, such as crickets, in wheat bread formulations can lead to improved quality characteristics compared to control bread. Furthermore, traditional foodstuffs (e.g., biscuits, bars, bread, etc.), which contain insignificant levels of insect ingredients, have the potential to offer high nutritional value and desirable sensory attributes based on consumer perception [95]. Given the rich nutritional profile, BACs, and healthy-functional benefits of EIs, an emerging trend in the food industry involves the design and development of food products incorporating these species, with a focus on bakery and meat products. Effective marketing strategies targeting specific consumer groups are expected to play a crucial role in the successful adoption of these insect-based products in the market.

3.1 *Bread:*

Table 4 provides an overview of recent studies that have explored the use of EIs insect powders in the production of various types of bread. These studies have utilized a wide range of EIs, including cinereous cockroaches, grasshoppers, house and tropical crickets, lesser and yellow mealworms, black soldier fly, and migratory locusts, to create both wheat and gluten-free bread varieties. The substitution level for wheat flour with insect powder has typically fallen within the range of 5% and 30%. The nutritional profile of the resulting bread products has been significantly improved with increased levels of insect powder substitution. These insect-enriched breads tend to have higher protein content, elevated levels of EAAs (e.g., valine and tyrosine), increased fat and fiber content, as well as higher concentrations of bioaccessible minerals (e.g., Fe, Zn, Mn, Ca, and P). Moreover, these breads often exhibit enhanced antioxidant properties, thanks to their higher polyphenolic compound content (**Table 4**). In addition, fermentation processes have been shown to be effective in reducing total biogenic amine and acrylamide levels before incorporating insect powders into bread formulations [95]. Furthermore, the incorporation of yellow and lesser mealworm powders in combination with semolina flour and sourdough starters has been found to improve the antioxidant potential of the final bread products, accompanied by a significant decrease in their glycemic index [96]. The specific volume of bread was found to vary depending on the level and type of supplemented insect flours. It is demonstrated that low supplementation levels (2-5%) of insect flours, including house cricket, yellow mealworm, and migratory locust, had no significant effect on the specific volume. However, it is worth noting that fermentation could potentially enable the use of higher amounts of insect flour to increase this parameter. For example, Bartkiene et al. [95] reported that using 30% house cricket flour fermented by 8.24 log CFU/g of *Lactiplantibacillus plantarum*-No.122 led to an improvement in the specific volume of the bread. The presence of insect flour, particularly at high substitution levels, was associated with darker bread crusts.

Mafu et *al*.[97] found that the addition of insect flour had no significant effect on the crust colour of enriched bread, but it did result in a darker crumb than the control. This suggests that the crumb colour is more affected by the addition of insect flour than the crust color. When wheat or legume flours are mixed with insect powders, they can significantly alter the dough's rheological properties, leading to changes in water absorption, softening, and stability. These changes can result in both softer and harder textures for the bread. González *et al.*[98] determined that replacing 5% of wheat flour with black soldier fly and house cricket flours led to a decreased rate of water absorption and increased dough stability. Perez-Fajardo et *al.* [99] observed that the incorporation of fine insect powders from house and tropical crickets, whether in spray-dried (Gripo) or roasted (Entono Formas) forms, into bread dough had varying effects. Specifically, it led to increases in water absorption while decreasing dough stability and altering bread rheology. Therefore, the choice of EIs species, the level of substitution, and the processing method of the insect flour can have significant impacts on dough rheology and bread texture. Furthermore, researchers found that bread samples enriched with various insect flours, such as grasshopper (10%), migratory locust (1-4%), and yellow mealworm (5%), exhibited similar sensory properties to the control bread (**Table 4**).

Indeed, the level of insect flour supplementation of insect flour appears to play a crucial role in determining the overall acceptability of bread products, as seen with grasshopper (20%) and yellow or lesser mealworm (10%) flour supplementation, which resulted in reduced acceptability (**Table 4**). However, is worth noting that some studies have reported improvements in the organoleptic properties of bread when supplemented with insect powders [97, 100]. Gantner et *al.* [101] found that the bread enriched with yellow mealworm flour maintained a favourable microbiological quality with minimal growth of yeasts and molds. Kowalczewski et *al.* [102] investigated the impact of cricket powder-enriched gluten-free bread on intestinal microflora. They realized that the addition of insect flour at low levels did not prevent microfloral growth, but as the concentration of cricket flour in the bread increased, the levels of antimicrobial compounds also increased.

In a recent study by Gharibzahedi and Altintas [103], a dual approach was employed to enhance lesser mealworm protein isolate (LMPI)-based gels for gluten-free bread making while retaining vitamin B_{12}. They utilized microbial transglutaminase (MTGase) crosslinking and high-intensity ultrasound (HIU). Prolonged HIU treatment (60-75 min) resulted in reduced LMPI particle size and enhanced gel properties, including shear-thinning flow, improved thermal stability, water retention, and strength. Notably, the study revealed a strong correlation between LMPI particle size and vitamin B_{12} release during simulated gastrointestinal digestion. Gels prepared with 60 min HIU and MTGase exhibited controlled vitamin B_{12} release. Furthermore, incorporating freeze-dried gel powders from the optimized LMPI gels into gluten-free bread enhanced its physicochemical properties, color, texture, and sensory attributes. High-performance liquid chromatography (HPLC) analysis confirmed higher vitamin B12 levels in these gluten-free breads compared to the control, suggesting the potential of this innovative approach for improving the nutritional content of gluten-free bread while maintaining desirable quality attributes [103].

Table 4. The quality assessment of bread produced by EI flours

Edible insect type	**Replacement level with wheat flour**	**Bakery product type**	**Quality keynote(s)**	**Reference**
Cinereous cockroach (*Nauphoeta cinerea*)	5, 10, and 15%	Wheat bread	– Developing a highly nutritious bread enriched with 10% roasted flour with a little difference in the sensory properties with the white and whole wheat bread	[104]
Cricket (*Gryllus assimilis*)	10 and 20%	Guten-free bread	– The production of gluten-free breads with acceptable technological properties and high protein content	[105]
Black soldier fly (*H. illucens*), House cricket (*A. domesticus*), Yellow mealworm (*T. molitor*)	5%	Wheat bread	– Changing the rheological properties (water absorption and stability) of dough during mixing, having less water adsorption – Similar specific volume and texture attributes control and enriched breads by house cricket powders – A higher content of proteins and fibers in *A. domestica* flour-enriched breads	[98]
Grasshopper (*Schistocerca gregaria*)	10 and 20%	Wheat bread	– Decreasing the specific volume of insect-based bread by producing a softer texture – Similar sensory properties between the control and 100 g/kg insect flour-enriched breads – A reduction in the overall acceptability by adding higher levels of insect powders to breads	[106]
Yellow mealworm (*T. molitor*)	5 and 10%	Wheat bread	– A significant increase in the content of free and EAAs – The highest specific volume and the lowest firmness in breads formulated with 5% insect flour – A significantly higher texture and overall liking scores by enriching breads with insect powders	[100]

House cricket (*A. domesticus*)	5, 10, and 15%	Wheat bread	– Increasing the content of protein, iron, and phosphorus with a darker color in breads enriched with 10% insect flour	[107]
House cricket (*A. domesticus*), Yellow mealworm (*T. molitor*)	5, 10, and 15%	Wheat bread	– Increasing the dough stability and reducing the softening degree by increasing the substitution rate up to 15% insect flour – Improving the dough stability, bread volume, and nutritional values	[108]

Table 4. The quality assessment of bread produced by EI flours (cont.)

Edible insect type	**Replacement level with wheat flour**	**Bakery product type**	**Quality keynote(s)**	**Reference**
Yellow mealworm (*T. molitor*), Lesser mealworm (*Alphitobius diaperinus*)	5 and 10%	Wheat bread	– Improving the nutritional value with an increase in the replacement level of insect powder – A significant difference in the crust color between enriched and control breads	[109]
Cricket (*G. assimilis*)	2, 6, and 10%	Guten-free bread	– A significant increase in the protein content, minerals (Cu, P, and Zn), polyphenolic compounds, and antioxidant activity in enriched breads – No inhibitory effect on the growth of microflora including probiotic and pathogenic bacteria – A significant increase in the hardness and consistency of enriched breads – A decrease in water activity and transport in insect-based breads	[102,110]
Migratory locust (*L. migratoria*)	1, 2, 3, 4, and 5%	Wheat bread	– A significant increase in the protein (EAAs), fat, fiber, and ash content of bread supplemented by insect powders – No significant differences in the specific volume of control	[111]

			and insect-based (up to 2%) breads. – High overall acceptability of bread samples with insect powders at 1-4% levels	
Yellow mealworm (*T. molitor*), Lesser mealworm (*A. diaperinus*)	10% on the weight of semolina plus sourdough	Sourdough "ciabatta" bread	– Increasing the antioxidant activities of breads using SMS (semolina plus powdered yellow mealworm larvae and sourdough) and SBS (semolina plus powdered lesser mealworm larvae and sourdough) – A 70% reduction in the glycemic index of bread in SMS-based breads – A lower overall acceptability of SMS-fortified breads than the control ones	[96]
Yellow mealworm (*T. molitor*), Lesser mealworm (*A. diaperinus*)	5 and 10%	Wheat bread	– The highest amino acid release from breads in the intestinal phase – A significantly higher value of total free amino acids than the control – Inducing higher release of amino acids during the digestion at higher protein enrichment	[112]

Table 4. The quality assessment of bread produced by EI flours (cont.)

