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Edible insect powder for enrichment of bakery products– A review of nutritional, physical characteristics and acceptability of bakery products to consumers

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ABSTRACT

Bakery products including bread are traditionally good sources of carbohydrate but not nutrient-dense. Enrichment with edible insect powder could improve the quantity and quality of protein, fat and dietary fibers to bakery products. A systematic search carried out on the databases PubMed, Scopus and ScienceDirect identified 44 articles that would answer the question: what is known about the effect of enrichment of bakery products with various edible insect powders on the physical, nutritional composition and sensory properties of bakery products. The search strategy and terms applied were (Insect* OR Edible insect* OR Entomophagy*) AND (Bakery product* OR Bake* product*). Bread was the most common bakery product that was insect-enriched, yet muffins/biscuits/crackers/cookies were also reported. Commonly reported edible insects and their larvae were crickets, mealworms, palm weevil larvae, grasshoppers and African emperor moth caterpillars. Before milling into powders, insects and larvae were pre-treated by freeze-drying, oven/tray and microwave drying, blanching and roasting but was not reported for all studies. Generally, bread with up to 10% and muffins/biscuits/crackers/cookies with 5% of insect powder were acceptable to consumers. New areas of research should focus on comparing the water activity, shelf-life and cost of pre-treatment processing methods alongside the nutritional properties of edible insect powders.

Introduction

In the past five years, there has been a surge in consumer interest for alternative and sustainable sources of foods that increase protein and add nutritional value to the diet. Factors driving the demand for protein include the increasing global population (de Carvalho, Madureira, and Pintado, 2020), the high carbon footprint associated with beef and dairy production which subsequently accelerate climate change (Anusha Siddiqui et al., 2022; Herbert and Beacom, 2021) and the relatively high price of muscle meat (Eckl et al., 2021). Edible insects are one of the alternative protein sources that can be targeted for improved human nutrition (Onwezen et al., 2021). They are good sources of protein, mono and polyunsaturated fatty acids, vitamins and minerals (Bukkens, 1997) and dietary fibre in the form of chitin (Stull and Weir, 2023). Across the lifecycle of edible insect production systems and dependant on the diet of the insect, nutritional composition varies (Nikkhah et al., 2021). In fact, the consumption of farmed edible insects is not new in several Asian and sub-Saharan African countries including Thailand, Nigeria and Ghana (Bukkens, 1997; Raheem et al., 2019). For example, in Ghana, the "Akokono House" located at the Kwame Nkrumah University of Science and Technology (KNUST) campus in Kumasi is a restaurant that has prioritised the production and sales of larvae of the palm weevil *Rhynchophorus phoenicis* locally called "Akokono" (Legendary Foods Africa, 2021).

In developed countries, barriers to the willingness to consume edible insect include food neophobia and disgust due to the apparent lack of familiarity with edible insect consumption (Anusha Siddiqui et al., 2022; Herbert and Beacom, 2021), perceived cultural norms (Herbert

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and Beacom, 2021) and increased meat-attachment (Eckl et al., 2021). Consequent to these challenges, several studies have focused on evaluating consumer behaviour and perceptions regarding the acceptance of insect and insect-based products as part of their regular dietary patterns (Anusha Siddiqui et al., 2022; Castro Delgado et al., 2020; Castro and Chambers, 2019; Mancini et al., 2019; Orkusz et al., 2020; Pambo et al., 2018; Wilkinson et al., 2018). In Ireland for example, consumers reported their preference for edible insect consumption when utilised in protein bars with appealing flavour and being priced competitively with best sellers in the protein bar category (Herbert and Beacom, 2021). In Australia, consumers indicated that they would consume a biscuit enriched with edible insects but the product must have an appealing appearance and taste with good food safety, quality and nutritional values (Wilkinson et al., 2018). In Poland, Polish students expressed low willingness to consume whole edible insects, yet they indicated an increased liking for edible insect-enriched bakery products, especially breads and biscuits (Orkusz et al., 2020). These findings highlight that there is willingness to consume edible insects when included in familiar bakery products (Herbert and Beacom, 2021; Orkusz et al., 2020).