Edible insect type	**Replacement level with wheat flour**	**Bakery product type**	– **Quality keynote(s)**	**Reference**
Cricket (*G. assimilis*)	5, 10, and 15%	Wheat bread	– Decreasing the dough's pH, redness, and yellowness by supplementing the flour – Increasing the bread porosity affects specific volume and shape coefficient, and mass loss after adding the insect powder – No negative impact on bread quality by incorporating 5% cricket flour into the main formula	[113]

Cricket (*G. assimilis*), Yellow mealworm (*T. molitor*)	10%	White wheat bread	– A significant increase in the protein (EAAs like valine and tyrosine), lipid, and fiber contents of loaves of bread enriched with 10% of each insect powder – A higher bioaccessibility of Na, K, Ca, Mg, P, Fe, Zn, Mn, and Li in insect breads than in wheat ones – A more bioaccessibility of Cu in wheat bread than in insect ones.	[114]
Yellow mealworm (*T. molitor*)	5, 10, and 15%	Wheat bread	– A similar density and water activity compared to the control bread without any negative impact on the other properties of bread – Increasing the protein (15-59%) and flat (35-113%.) content in bread Fortified with 5–15% mealworm powder – A generally good microbial (yeasts and molds) quality after baking bread – 5% mealworm powder was the optimal enrichment level for acceptable organoleptic characteristics of bread	[101]
House cricket (*A. domesticus*), Yellow mealworm (*T. molitor*), Lesser mealworm (*A. diaperinus*)	10, 20, and 30%	Wheat bread	– Increasing the protein, fat, and fiber content than the control – An increase of amino acid score for lysine from over 40% to ~70% than wheat bread – A 10% supplementation of insect flour to bakery products is generally acceptable	[115]
House cricket (*A. domesticus*)	10, 15, 20, 25, and 30%	Wheat bread	– No significant difference in the crust color and shelf life (5 days, based on mold growth data) compared to the control – A darker crumb, harder texture, more indispensable amino acids, and better consumer acceptance scores than the control	[97]

Table 4. The quality assessment of bread produced by EI flours (cont.)

Edible insect type	Replacement level with wheat flour	Bakery product type	Quality keynote(s)	Reference
House cricket (*A. domesticus*)	10, 20, and 30%	Wheat bread	– Reducing the content of total biogenic amines (by 13.1%) and acrylamide by maximizing the specific volume using lactic fermentation of insect powders	[95]
House cricket (A. domesticus), Tropical/Indian house cricket (*Gryllodes sigillatus*)	5, 10, and 20%	Wheat bread	– An increase in the dough stability and rheology at 20% spray-dried powders – A softer dough and lower stability at the 20% replacement level with roasted fine powders without any significant difference in water absorption	[99]

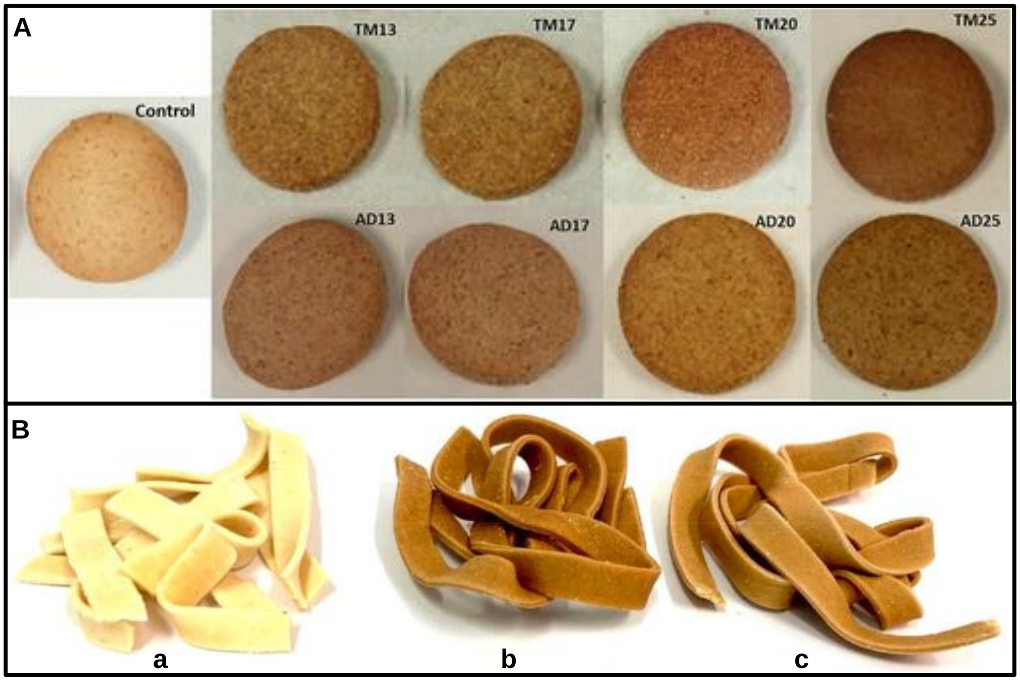

Figure 4. (A): Biscuits made of *T. molitor* (TM) and *A. diaperinus* (AD) flours at different substitution levels (0, 13, 17, 20, and 25%) of wheat flour, and (B) Visual appearance of the control pasta (a), and pasta products containing house cricket (b) and with yellow mealworm (c) protein extracts. Images retrieved from Ortolá et *al*. (2022) [116] and Pasini et *al*. (2022) [117] with a permission, respectively.

Biró et *al*. [118] conducted a study in which they produced buckwheat pasta enriched with 5% and 10% silkworm powders. The addition of insect flour resulted in an increase in the nutritional value and protein content while reducing the calorie content. These insect-enriched pastas also had a shorter optimum cooking time. However, higher acidity levels were recorded in these pastas during storage. Surprisingly, the samples containing 10% silkworm powders received the best sensory scores, whereas the control sample had the lowest overall acceptability. Çabuk and Yılmaz [119] conducted research on the development of traditional Turkish egg pasta (erişte) using a combination of wheat, legume (i.e., lentil and white kidney bean), and insect (i.e., mealworm and grasshopper) flours. Their findings showed that the inclusion of insect powders while improving the nutritional content, led to a decrease in volume expansion (8.91-16.81%) compared to the control pasta. Also, legume-based pastas received higher ratings in flavour and overall acceptability compared to insect-based pastas. Pasini et *al*.[117] have recently evaluated the quality of pasta products enriched with proteins extracted from house crickets and yellow mealworms. They found that the pasta products enriched with insect extract proteins exhibited darker coloration and firmer texture, and they had improved water-absorption capabilities when compared to the control pasta (**Figure 4B**). However, it was noted that these insect protein-enriched samples experienced a higher degree of cooking loss. A previous research group assessed the nutritional and technological quality of durum wheat pasta enriched with 5-15% cricket powder. They observed that the addition of insect flour to wheat flour led to an increase in firmness but also resulted in reduced cooking weight, cooking loss, and lightness value. While sensory attributes of the insect-based pasta were found to be comparable to the control pasta, the most significant change in organoleptic characteristics noted by the panellists was related to the flavour of the insect-enriched pasta [120].

3.2 *Meat products:*

In recent years, there has been a great surge of interest in incorporating alternative proteins (such as insect flour, single-cell protein, etc.) into meat products. EIs, given their high protein content, make excellent candidates for the development of meat analogues. In a study by Talens et *al.* [121], hybrid sausages were formulated with 50% animal protein along with an optimal blend of 22% broccoli, 3% upcycled brewer's spent grain, and 10% yellow mealworm flour. The aim was to enhance the textural, nutritional, and sensory (e.g., juiciness and odour) characteristics compared to meat-only products. The inclusion of insect flours contributed to improvements in texture because of the gelation and emulsification processes of their protein content, which involved the formation of hydrogen bonds during cooling. Smetana et *al.*[122] were able to create an optimal meat-like texture for mimicking meat products by combining soy protein concentrate with 40% mealworm protein concentrate. They achieved this using a high-moisture extrusion process at a temperature of 170°C. Also, the coagulation of proteins from lesser mealworms in the design of insect-based meat analogues was explored with a focus on the role of calcium and temperature. The study found that an increase in temperature led to an improvement in the hardness of the coagulum due to a significant increase in the protein denaturation degree and the formation of a greater number of hydrophobic interactions and disulfide bonds within the matrix. This, in turn, resulted in the creation of larger protein aggregates that contributed to a firmer texture. Furthermore, the addition of calcium chloride, up to a concentration of 20 mM at 100 °C, improved the hardness of the coagulum, resulting in a smoother network [123].

In a recent study by Kim et *al*.[124], restructured jerky analogues were developed by incorporating textured vegetable protein and yellow mealworm protein at different ratios to produce a tender dried meat product with exceptional nutritional value. The research found that jerky analogues containing 100% insect proteins had higher levels of EAAs and displayed enhanced thermal stability. On the other hand, a combination of 60% textured vegetable proteins and 40% insect proteins yielded meat analogues with the most favorable textural attributes. Scholliers et *al*. [125] conducted experiments in which they prepared hybrid meat products by combining super worm (*Zophobas morio*) larvae with meat proteins at different nitrogen ratios and subjected them to different heating temperatures. Their results indicated that when insect and meat proteins were combined, the resulting meat products exhibited lower gel strengths than products made solely from either insect or meat proteins. Besides, the gel stability decreased significantly as the content of insect protein increased. In another study by the same researchers, they found that the partial substitution of insect proteins at levels of 5% and 10% contributed to effective water and fat stabilization in the hybrid cooked sausages. However, they observed that the structural stability of these hybrid cooked sausages considerably decreased after the heating process [126]. These findings shed light on the complex interplay of ingredients and processing conditions in developing hybrid meat products with insect proteins. Lanng et *al*.[127] conducted an evaluation of the consumption of hybrid pork meats in a healthy rat model with partial replacement of proteins from lesser mealworms during a 28 day-dietary intervention. Their study revealed that incorporating insects in a meat-based diet led to alterations in the diversity of the gut microbiome, which subsequently had implications for endogenous metabolism. As a result, there are potential concerns related to meat analogues containing insect protein. These include microbiological risks and the presence of allergens, specifically tropomyosin and arginine kinase, as highlighted by Kurek et *al*. [128]. These findings underscore the importance of assessing the safety and allergenicity of meat analogues that incorporate insect proteins.

3.3 *Dairy products:*

Kim et *al*. [129] conducted preliminary research on the influence of grasshopper (*Oxya chinensis sinuosa*) flour on the quality of an enriched yogurt formulation. Their findings showed no significant differences in pH, acidity, and sensory evaluations related to colour and texture between the control samples and those supplemented with insect flour. However, they did observe a decrease in other organoleptic characteristics (such as taste, flavour, and overall acceptability) as the proportion of the insect powder in the yogurt increased. Recently, Gharibzahedi and Altintas [130] have developed non-fat probiotic set-style yogurts by infusing them with LMPI crosslinked by MTGase. Through meticulous optimization, a remarkable formula comprising 4.65% w/w MTGase-crosslinked LMPI and a robust probiotic population of 10.1 Log CFU/mL of *L. acidophilus* La-5® was achieved, resulting in innovative yogurts excelling in lightness, firmness, viscosity, and probiotic survivability. These creations exhibited minimal syneresis and a coveted acidity profile. Microscopic analysis confirmed small protein clusters with delicate serum pores, seen through fluorescence microscopy and laser diffraction particle size analysis. Newly developed yogurts outperformed control yogurts in sensory attributes during refrigerated storage, showing slower declines in key markers like DPPH-free radical inhibition activity, ferric-reducing power, and riboflavin content. The *in vitro* simulated gastrointestinal digestion highlighted the optimal yogurt's superiority, with the highest content of digestive products under 15 kDa and an impressive proteolysis rate by pepsin and trypsin within 50 and 30 min, respectively. MTGase-crosslinked LMPI promises a bright future for healthy-functional probiotic yogurts, setting a new standard in fat-free dairy delights [130]. Chailangka *et al.*[131] have recently utilized the conjugated cricket protein with fructooligosaccharide (FOS) as a new alternative protein ingredient for imitation mozzarella cheese. Their research demonstrated that incorporating 10-20 g cricket protein with FOS into 100 g of imitation cheese not only enhances the stability of vitamin D_3 but also results in sensory attributes that are acceptable to consumers.

3.4 *Other food products:*

Karnjanapratum et *al*.[132] conducted a study where they used varying replacement levels of silkworm (*Bombyx mori*) pupae powder (25%, 50%, and 75%) to develop chicken bread spreads. They observed that the fat content significantly increased, while the protein content decreased as higher levels of insect flour were added. Furthermore, the product's color noticeably diminished with the increase in insect flour levels. Interestingly, the sensory acceptance of the spreads containing 50% insect flour was found to be favorable, particularly when different levels of coconut oil were incorporated. In a recent study by Jang and Chung[133], the feasibility of producing a high-protein bar enriched with yellow mealworm powder was examined. Their findings revealed that young Korean females had a greater inclination to consume this novel food, which boasted favourable sensory attributes compared to other gender and age groups. Furthermore, an earlier research group investigated the impact of drying and defatting techniques on the organoleptic characteristics of cereal-type bars comprising oats and dehydrated fruits, which included yellow mealworm and house cricket flours. Their results indicated similar liking and willingness-to-consume scores for the control bar and samples with defatted or microwaved mealworms [134].

4. Conclusions and future trends

Given the increasing demand for alternative protein sources and micronutrients, along with the appealing sustainability benefits of insect farming, the trend of consuming insect-based foods is gradually reshaping Western dietary habits. This shift has recently made its way into the European market. It is worth noting that while there are over 2,000 EI species, only four (i.e., *T. molitor*, *L. migratoria*, *A. domesticus*, and A. *diaperinus*) have received approval from EU regulations. The upcycling of insects into nutrients and functional foods shows significant potential in tackling sustainability challenges in the food industry and promoting human nutrition. Insects are readily available, exceptionally nutritious, and teeming with BACs like proteins, peptides, fatty acids, and antioxidants, which confer diverse functional properties and health benefits.

The development of innovative processing technologies is paramount in optimizing the utilization of insect-derived BACs and elevating their functionality in food products. Importantly, these techniques align with the principles of Green Chemistry, as they improve the efficiency of recovering bioactives through both physical and chemical mechanisms. This, in turn, contributes to the overall sustainability of the process, considering economic, social, and environmental factors. Nonetheless, there are several challenges that must be tackled to achieve the successful upcycling of insects into functional foods. Regulatory frameworks must be put in place to ensure the safety and quality of food products derived from EIs. Consumer acceptance and perception will significantly influence market adoption, making it imperative to conduct education and awareness campaigns that emphasize the advantages and sustainability of insect-based foods.

Looking ahead, the future trends in upcycling insects into nutrients and functional foods are highly promising. Research endeavors should prioritize gaining a deeper understanding of the specific compounds found in different EI species and their associated health effects. This increased knowledge plays a pivotal role in the development of tailored functional foods designed to address specific nutritional requirements and health conditions. In the coming years, innovative processing technologies will continue to advance, facilitating the extraction, purification, and incorporation of insect-derived compounds into various food products. Additionally, collaboration among researchers, industry stakeholders, and policymakers will be essential in propelling the development, regulation, and commercialization of insect-based food products. Ongoing efforts in consumer education, marketing, and product diversification will play a significant role in promoting greater acceptance and the seamless integration of insect-based nutrients and functional foods into mainstream dietary practices.

Acknowledgments

This study is part of the AGROALNEXT program (AGROALNEXT/2022/060 - Desarrollo y optimización de procesos innovadores y sostenibles de extracción de aceite y proteínas a partir de microalgas, insectos, residuos y subproductos agroalimentarios: Evaluación de propiedades biológicas (EXTRAOLIOPRO)). The research received support from by MCIN, funded by the European Union's NextGenerationEU (PRTR-C17.I1), and from the Generalitat Valenciana. Also, Seyed Mohammad Taghi Gharibzahedi (SMTG) and Zeynep Altintas would like to acknowledge the support of the Alexander von Humboldt Foundation for SMTG via the Georg Forster Research Fellowship. Manuel Salgado-Ramos expresses gratitude for the post-PhD program from the Universidad de Castilla-La Mancha (UCLM), supported by the Ministry of Universities of the Spanish Government, under the “Margarita Salas - Complementaria” modality (2023-POST-21234), financed by the European Union, Next Generation EU. Juan Manuel Castagnini is beneficiary of the grant (ZA21-028) for the requalification of the Spanish university system from the Ministry of Universities of the Government of Spain, modality “Maria Zambrano”, financed by the European Union, NextGeneration EU through the project “Extraction of bioactive compounds from food matrices using innovative and sustainable technologies (EXTRABIO)”.