Globally, bakery products including bread (Kourkouta et al., 2017), biscuits/cookies, cakes and muffins (Guiné, 2022) formulated from refined wheat flour are commonly consumed but nutritionally-poor staple foods and snacks. Enrichment and fortification of staple foods is becoming more popular, as it is relatively simple to increase nutrient intake of a target population when the staple food is being consumed, without having to adopt drastic and difficult dietary changes. One of the economical ways to enhance the protein content of bakery products is through enrichment with edible insects (Ardoin et al., 2021). Prior to their enrichment in bakery products, edible insect are subjected to various pre-treatment and preservation methods including oven and freeze drying then grinding into powder. This review focuses on what is known about the effect of edible insect enrichment on the physical properties, nutritional composition, sensory properties of bakery products.

Method

Literature search strategy

This systematic review was conducted in accordance with the guidelines of the recently updated Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al., 2021). A systematic search for all published articles on bakery products enriched with edible insects was conducted on the databases PubMed, Scopus and ScienceDirect on 5 January 2023. The search terms employed were (Insect* OR Edible insect* OR Entomophagy*) AND (Bakery product* OR Bake* product*). During the article search and retrieval, there was no use of filters or restriction of dates and language. Records obtained from PubMed, Scopus and ScienceDirect were imported to the reference manager, ENDNOTE™ Library. Duplicate records were removed using the ENDNOTE™ Library. The final articles selected for the systematic review were critically checked to ensure they met the inclusion and exclusion criteria established for this review below.

Selection of studies

Eligibility criteria

Inclusion criteria

The inclusion criteria adopted for the selection of articles for the systematic review included: (i) articles published must be original research; (ii) articles must be written in English with its full text readily accessible and (iii) articles must report bakery products formulated with edible insects.

Exclusion criteria

The exclusion criteria were: (i) studies that were published as review articles, book chapters, commentaries, letters to editors, and conference proceedings; (ii) studies that used non- bakery products for edible insect enrichment and (iii) studies that reported only on the nutritional composition of edible insect powders.

Data extraction

Characteristics extracted included country of study, year of publication, type of insect used, pre-treatment method used for insect processing, form of edible insects used for the bakery enrichment, substitution levels of the edible insects used for enrichment, other ingredients used in the bakery enrichment, type of bakery products, study objectives and study outcome.

Literature search results

A total of 7490 records were retrieved from the databases PubMed ($n = 167$), Scopus ($n = 1323$), and ScienceDirect ($n = 6000$). The removal of duplicates from the retrieved articles ($n = 7490$) yielded 7119 studies. Following the screening of titles and abstracts of the studies as described above and in Fig. 1, 44 full-text studies that met the systematic review criteria were assessed.

Geographical distribution of studies

Most studies (25/44) originated in Europe with 7 from Italy 5 from Poland 4 from Spain, 2 from Turkey and one each from Lithuania, Romania, Portugal, Sweden, Hungary and Bulgaria. This was followed by 10 from the Asian continent. The specific Asian countries were Thailand (6), China (2), Saudi Arabia (1) and Israel (1). Africa was the source of 6 studies. The specific African countries include Nigeria (3), Kenya (2), and Uganda (1). South America with Brazil (2) recorded the least number of reports.

The higher number of publications emerging from Europe could be attributed to the increasing recent European consumer interest in alternative protein sources that have lower carbon footprint and consequentially a lower impact on climate change (Sanchez-Sabate and Sabate, 2019). However insects are a traditional food of Asia, Africa and South America not Western countries (Baiano, 2020). Additionally, there is a geographic bias in knowledge diffusion that may favour research from European and other developed countries at the expense of articles submitted for publication from Africa and South East Asia (Skopec et al., 2020).