Declaration of interest statement

The authors confirm that there are no known conflicts of interest associated with this publication.

References

[1] Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M. K., Jayasinghe, S. L., Kariyawasam, C. S., Kogo, B.K., & Ratnayake, S. Climate change and future of agri-food production. In *Future Foods*. Ed. R. Bhat Academic Press, **2022**; pp. 49-79. DOI:10.1016/B978-0-323-91001-9.00009-8

[2] Hassoun, A., Aït-Kaddour, A., Abu-Mahfouz, A. M., Rathod, N. B., Bader, F., Barba, F. J., Biancolillo, A., Cropotova, J., Galanakis, C.M., Jambrak, A.R., *et al.* The fourth industrial revolution in the food industry—Part I: Industry 4.0 technologies. *Crit. Rev. Food Sci. Nutr.*, **2023**, *63*(23), 6547-6563. DOI:10.1080/10408398.2022.2034735

[3] Clark, M., Hill, J., & Tilman, D. The diet, health and environment trilemma. *Annu. Rev. Environ. Resour.*, **2018**, *43*, 109-134. DOI:10.1146/annurev-environ-102017-025957

[4] McClements, D. J., Barrangou, R., Hill, C., Kokini, J. L., Lila, M. A., Meyer, A. S., Yu, L. Building a resilient, sustainable, and healthier food supply through innovation and technology. *Annu. Rev. Food Sci. Technol.*, **2021**, *12*, 1-28. DOI:10.1146/annurev-food-092220-030824

[5] FAO. *The future of food and agriculture-Trends and challenges*. Food and Agricultural Organization of the United Nations: Rome, Italy, **2019**.

[6] Toviho, O. A., & Péter, B. Insect based-protein: A new opportunity in animal nutrition. *Acta Agrar. Debr.*, **2020**, *1*, 129-138. DOI:10.34101/actaagrar/1/3744

[7] Baiano, A. Edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications. *Trends Food Sci. Technol.*, **2020**, *100*, 35-50. DOI:10.1016/j.tifs.2020.03.040

[8] Gharibzahedi, S. M. T., & Altintas, Z. Lesser mealworm (*Alphitobius diaperinus L.*) larvae oils extracted by pure and binary mixed organic solvents: Physicochemical and antioxidant properties, fatty acid composition, and lipid quality indices. *Food Chem.*, **2023**, *408*, 135209. DOI:10.1016/j.foodchem.2022.135209

[9] Mota de Carvalho, N., Madureira, A.R., Estevez Pintado, M. The potential of insects as food sources-A review. *Crit. Rev. Food Sci. Nutr.*, **2020**, *60*(21), 3642-3652. DOI:10.1080/10408398.2019.1703170

[10] Goumperis, T. Insects as food: Risk assessment and their future perspective in Europe. In *Edible insects in the food sector*; Sogari, G., Mora, C., Menozzi, D. (Eds.). Springer Cham, Switzerland. Springer Cham: Switzerland, **2019**; pp 1-9. DOI:10.1007/978-3-030-22522-3_1

[11] Ros-Baró, M., Sánchez-Socarrás, V., Santos-Pagés, M., Bach-Faig, A., Aguilar-Martínez, A. Consumers´acceptability and perception of edible insects as an emerging protein source. *Int. J. Environ. Res. Public Health*, **2022**, *19*(23), 15756. DOI:10.3390/ijerph192315756

[12] Kröger, T., Dupont, J., Büsing, L., & Fiebelkorn, F. Acceptance of insect-based food products in Western societies: A systematic review. *Front. Nutr.*, **2022**, *8*, 759885. DOI:10.3389/fnut.2021.759885

[13] Siddiqui, S. A., Yunusa, B. M., Fernando, I., & Nagdalian, A. Grasshoppers and locusts as human foods – A comprehensive review. *J. Insects. Food Feed*, **2023**, 1-18. DOI:10.3920/JIFF2023.0010

[14] Raheem, D., Carrascosa, C., Oluwole, O. B., Nieuwland, M., Saraiva, A., Millán, R., & Raposo, A. Traditional consumption of and rearing edible insects in Africa, Asia and Europe. *Crit. Rev. Food Sci. Nutr.*, **2019**, *59*(14), 2169-2188. DOI:10.1080/10408398.2018.1440191

[15] Knežević, N., Grbavac, S., Palfi, M., Badanjak Sabolović, M., & Rimac Brnčić, S. Novel food legislation and consumer acceptance - Importance for the food industry. *Emir. J. Food Agric.*, **2021**, *33*(2), 93-100. DOI:10.9755/ejfa.2021.v33.i2.2257

[16] Quintieri, L., Nitride, C., De Angelis, E., Lamonaca, A., Pilolli, R., Russo, F., & Monaci, L. Alternative protein sources and novel foods: Benefits, food applications and safety issues. *Nutrients*, **2023**, *15*, 1509. DOI:10.3390/nu15061509

[17] van Huis, A. Potential of insects as food and feed in assuring food security. *Annu. Rev. Entomol.*, **2013**, *58*, 563-583. DOI:10.1146/annurev-ento-120811-153704

[18] da Silva Lucas, A. J., de Oliveira, L. M., Da Rocha, M., & Prentice, C. Edible insects: An alternative of nutritional, functional and bioactive compounds. *Food Chem.*, **2020**, *311*, 126022. DOI:10.1016/j.foodchem.2019.126022

[19] Hawkey, K. J., López-Viso, C., Brameld, J. M., Parr, T., & Salter, A. M. Insects: A potential source of protein and other nutrients for feed and food. *Annu. Rev. Anim. Biosci.*, **2021**, *9*, 333-354. DOI:10.1146/annurev-animal-021419-083930

[20] van Huis, A. Insects as food and feed, a new emerging agricultural sector: a review. *J. Insects. Food Feed*, **2020**, *6*(1), 27-44. DOI:10.3920/JIFF2019.0017

[21] Numbi Muya, G. M., Mutiaka, B. K., Bindelle, J., Francis, F., & Caparros Megido, R. Human consumption of insects in sub-saharan Africa: Lepidoptera and potential species for breeding. *Insects*, **2022**, *13*(10), 886. DOI:10.3390/insects13100886

[22] Kim, T., Yong, H. I., Kim, Y., & Kim, H. Edible insects as a protein source: A review of public perception, processing technology, and research trends. *Food Sci. Anim. Resour.*, **2019**, *39*(4), 521-540. DOI:10.5851/kosfa.2019.e53

[23] Meyer-Rochow, V. B., Gahukar, R. T., Ghosh, S., & Jung, C. Chemical composition, nutrient quality and acceptability of edible insects are affected by species, developmental stage, gender, diet, and processing method. *Foods*, **2021**, *10*(5), 1036. DOI:10.3390/foods10051036

[24] Orkusz, A. Edible insects versus meat - Nutritional comparison: Knowledge of their composition is the key to good health. *Nutrients*, **2021**, *13*(4), 1207. DOI:10.3390/nu13041207

[25]Lopez-Santamarina, A., Mondragon, C., Lamas, A., Miranda, J. M., Franco, C. M., & Cepeda, A. Animal-origin prebiotics based on chitin: An alternative for the future? A critical review. *Foods*, **2020**, *9*(6), 782. DOI:10.3390/foods9060782

[26] Anaduaka, E. G., Uchendu, N. O., Osuji, D. O., Ene, L. N., & Amoke, O. P. Nutritional compositions of two edible insects: *Oryctes rhinoceros* larva and *Zonocerus variegatus*. *Heliyon*, **2021**, *7*(3), e06531. DOI:10.1016/j.heliyon.2021.e06531

[27] Kou, L., & Adámková, A. Nutritional and sensory quality of edible insects. *NFS Journal*, **2016**, *4*, 22-26. DOI:10.1016/j.nfs.2016.07.001

[28] D´Antonio, V., Battista, N., Sacchetti, G., Di Mattia, D., Serafini, M. Functional properties of edible insects: A systematic review. *Nutr. Res. Rev.*, **2023**, *36*(1), 98-119. DOI:10.1017/S0954422421000366

[29] Djuricic, I., & Calder, P. C. Beneficial outcomes of omega-6 and omega-3 polyunsaturated fatty acids on human health: An update for 2021. *Nutrients*, **2021**, *13*(7), 2421. DOI:10.3390/nu13072421

[30] Gharibzahedi, S. M. T., & Altintas, Z. Ultrasound-assisted alcoholic extraction of lesser mealworm larvae oil: process optimization, physicochemical characteristics, and energy consumption. *Antioxidants*, **2022**, *11*(10), 1943. https://doi.org.10.3390/antiox11101943