Products and insects

The forty-four articles included in this systematic review are summarised (Table 1). Diverse bakery products were enriched with edible insects with almost half the studies reporting the addition of insects to bread (21) and the other studies adding insects to cookies (5), crackers (3), cupcakes (1), muffins (4), pie (1) and biscuits (6), cakes (2), pita chips (1) and brownies (1).

Out of the 44 articles that report bakery products enriched with edible insects in Table 1, 21 species of insects were reported for a total of 63 separate instances (Fig. 2). Cricket (*Acheta domesticus*) and mealworm (*Tenebrio molitor*) enrichment each had 18 reports of use to enrich bakery products. This could be due to their availability, high known nutritional content compared to other insects, which includes protein, essential amino acids, lipids, monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), mineral elements, carbohydrates, and energy.

Pre-treatment methods and the nutritional composition of insect powders used in bakery products

Before milling into powders, insects and larvae were pre-treated by

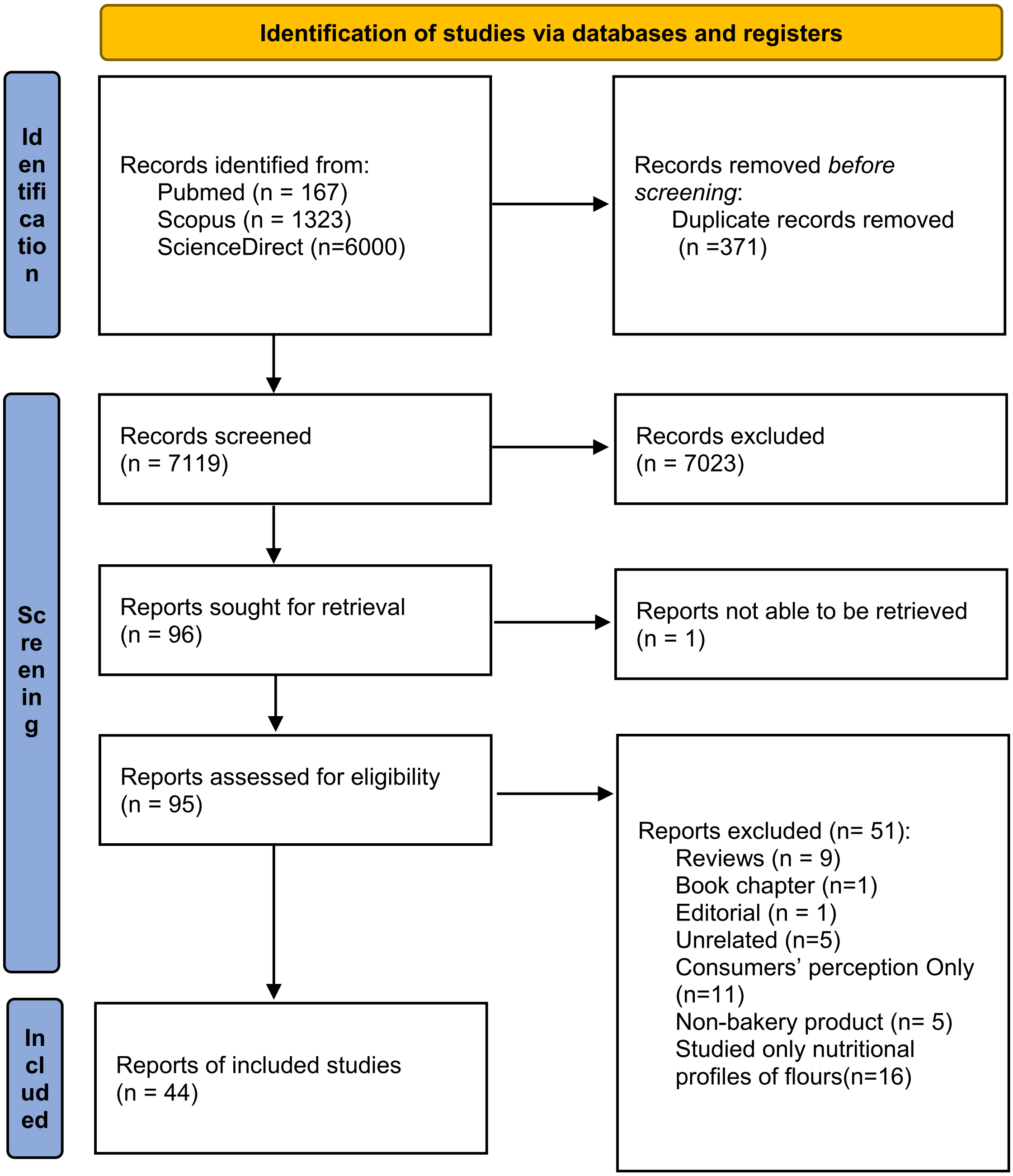

Fig. 1. Summary of screening and critical appraisal processes.

freeze-drying, oven/tray and microwave drying, blanching and roasting (Table 1). However, the pre-treatment or other information about the processing and source of the insect powders was not reported for many studies we reviewed. Across their lifecourse, edible insects vary in content and concentration of protein, mono and polyunsaturated fatty acids, vitamins and minerals (Bukkens, 1997). In addition the initial processing method employed to produce edible insect powders may affect its nutrient content. Prior to human consumption and after harvesting, the initial processing of edible insects to powders with improved bioavailability and storage time include the most common method of freeze drying (Aguilera et al., 2021; González et al., 2019) but also oven drying (Lucas-González et al., 2019), micro-wave drying (Haber et al., 2019), blanching (Althwab et al., 2021), tray drying (Mafu et al., 2022) and dehydration (da Rosa Machado and Thys, 2019). Compared to other heat-treatment methods, freeze-drying is associated with minimal losses in nutrients, reduced water activity and increased nutrient retention and the ability to retain the structural integrity of the insect cell membrane (Bhatta et al., 2020). The final stage in the production of edible insect powder requires milling. Protein, fat and ash composition of powders from edible insects and their larvae prepared with different initial processing methods have been reported (Table 2).

The protein content of crickets and ants that had water removed by freeze-drying ranged from 30% to 67% (Table 2). A major limitation of all but one of the studies reviewed is lack of comparison of the pre-treatment methods on the same insect product. The study that directly compared freeze-drying with oven drying as a processing method of the same edible insect species, cricket (*Acheta domesticus*) (Lucas-González et al., 2019) and found similar protein content (Table 2).

The effect of edible insect processing on the fat content of the powder has been reported. Freeze-dried ant, mealworm and black soldier larvae recorded the highest fat content of 50.1, 40.6 and 35.82 g/100 g respectively. These edible larvae could consequently be targeted for fat

Table 1
Characteristics of included studies of insect-enrichment of bakery products, pre-treatment and effects of substitution on product properties. Listed in order of products bread, cookies, crackers, cupcakes, muffins, pie, pita chips, cake, brownies and biscuits.