[31] Mendoza-Salazar, A., Santiago-l, L., & Torres-llanez, M. J. In vitro antioxidant and antihypertensive activity of edible insects flours (mealworm and grasshopper) fermented with *Lactococcus lactis* strains. *Fermentation*, **2021**, *7*(3), 153. DOI:10.3390/fermentation7030153

[32] D´Antonio, V. D., Serafini, M., & Battista, N. Dietary modulation of oxidative stress from edible insects: A mini-review. *Front. Nutr.*, **2021**, *8*, 642551. DOI:10.3389/fnut.2021.642551

[33] Zielinska, E., Pankiewicz, U., & Sujka, M. Nutritional, physiochemical, and biological value of muffins enriched with edible insects flour. *Antioxidants*, **2021**, *10*(7), 1122. DOI:10.3390/antiox10071122

[34] Aiello, D., Barbera, M., Bongiorno, D., Cammarata, M., Censi, V., Indelicato, S., Mazzotti, F., Napoli, A., Piazzese, D., & Saiano, F. Edible insects as alternative nutritional source of bioactive compounds: A review. *Molecules*, **2023**, *28*(2), 699. DOI:10.3390/molecules28020699

[35] Rivera-Jiménez, J., Berraquero-García, C., Pérez-Gálvez, R., García-Moreno, P. J., Espejo-Carpio, F. J., & Guadix, E. M. Function and modulation mechanisms. *Food Funct.*, **2022**, *13*, 12510-12540. DOI:10.1039/d2fo02223k

[36] Patil, K. R., Mahajan, U. B., Unger, B. S., & Goyal, S. N. Animal models of inflammation for screening of anti-inflammatory drugs: Implications for the discovery and development of phytopharmaceuticals. *Int. J. Mol. Sci.*, **2019**, *20*(18), 4367. DOI:10.3390/ijms20184367

[37] Dutta, P., Kumar, R., Dey, T., Datta, M., Manna, P., & Kalita, J. Chemico-Biological interactions beneficial role of insect-derived bioactive components against inflammation and its associated complications (colitis and arthritis) and cancer. *Chem.-Biol. Interact.*, **2019**, *313*, 108824. DOI:10.1016/j.cbi.2019.108824

[38] Kipkoech, C. Beyond proteins - edible insects as a source of dietary fiber. *Polysaccharides*, **2023**, *4*(2), 116-128. DOI:10.3390/polysaccharides4020009

[39] Quah, Y., Tong, S., Bojarska, J., Giller, K., Tan, S., Ziora, Z. M., Esatbeyoglu, T., & Chai, T. Bioactive peptide discovery from edible insects for potential applications in human health and agriculture. *Molecules*, **2023**, *28*(3), 1233. DOI:10.3390/molecules28031233

[40] Komi, D. E. A., Sharma, L., & De la Cruz, C. S. Chitin and its effects on inflammatory and immune responses. *Clin. Rev. Allergy Immunol.*, **2017**, *54*, 213-223. DOI:10.1007/s12016-017-8600-0

[41] Young, W., Arojju, S. K., Mcneill, M. R., Rettedal, E., Gathercole, J., Bell, N., & Payne, P. Feeding bugs to bugs: Edible insects modify the human gut microbiome in an *in vitro* fermentation model. *Front. Microbiol.*, **2020**, *11*, 1763. DOI:10.3389/fmicb.2020.01763

[42] Aguilar-Toalá, J.E., Cruz-Monterrosa, R.G., & Liceaga, A.M. Beyond human nutrition of edible insects: Health benefits and safety aspects. *Insects*, **2022**, *13*(11), 1007. DOI:10.3390/insects13111007

[43] Maniello, M. D., Moretta, A., Salvia, R., Scieuzo, C., Lucchetti, D., Vogel, H., Sgambato, A., & Falabella, P. Insect antimicrobial peptides: potential weapons to counteract the antibiotic resistance. *Cell. Mol. Life Sci.*, **2021**, *78*, 4259-4282. DOI:10.1007/s00018-021-03784-z

[44] Torres-Castillo, J. A., & Olazarán-Santibáñez, F. E. Insects as source of phenolic and antioxidant entomochemicals in the food industry. *Front. Nutr.*, **2023**, *10*, 113342. DOI:10.3389/fnut.2023.1133342

[45] Gharibzahedi, S. M. T., & Smith, B. The functional modification of legume proteins by ultrasonication: A review. *Trends Food Sci. Technol.*, **2020**, *98*, 107-116. DOI:10.1016/j.tifs.2020.02.002

[46] Gharibzahedi, S. M. T., & Smith, B. Effects of high hydrostatic pressure on the quality and functionality of protein isolates, concentrates, and hydrolysates derived from pulse legumes: A review. *Trends Food Sci. Technol.*, **2021**, *107*, 466-479. DOI:10.1016/j.tifs.2020.11.016

[47] Melgar-Lalanne, G., Hernández-Álvarez, A. J., & Salinas-Castro, A. Edible insects processing: Traditional and innovative technologies. *Compr. Rev. Food Sci. Food Saf.*, **2019**, *18*(4), 1166-1191. DOI:10.1111/1541-4337.12463

[48] Ojha, S., Bußler, S., Psarianos, M., Rossi, G., & Schlüter, O. K. Edible insect processing pathways and implementation of emerging technologies. *J. Insects Food Feed*, *7*(5), **2021**, 877-900. DOI:10.3920/JIFF2020.0121

[49] Chemat, F., Abert Vian, M., Fabiano-Tixier, A.-S., Nutrizio, M., Režek Jambrak, A., Munekata, P. E. S., Lorenzo, J. M., Barba, F. J., Binello, A., & Cravotto, G. A review of sustainable and intensified techniques for extraction of food and natural products. *Green Chem.*, **2020**, *22*(8), 2325-2353. DOI:10.1039/C9GC03878G

[50] Mariatti, F., Gunjević, V., Boffa, L., & Cravotto, G. Process intensification technologies for the recovery of valuable compounds from cocoa by-products. *Innov. Food Sci. Emerg. Technol.*, **2021**, *68*, 102601. DOI:10.1016/j.ifset.2021.102601

[51] Navarro del Hierro, J., Cantero-Bahillo, E., Fernández-Felipe, M. T., García-Risco, M. R., Fornari, T., Rada, P., Doblado, L., Ferreira, V., Hitos, A. B., Valverde, Á. M., *et al.* Effects of a mealworm (*Tenebrio molitor*) extract on metabolic syndrome-related pathologies: In vitro insulin sensitivity, inflammatory response, hypolipidemic activity and oxidative stress. *Insects*, **2022**, *13*(10), 896. DOI:10.3390/insects13100896

[52] Navarro del Hierro, J., Cantero-Bahillo, E., Fornari, T., & Martin, D. Effect of defatting and extraction solvent on the antioxidant and pancreatic lipase inhibitory activities of extracts from *Hermetia illucens* and *Tenebrio molitor*. *Insects*, **2021**, *12*(9), 789. DOI:10.3390/insects12090789

[53] Navarro del Hierro, J., Gutiérrez-Docio, A., Otero, P., Reglero, G., & Martin, D. Characterization, antioxidant activity, and inhibitory effect on pancreatic lipase of extracts from the edible insects *Acheta domesticus* and *Tenebrio molitor*. *Food Chem.*, **2020**, *309*, 125472. DOI:10.1016/j.foodchem.2019.125742

[54] Otero, P., Gutierrez-Docio, A., Navarro del Hierro, J., Reglero, G., & Martin, D. Extracts from the edible insects *Acheta domesticus* and *Tenebrio molitor* with improved fatty acid profile due to ultrasound assisted or pressurized liquid extraction. *Food Chem.*, **2020**, *314*, 126200. DOI:10.1016/j.foodchem.2020.126200

[55] Psarianos, M., Dimopoulos, G., Ojha, S., Cavini, A. C. M., Bußler, S., Taoukis, P., & Schlüter, O. K. Effect of pulsed electric fields on cricket (*Acheta domesticus*) flour: Extraction yield (protein, fat and chitin) and techno-functional properties. *Innov. Food Sci. Emerg. Technol.*, **2022**, *76*, 102908. DOI:10.1016/j.ifset.2021.102908

[56] Alles, M. C., Smetana, S., Parniakov, O., Shorstkii, I., Toepfl, S., Aganovic, K., & Heinz, V. Bio-refinery of insects with pulsed electric field pre-treatment. *Innov. Food Sci. Emerg. Technol.*, **2020**, *64*, 102403 DOI:10.1016/j.ifset.2020.102403

[57] Nino, M. C., Reddivari, L., Ferruzzi, M. G., & Liceaga, A. M. Targeted phenolic characterization and antioxidant bioactivity of extracts from edible *Acheta domesticus*. *Foods*, **2021**, *10*(10), 2295. DOI:10.3390/foods10102295

[58] Hernández-Álvarez, A. J., Mondor, M., Piña-Domínguez, I. A., Sánchez-Velázquez, O. A., & Melgar Lalanne, G. Drying technologies for edible insects and their derived ingredients. *Dry. Technol.*, **2021**, *39*(13), 1991-2009. DOI:10.1080/07373937.2021.1915796

[59] Parniakov, O., Mikhrovska, M., Wiktor, A., Alles, M., Ristic, D., Bogusz, R., Nowacka, M., Devahastin, S., Mujumdar, A., Heinz, V., & Smetana, S. Insect processing for food and feed: A review of drying methods. *Dry. Technol.*, **2022**, *40*(8), 1500-1513. DOI:10.1080/07373937.2021.1962905

[60] 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*(11), 572. DOI:10.3390/foods8110572

[61] Fornari, T., Vázquez, L., Villanueva-Bermejo, D., Hurtado-Ribeira, R., Martín Hernández, D., & Martin, D. Effect of moisture and oil content in the supercritical CO_2 defatting of *Hermetia illucens* larvae. *Foods*, **2023**, *12*(3), 490. DOI:10.3390/foods12030490

[62] Cantero-Bahillo, E., del Hierro, J. N., Hernández, D. M., Fernández-Felipe, M. T., Fornari, T., & Martin, D. Supercritical-CO_2 for defatting and production of bioactive extracts from black soldier fly (*Hermetia illucens*) larvae. *J. Insects. Food Feed*, **2022**, *8*(12), 1441-1453. DOI:10.3920/JIFF2021.0210

[63] Laurent, S., Jury, V., de Lamballerie, M., & Fayolle, F. Effect of two defatting processes on the physicochemical and flow properties of *Hermetia illucens* and *Tenebrio molitor* larvae powders. *J. Food Process. Preserv.*, **2022**, *46*(10), e16853. DOI:10.1111/jfpp.16853

[64] Purschke, B., Stegmann, T., Schreiner, M., & Jäger, H. Pilot-scale supercritical CO_2 extraction of edible insect oil from *Tenebrio molitor L*. larvae – Influence of extraction conditions on kinetics, defatting performance and compositional properties. *Eur. J. Lipid. Sci. Technol.*, **2017**, *119*(2), 1600134. DOI:10.1002/ejlt.201600134

[65] Tang, Q., & Dai, Y. Immunomodulatory effects of supercritical fluid CO_2 extracts from freeze-dried powder of *tenebrio molitor* larvae (Yellow mealworm). *Food Sci. Technol.*, **2016**, *36*(3), 493-498. DOI:10.1590/1678-457X.0017

[66] Boukil, A., Marciniak, A., Mezdour, S., Pouliot, Y., & Doyen, A. Effect of high hydrostatic pressure intensity on structural modifications in mealworm (*Tenebrio molitor*) proteins. *Foods*, **2022**, *11*(7), 956. DOI:10.3390/foods11070956

[67] Kim, T. K., Yong, H. I., Kang, M. C., Jung, S., Jang, H. W., & Choi, Y. S. Effects of high hydrostatic pressure on technical functional properties of edible insect protein. *Food. Sci. Anim. Resour.*, **2021**, *41*(2), 185-195. DOI:10.5851/kosfa.2020.e85

[68] Boukil, A., Perreault, V., Chamberland, J., Mezdour, S., Pouliot, Y., & Doyen, A. High hydrostatic pressure-assisted enzymatic hydrolysis affect mealworm allergenic proteins. *Molecules*, **2020**, *25*(11), 2685. DOI:10.3390/molecules25112685

[69] Urbina, P., Marin, C., Sanz, T., Rodrigo, D., & Martinez, A. Effect of HHP, enzymes and gelatin on physicochemical factors of gels made by using protein isolated from common cricket (*Acheta domesticus*). *Foods*, **2021**, *10*(4), 858. DOI:10.3390/foods10040858

[70] Bolat, B., Ugur, A. E., Oztop, M. H., & Alpas, H. Effects of high hydrostatic pressure assisted degreasing on the technological properties of insect powders obtained from *Acheta domesticus* & *Tenebrio molitor*. *J. Food Eng.*, **2021**, *292*, 110359. DOI:10.1016/j.jfoodeng.2020.110359

[71] Pina-Pérez, M. C., Rodrigo, D., Ellert, C., & Beyrer, M. Surface micro discharge–cold atmospheric pressure plasma processing of common house cricket *Acheta domesticus* powder: Antimicrobial potential and lipid-quality preservation. *Front. Bioeng. Biotechnol.*, **2021**, *9*, 644177. DOI:10.3389/fbioe.2021.644177

[72] Calcio Gaudino, E., Cravotto, G., Manzoli, M., & Tabasso, S. Sono- and mechanochemical technologies in the catalytic conversion of biomass. *Chem. Soc. Rev.*, **2021**, *50*(3), 1785-1812. DOI:10.1039/D0CS01152E

[73] Tabasso, S., Carnaroglio, D., Calcio Gaudino, E., & Cravotto, G. Microwave, ultrasound and ball mill procedures for bio-waste valorisation. *Green Chem.*, **2015**, *17*(2), 684-693. DOI:10.1039/c4gc01545b

[74] Al Khawli, F., Martí-Quijal, F. J., Pallarés, N., Barba, F. J., & Ferrer, E. Ultrasound extraction mediated recovery of nutrients and antioxidant bioactive compounds from phaeodactylum tricornutum microalgae. *Appl. Sci.*, **2021**, *11*(4), 1–19. DOI:10.3390/app11041701

[75] Salgado-Ramos, M., Tabasso, S., Calcio Gaudino, E., Moreno, A., Mariatti, F., & Cravotto, G. An innovative, green cascade protocol for grape stalk valorization with process intensification technologies. *Appl. Sci.*, **2022**, *12*(15), 7417. DOI:10.3390/app12157417

[76] Verdini, F., Calcio Gaudino, E., Grillo, G., Tabasso, S., & Cravotto, G. Cellulose recovery from agri-food residues by effective cavitational treatments. *Appl. Sci.*, **2021**, *11*(10), 4693. DOI:10.3390/app11104693

[77] Calleja-Gómez, M., Castagnini, J. M., Carbó, E., Ferrer, E., Berrada, H., & Barba, F. J. Evaluation of pulsed electric field-assisted extraction on the microstructure and recovery of nutrients and bioactive compounds from mushroom (*Agaricus bisporus*). *Separations*, **2022**, *9*(10), 302. DOI:10.3390/separations9100302

[78] Martí-Quijal, F. J., Ramon-Mascarell, F., Pallarés, N., Ferrer, E., Berrada, H., Phimolsiripol, Y., & Barba, F. J. Extraction of antioxidant compounds and pigments from spirulina (*Arthrospira*

platensis) assisted by pulsed electric fields and the binary mixture of organic solvents and water. *Appl. Sci*,, **2021**, *11*(16), 7629. DOI:10.3390/app11167629

[79] Salgado-Ramos, M., Martí-Quijal, F. J., Huertas-Alonso, A. J., Sánchez-Verdú, M. P., Barba, F. J., & Moreno, A. Almond hull biomass: Preliminary characterization and development of two alternative valorization routes by applying innovative and sustainable technologies. *Ind. Crops. Prod.*, **2022**, *179*, 114697. DOI:10.1016/j.indcrop.2022.114697

[80] Gabrić, D., Barba, F., Roohinejad, S., Gharibzahedi, S. M. T., Radojčin, M., Putnik, P., & Bursać Kovačević, D. Pulsed electric fields as an alternative to thermal processing for preservation of nutritive and physicochemical properties of beverages: A review. *J. Food Process Eng.*, **2018**, *41*(1), e12638. DOI:10.1111/jfpe.12638

[81] Pallarés, N., Barba, F. J., Berrada, H., Tolosa, J., & Ferrer, E. Pulsed electric fields (PEF) to mitigate emerging mycotoxins in juices and smoothies. *Appl. Sci.*, **2020**, *10*(19), 1-13. DOI:10.3390/app10196989

[82] de la Hoz, A., Díaz-Ortiz, À., & Moreno, A. Microwaves in organic synthesis. Thermal and non-thermal microwave effects. *Chem. Soc. Rev.*, **2005**, *34*(2), 164–-178. DOI:10.1039/b411438h

[83] Mustafa, A., Trevino, L. M., & Turner, C. Pressurized hot ethanol extraction of carotenoids from carrot by-products. *Molecules*, **2012**, *17*(2), 1809–1818. DOI:10.3390/molecules17021809