Authors, Year	*Country of study*	*Edible insects and their larvae used*	*Pre-treatment method used*	*Form of insect used for enrichment/ substitution*	*Bakery Product*	*Findings*	*Acceptable substitution*	*Reference(s)*
Gantner *et al.*, (2022)	Poland	Mealworm (*Tenebrio molitor*)	N/A	Powder (5, 10, 15%)	Bread	↓Hardness, L*, and specific density for all substitutions as compared to the control ↑Protein, fat and fibre with increasing edible insect powder substitution	5% enrichment	(Gantner, M. et al., 2022)
Osimani et al. (2018)	Italy	Cricket (*Acheta domesticus*)	N/A	Powder (10, 30%)	Bread	↓Specific volume for all substitutions as compared to the control ↑Bread firmness, fat, protein and fibre with respect to increasing substitution	↓ Acceptability of cricket-enriched bread	(Osimani et al., 2018)
de Oliveira et al. (2017)	Brazil	Cinerous cockroach (*Nauphoeta cinerea*)	Oven drying	Powder (5, 10, 15%)	Bread	↓Specific volume for all substitutions as compared to the control ↑Hardness with respect to increasing substitution ↑protein, fat and fibre of the 10% enriched bread compared to the control ↓L* crumb and L* crust for all substitutions as compared to the control	10% cinereous cockroach powder	(de Oliveira, da Silva Lucas, Cadaval, & Mellado, 2017)
da Rosa Machado & Thys (2019)	Brazil	Cricket powder (*Gryllus assimilis*)	N/A	Powder (10, 20%)	Bread	↑Hardness, springiness, chewiness, protein and lipid for both substitutions as compared to the control ↓Specific volume, crumb L* and crust L* as compared to the control	N/A	(da Rosa Machado & Thys, 2019)
Khuenpet et al. (2020)	Thailand	larval-stage mealworm (*Tenebrio molitor*)	Freeze drying	Powder (5, 10, 15%)	Bread	↓Specific volume, springiness, crumb L* and crust L* with increasing substitution levels as compared to the control ↑Hardness, chewiness and proteins for all substitution compared to the control	N/A	(Khuenpet, Pakasap, Vatthanakul, & Kitthawee, 2020)
Xie et al. (2022)	China	Mealworm (*Tenebrio molitor*)	N/A	Powder (5, 10, 15, 20%)	Bread	↓L* for all substitutions (straight dough method) ↑Specific volume for up 10% substitution (straight dough	N/A	(Xie, Cai, Yuan, Shang, & Deng, 2022)

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Table 1 (*continued*)

Authors, Year	*Country of study*	*Edible insects and their larvae used*	*Pre-treatment method used*	*Form of insect used for enrichment/ substitution*	*Bakery Product*	*Findings*	*Acceptable substitution*	*Reference(s)*
						method) ↑Hardness for all substitutions except 5 and 10% (straight dough method)		
Althwab et al. (2021)	Saudi Arabia	Migratory locust (*Locusta migratoria*)	Blanching followed by oven drying	Powder (1, 2, 3, 4, 5%)	Bread	↓Specific volume for all substitutions as compared to the control ↑Proteins, fats and fibre contents with increasing substitution	Up to 4%	(Althwab, Alhomaid, Ali, Mohammed El-Anany, & Mousa, 2021)
Montevecchi et al. (2021)	Italy	Black soldier fly prepupae (*Hermetia illucens*)	Oven drying	Powder (2, 4%)	Bread	↓Bread weight as compared to control	N/A	(Montevecchi, Licciardello, Masino, Miron, & Antonelli, 2021)
González et al. (2019)	Spain	Cricket (*Acheta domesticus*), Black soldier fly (*Hermetia illucens*), Mealworm (*Tenebrio molitor*)	Freeze drying	Powder (5%) for all insects	Bread	↓Specific volume and L* for all substitutions as compared to the control ↑Hardness for all substitutions as compared to the control ↑Proteins, fats and fibre for all insect enriched breads as compared to control except those from defatted powder from Black soldier fly (*Hermetia illucens*)	N/A	(González, Garzón, & Rosell, 2019)
Roncolini et al. (2020)	Italy	Lesser mealworm (*Alphitobius diaperinus*)	N/A	Powder (10, 30%)	Bread	↓Specific volume for all substitutions as compared to the control except the 10% sourdough bread ↑Proteins, fats and fibre for all substitutions as compared to control	N/A	(Roncolini, Andrea et al., 2020)
Bawa et al., (2020)	Thailand	Cricket (*Acheta domesticus*)	Liquid nitrogen freezing, Microwave drying	Powder (5, 10, 15%)	Bread	↓Specific volume for all substitutions as compared to the control ↑Hardness and springiness for all substitutions as compared to the control ↑Proteins, fats and fibre for the 10% enriched bread ↓L* for all substitutions	10% substitution	(Bawa, Songsermpong, Kaewtapee, & Chanput, 2020)
Garciá-Segovia et al. (2020)	Spain	Mealworm (*Tenebrio molitor*), Buffalo worm (*Alphitobius diaperinus*)	N/A	Powder 5, 10%	Bread	↓Hardness and springiness for all substitutions as compared to the control ↑Appearance, taste and overall liking for all substitutions of insect powders	5 and 10% mealworm enriched breads	(Garcia-Segovia, Igual, & Martinez-Monzo, 2020)
Roncolini et al. (2019)	Italy	Mealworm (*Tenebrio molitor*)	N/A	Powder (5, 10%)	Bread	↑Specific volume for all substitutions as compared to the	↓ Acceptability of the enriched breads	(Roncolini, A. et al., 2019)