[84] Dhua, S., Kumar, K., Sharanagat, V. S., & Nema, P. K. Bioactive compounds and its optimization from food waste: review on novel extraction techniques. *Nutr. Food Sci.*, **2022**, *52*(8), 1270-1288. DOI:10.1108/NFS-12-2021-0373

[85] Plaza, M., & Marina, M. L. Pressurized hot water extraction of bioactives. *Trends Anal. Chem.*, **2019**, *116*, 236-247. DOI:10.1016/j.trac.2019.03.024

[86] Salgado-Ramos, M., Martí-Quijal, F. J., Huertas-Alonso, A. J., Sánchez-Verdú, M. P., Moreno, A., & Barba, F. J. A preliminary multistep combination of pulsed electric fields and supercritical fluid extraction to recover bioactive glycosylated and lipidic compounds from exhausted grape marc. *LWT-Food Sci Technol.*, **2023**, *180*, 114725. DOI:10.1016/j.lwt.2023.114725

[87] Talmaciu, A. I., Ravber, M., Volf, I., Knez, Ž., & Popa, V. I. Isolation of bioactive compounds from spruce bark waste using sub- and supercritical fluids. *J. Supercrit. Fluids*, **2016**, *117*, 243-251. DOI:10.1016/j.supflu.2016.07.001

[88] Teixeira, G. L., Maciel, L. G., Mazzutti, S., Barbi, R. C. T., Ribani, R. H., Ferreira, S. R. S., & Block, J. M. Sequential green extractions based on supercritical carbon dioxide and pressurized ethanol for the recovery of lipids and phenolics from *Pachira aquatica* seeds. *J. Clean. Prod.*, **2021**, *306*, 127223. DOI:10.1016/j.jclepro.2021.127223

[89] Yan, X., Laurent, S., Federighi, M., Boué, G., & Jury, V. Processing edible insects into powders: A review of available processes and potential microbial inactivation methods. *J. Insects Food Feed*, **2023**, *9*(3), 325-338. DOI:10.3920/JIFF2021.0203

[90] Rumpold, B. A., Fröhling, A., Reineke, K., Knorr, D., Boguslawski, S., Ehlbeck, J., & Schlüter, O. Comparison of volumetric and surface decontamination techniques for innovative processing of mealworm larvae (*Tenebrio molitor*). *Innov. Food Sci. Emerg. Technol.*, **2014**, *26*, 232-241. DOI:10.1016/j.ifset.2014.09.002

[91] Waghmare, R. Cold plasma technology for fruit based beverages: A review. *Trends Food Sci. Technol.*, **2021**, *114*, 60-69. DOI:10.1016/j.tifs.2021.05.018

[92] Yang, J., Zhou, S., Kuang, H., Tang, C., & Song, J. Edible insects as ingredients in food products: nutrition, functional properties, allergenicity of insect proteins, and processing modifications. *Crit. Rev. Food Sci. Nutr.*, **2023**, DOI:10.1080/10408398.2023.2223644

[93] Palmieri, N., Nervo, C., & Torri, L. Consumers' attitudes towards sustainable alternative protein sources: Comparing seaweed, insects and jellyfish in Italy. *Food Qual. Prefer.*, **2023**, *104*, 104735. DOI:10.1016/j.foodqual.2022.104735

[94] Borges, M. M., da Costa, D. V., Trombete, F. M., & Câmara, A. K. F. I. Edible insects as a sustainable alternative to food products: an insight into quality aspects of reformulated bakery and meat products. *Curr. Opin. Food Sci.*, **2022**, *46*, 100864. DOI:10.1016/j.cofs.2022.100864

[95] Bartkiene, E., Zokaityte, E., Starkute, V., Zokaityte, G., Kaminskaite, A., Mockus, E., Klupsaite, D., Cernauskas, D., Rocha, J.M., Özogul, F., *et al.* Crickets (*Acheta domesticus*) as wheat bread ingredient: influence on bread quality and safety characteristics. *Foods*, **2023**, *12*(2), 325. DOI:10.3390/foods12020325

[96] Gaglio, R., Barbera, M., Tesoriere, L., Osimani, A., Busetta, G., Matraxia, M., Attanzio, A., Restivo, I., Aquilanti, L., & Settanni, L. Sourdough "ciabatta" bread enriched with powdered insects: Physicochemical, microbiological, and simulated intestinal digesta functional properties. *Innov. Food Sci. Emerg. Technol.*, **2021**, *72*, 102755. DOI:10.1016/j.ifset.2021.102755

[97] Mafu, A., Ketnawa, S., Phongthai, S., Schönlechner, R., & Rawdkuen, S. Whole wheat bread enriched with cricket powder as an alternative protein. *Foods*, **2022**, *11*(14), 2142. DOI:10.3390/foods11142142

[98] González, C. M., Garzón, R., & Rosell, C. M. Insects as ingredients for bakery goods. A comparison study of *H. illucens*, *A. domestica* and *T. molitor* flours. *Innov. Food Sci. Emerg. Technol.*, **2019**, *51*, 205-210. DOI:10.1016/j.ifset.2018.03.021

[99] Perez-Fajardo, M., Bean, S. R., & Dogan, H. Effect of cricket protein powders on dough functionality and bread quality. *Cereal Chem.*, **2023**, *100*, 587-600. DOI:10.1002/cche.10652

[100] Roncolini, A., Milanović, V., Cardinali, F., Osimani, A., Garofalo, C., Sabbatini, R., Clementi, F., Pasquini, M., Mozzon, M., Foligni, R., *et al.* Protein fortification with mealworm (*Tenebrio molitor* L.) powder: Effect on textural, microbiological, nutritional and sensory features of bread. *PloS One*, **2019**, *14*(2), e0211747. DOI:10.1371/journal.pone.0211747

[101] Gantner, M., Król, K., Piotrowska, A., Sionek, B., Sadowska, A., Kulik, K., & Wiącek, M. Adding mealworm (*Tenebrio molitor* L.) powder to wheat bread: effects on physicochemical, sensory and microbiological qualities of the end-product. *Molecules*, **2022**, *27*(19), 6155. DOI:10.3390/molecules27196155

[102] Kowalczewski, P. Ł., Gumienna, M., Rybicka, I., Górna, B., Sarbak, P., Dziedzic, K., & Kmiecik, D. Nutritional value and biological activity of gluten-free bread enriched with cricket powder. *Molecules*, **2021**, *26*(4), 1184. DOI:10.3390/molecules26041184

[103] Gharibzahedi, S. M. T.; & Altintas, Z.. Integrated ultrasonic-transglutaminase modification of lesser mealworm protein isolate: a pioneering cobalamin delivery vehicle in gluten-free breads. *Food Hydrocolloids*, **2024**.

[104] de Oliveira, L. M., da Silva Lucas, A. J., Cadaval, C. L., & Mellado, M. S. Bread enriched with flour from cinereous cockroach (*Nauphoeta cinerea*). *Innov. Food Sci. Emerg. Technol.*, **2017**, *44*, 30-35. DOI:10.1016/j.ifset.2017.08.015

[105] da Rosa Machado, C., & Thys, R. C. S. Cricket powder (*Gryllus assimilis*) as a new alternative protein source for gluten-free breads. *Innov. Food Sci. Emerg. Technol.*, **2019**, *56*, 102180. DOI:10.1016/j.ifset.2019.102180

[106] Haber, M., Mishyna, M., Martinez, J. I., & Benjamin, O. The influence of grasshopper (*Schistocerca gregaria*) powder enrichment on bread nutritional and sensorial properties. *LWT-Food Sci. Technol.*, **2019**, *115*, 108395. DOI:10.1016/j.lwt.2019.108395

[107] Bawa, M., Songsermpong, S., Kaewtapee, C., & Chanput, W. Nutritional, sensory, and texture quality of bread and cookie enriched with house cricket (*Acheta domesticus*) powder. *J. Food Process. Preserv.*, **2020**, *44*(8), e14601. DOI:10.1111/jfpp.14601

[108] Cappelli, A., Oliva, N., Bonaccorsi, G., Lorini, C., & Cini, E. Assessment of the rheological properties and bread characteristics obtained by innovative protein sources (*Cicer arietinum*, *Acheta domesticus*, *Tenebrio molitor*): Novel food or potential improvers for wheat flour? *LWT-Food Sci. Technol.*, **2020**, *118*, 108867. DOI:10.1016/j.lwt.2019.108867

[109] García-Segovia, P., Igual, M., & Martínez-Monzó, J. Physicochemical properties and consumer acceptance of bread enriched with alternative proteins. *Foods*, **2020**, *9*(7), 933. DOI:10.3390/foods9070933