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Table 1 (*continued*)

Authors, Year	***Country of study***	***Edible insects and their larvae used***	***Pre-treatment method used***	***Form of insect used for enrichment/ substitution***	***Bakery Product***	***Findings***	***Acceptable substitution***	***Reference(s)***
						control ↑Protein and fat contents with increasing substitution		
Gaglio et al. (2021)	Italy	Mealworm (*Tenebrio molitor*), Buffalo worm (*Alphitobius diaperinus*)	N/A	Powder (10%)	Bread	↓L* crust and L* crumb for all substitutions as compared to the control ↑Hardness for all substitutions as compared to the control	10% mealworm enriched bread	(Gaglio et al., 2021)
Bresciani et al. (2022)	Italy	Cricket (*Acheta domesticus*)	Blanching, Freeze drying	Powder (10, 20%)	Bread	↓Specific volume for all substitution as compared with the control ↑Hardness for all substitutions as compared to the control	N/A	(Bresciani, Cardone, Jucker, Savoldelli, & Marti, 2022)
Bartkiene et al. (2022)	Lithuania	Cricket	N/A	Powder (5, 10, 15%)	Bread	↓ Specific volume for all substitution except 5% ↑ L* crust for all substitution except 5% ↓L* crumb for all substitution	5 and 10% enriched bread	(Bartkiene et al., 2022)
Haber et al. (2019)	Israel	Grasshopper (*Schistocerc-a gregaria*) Defatted Grasshopper (*Schistocerc-a gregaria*)	Microwave drying	Powder (0.1, 0.2%) Powder (Defatted) (0.2%)	Bread	↓Specific volume and hardness for all substitution as compared to the control ↑Protein, fibre and fat content	0.1% enriched bread	(Haber, Mishyna, Martinez, & Benjamin, 2019)
Kowalski et al. (2022)	Polamd	Mealworm (*Tenebrio molitor*) Buffalo worm (*Alphitobius diaperinus*) Cricket (*Acheta domesticus*)	N/A	Powder 10, 20, 30%) %	Bread	↑Specific volume for all substitution except 20 and 30% substitutions of buffalo worm and cricket ↓Hardness for all substitution except 20 and 30% substitutions of buffalo worm and cricket	10% buffalo worm and cricket powder enriched bread	(Kowalski, Mikulec, Mickowska, Skotnicka, & Mazurek, 2022)
Mafu et al. (2022)	Thailand	Cricket (*Acheta domesticus*)	Tray drying	Powder (10, 15, 20, 25, 30%)	Bread	↑ Hardness for all substitution as compared to control ↑ L* crust for all substitution except 25 and 30% ↑ Proteins and fat with increasing concentration ↓ L* crumb for all substitution	10% cricket powder enriched bread	(Mafu, Ketnawa, Phongthai, Schonlechner, & Rawdkuen, 2022)
Mihaly Cozmuta et al. (2022)	Romania	Cricket (*Acheta domesticus*) Yellow mealworm (*Tenebrio molitor*)	N/A	Powder (5, 10, 15%) for all insects	Bread	↓ Specific volume for the 10% substitution as compared with the control (only 10% substitution was determined)	N/A	(Mihaly Cozmuta et al., 2022)
Cappelli et al. (2020)	Italy	Mealworm (*Tenebrio molitor*) Cricket (*Acheta domesticus*)	N/A	Powder (5, 10, 15%)	Bread	↓ Bread volume for all insect substitution as compared to	N/A	(Cappelli, Oliva, Bonaccorsi, Lorini, & Cini, 2020)