[110] Kowalczewski, P. Ł., Walkowiak, K., Masewicz, Ł., Bartczak, O., Lewandowicz, J., Kubiak, P., & Baranowska, H. M. Gluten-free bread with cricket powder—mechanical properties

and molecular water dynamics in dough and ready product. *Foods*, **2019**, *8*(7), 240. DOI:10.3390/foods8070240

[111] Althwab, S. A., Alhomaid, R. M., Ali, R. F., El-Anany, A. M., & Mousa, H. M. Effect of migratory locust (*Locusta migratoria*) powder incorporation on nutritional and sensorial properties of wheat flour bread. *Br. Food J.*, **2021**, *123*(11), 3576-3591. DOI:10.1108/BFJ-11-2020-1052

[112] Igual, M., García-Segovia, P., & Martínez-Monzó, J. Amino acids release from enriched bread with edible insect or pea protein during in vitro gastrointestinal digestion. *Int. J. Gastron. Food Sci.*, **2021**, *24*(10), 100351. DOI:10.1016/j.ijgfs.2021.100351

[113] Bartkiene, E., Starkute, V., Katuskevicius, K., Laukyte, N., Fomkinas, M., Vysniauskas, E., Kasciukaityte, P., Radvilavicius, E., Rokaite, S. Medonas, D. *et al.* The contribution of edible cricket flour to quality parameters and sensory characteristics of wheat bread. *Food Sci. Nutr.*, **2022**, *10*, 4319-4330. DOI:10.1002/fsn3.3024

[114] Cozmuta, A. M., Nicula, C., Peter, A., Cozmuta, L. M., Nartea, A., Kuhalskaya, A., Pacetti, D., Silvi, S., Fiorini, D., & Pruteanu, L. Cricket and yellow mealworm powders promote higher bioaccessible fractions of mineral elements in functional bread. *J. Funct. Foods*, **2022**, *99*, 105310. DOI:10.1016/j.jff.2022.105310

[115] Kowalski, S., Mikulec, A., Mickowska, B., Skotnicka, M., & Mazurek, A. Wheat bread supplementation with various edible insect flours. Influence of chemical composition on nutritional and technological aspects. *LWT-Food Sci. Technol.*, **2022**, *159*, 113220. DOI:10.1016/j.lwt.2022.113220

[116] Ortolá, M. D., Martínez-Catalá, M., Yuste Del Carmen, A., & Castelló, M. L. Physicochemical and sensory properties of biscuits formulated with *Tenebrio molitor* and *Alphitobius diaperinus* flours. *J. Texture Stud.*, **2022**, *53*(4), 540-549. DOI:10.1111/jtxs.12692

[117] Pasini, G., Cullere, M., Vegro, M., Simonato, B., & Dalle Zotte, A. Potentiality of protein fractions from the house cricket (*Acheta domesticus*) and yellow mealworm (*Tenebrio molitor*) for pasta formulation. *LWT-Food Sci Technol.*, **2022**, *164*, 113638. DOI:10.1016/j.lwt.2022.113638

[118] Biró, B., Fodor, R., Szedljak, I., Pásztor-Huszár, K., & Gere, A. Buckwheat-pasta enriched with silkworm powder: Technological analysis and sensory evaluation. *LWT-Food Sci. Technol.*, **2019**, *116*, 108542. DOI:10.1016/j.lwt.2019.108542

[119] Çabuk, B., & Yılmaz, B. Fortification of traditional egg pasta (erişte) with edible insects: Nutritional quality, cooking properties and sensory characteristics evaluation. *J. Food Sci. Technol.*, **2020**, *57*, 2750-2757. DOI:10.1007/s13197-020-04315-7

[120] Duda, A., Adamczak, J., Chełmińska, P., Juszkiewicz, J., & Kowalczewski, P. Quality and nutritional/textural properties of durum wheat pasta enriched with cricket powder. *Foods*, **2019**, *8*(2), 46. DOI:10.3390/foods8020046

[121] Talens, C., Llorente, R., Simó-Boyle, L., Odriozola-Serrano, I., Tueros, I., & Ibargüen, M. Hybrid sausages: modelling the effect of partial meat replacement with broccoli, upcycled brewer's spent grain and insect flours. *Foods*, **2022**, *11*(21), 3396. DOI:10.3390/foods11213396

[122] Smetana, S., Pernutz, C., Toepfl, S., Heinz, V., & Van Campenhout, L. High-moisture extrusion with insect and soy protein concentrates: Cutting properties of meat analogues under insect content and barrel temperature variations. *J. Insects Food Feed*, **2019**, *5*(1), 29-34. DOI:10.3920/JIFF2017.0066

[123] Azzollini, D., Wibisaphira, T., Lakemond, C. M. M., & Fogliano, V. Toward the design of insect-based meat analogue: The role of calcium and temperature in coagulation behavior of *Alphitobius diaperinus* proteins. *LWT-Food Sci Technol.*, **2019**, *100*, 75-82. DOI:10.1016/j.lwt.2018.10.037

[124] Kim, T. K., Yong, H. I., Cha, J. Y., Park, S. Y., Jung, S., & Choi, Y. S. Drying-induced restructured jerky analog developed using a combination of edible insect protein and textured vegetable protein. *Food Chem.*, **2022**, *373*, 131519. DOI:10.1016/j.foodchem.2021.131519

[125] Scholliers, J., Steen, L., & Fraeye, I. Gelation of a combination of insect and pork proteins as affected by heating temperature and insect: Meat ratio. *Food Res. Int.*, **2020**, *137*, 109703. DOI:10.1016/j.foodres.2020.109703

[126] Scholliers, J., Steen, L., & Fraeye, I. Partial replacement of meat by superworm (*Zophobas morio* larvae) in cooked sausages: Effect of heating temperature and insect: Meat ratio on structure and physical stability. *Innov. Food Sci. Emerg. Technol.*, **2020**, *66*, 102535. DOI:10.1016/j.ifset.2020.102535

[127] Lanng, S. K., Zhang, Y., Christensen, K. R., Hansen, A. K., Nielsen, D. S., Kot, W., & Bertram, H. C. Partial substitution of meat with insect (*Alphitobius diaperinus*) in a carnivore diet changes the gut microbiome and metabolome of healthy rats. *Foods*, **2021**, *10*(8), 1814. DOI:10.3390/foods10081814

[128] Kurek, M. A., Onopiuk, A., Pogorzelska-Nowicka, E., Szpicer, A., Zalewska, M., & Półtorak, A. Novel protein sources for applications in meat-alternative products-Insight and challenges. *Foods*, **2022**, *11*(7), 957. DOI:10.3390/foods11070957

[129] Kim, H. S., Kim, Y. J., Chon, J. W., Kim, D. H., Song, K. Y., Kim, H., & Seo, K. H. Organoleptic evaluation of the high-protein yoghurt containing the edible insect *Oxya chinensis sinuosa* (grasshopper): A preliminary study. *J. Dairy Sci. Biotechnol.*, **2017**, *35*(4), 266-269. DOI:10.22424/jmsb.2017.35.4.266

[130] Gharibzahedi, S. M. T., & Altintas, Z. Transglutaminase-crosslinked lesser mealworm protein isolate: A new milk fat substitute for high-quality probiotic set yogurts. *Food Hydrocoll.*, **2024**, *146*, 109172. DOI:10.1016/j.foodhyd.2023.109172

[131] Chailangka, A., Leksawasdi, N., Seesuriyachan, P., Ruksiriwanich, W., Sommano, S. R., Jantanasakulwong, K., Rachtanapun, P., Castagnini, J. M., Barba, F. J., & Phimolsiripol, Y. Improving vitamin D stability and antioxidant activity in imitation mozzarella cheese by conjugated cricket protein with fructooligosaccharide. *LWT-Food Sci Technol.*, **2023**, *183*, 114898. DOI:10.1016/j.lwt.2023.114898

[132] Karnjanapratum, S., Kaewthong, P., Indriani, S., Petsong, K., & Takeungwongtrakul, S. Characteristics and nutritional value of silkworm (*Bombyx mori*) pupae-fortified chicken bread spread. *Sci. Rep.*, **2022**, *12*(1), 1492. DOI:10.1038/s41598-022-05462-x

[133] Jang, H., & Chung, S. J. Shape of my likes: how explicit and implicit reference frames shape the liking of insect-based protein bar. *Food Sci. Biotechnol.*, **2023**, *32*, 1193-1203. DOI:10.1007/s10068-023-01257-6

[134] Ribeiro, J. C., Santos, C., Lima, R. C., Pintado, M. E., & Cunha, L. M. Impact of defatting and drying methods on the overall liking and sensory profile of a cereal bar incorporating edible insect species. *Future Foods*, **2022**, *6*, 100190. DOI:10.1016/j.fufo.2022.100190