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Table 1 (*continued*)

Authors, Year	*Country of study*	*Edible insects and their larvae used*	*Pre-treatment method used*	*Form of insect used for enrichment/ substitution*	*Bakery Product*	*Findings*	*Acceptable substitution*	*Reference(s)*
						control		
Bawa et al. (2020)	Thailand	Cricket (*Acheta domesticus*)	Liquid nitrogen freezing, Microwave drying	Powder (5, 10, 15%)	Cookies	↓ Specific volume for all substitutions as compared to the control ↑ Hardness for all substitutions as compared to the control	5 and 10% enriched cookie	(Bawa et al., 2020)
Aleman et al. (2022)	Honduras	Cricket (*Acheta domesticus*)	N/A	Powder (5, 7.5 and 10%)	Cookies	↓Hardness, L*. a* and b* for all substitution as compared to control ↑Protein and fat contents with increasing substitution	5% enriched cookie	(Aleman et al., 2022)
Awobusuyi et al., 2020	Nigeria	Winged termites (*Macrotermes belliscosusi*)	Oven dried	Powder (5, 10 and 15%)	Cookies	↓Hardness, L* for all substitutions as compared to control ↑ Protein and fat contents with increasing substitution	N/A	(Awobusuyi, Siwela, & Pillay, 2020)
Sriprablom et al. (2022)	Thailand	Mealworm (*Tenebrio molitor*) Giant mealworm beetle (*Zophobas atratus*)	N/A	Powder (10, 20, 30%) for all insects	Cookies	↓L* for all substitutions of insects as compared to control ↑Hardness for all substitutions of insects as compared to control ↑Protein and fat contents with increasing substitution	Up to 20% enriched cookies	(Sriprablom, Kitthawee, & Suphantharika, 2022)
Cheseto et al. (2020)	Kenya	African bush-cricket (*Ruspolia differens*) Desert locust (*Schistocerca gregaria*)	N/A	Oil 300mL	Cookies	↓Colour for desert locust cookies and African bush cricket as compared to the control ↑Protein, fiber and fat contents for all insect oil enriched products	Cookies from African bush-cricket enrichment	(Cheseto, Baleba, Tanga, Kelemu, & Torto, 2020)
Djouadi et al., 2022	Portugal	Mealworm (*Tenebrio molitor*)	Microwave dried	Powder (2, 4, 6, 10, 15 and 20%)	Crackers	↓L*, hardness, firmness for all substitutions ↑Protein and fat contents in 6% substitution ↑ a*, thickness, for all substitutions	Neither 6 nor 15% enriched crackers (sensory done on only these 2 formulations in addition to the control)	(Djouadi, Sales, Carvalho, & Raymundo, 2022)
Ardoin et al., 2021	USA	Crickets	N/A	Powder (5, 10, 15, 20%)	Crackers	↓L*, hardness and overall liking for all substitution	5% cricket powder enrichment	(Ardoin, R., B. D. Marx, C. Boeneke, & W. Prinyawiwatkul, 2021)
Akullo et al. (2018)	Uganda	Winged termites (*Macrotermes bellicosus*) Soldier termites (*Syntermes soldiers*) Crickets (*Brachytrupes spp.*)	Oven drying	Powder (8%)	Crackers	↓Colour and crunchiness for all substitution as compared to the control ↑Protein contents in winged termite substitution	5% winked termites enrichment	(Akullo, Nakimbugwe, Obaa, Okwee-Acai, & Agea, 2018)

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Table 1 (*continued*)

Authors, Year	*Country of study*	*Edible insects and their larvae used*	*Pre-treatment method used*	*Form of insect used for enrichment/ substitution*	*Bakery Product*	*Findings*	*Acceptable substitution*	*Reference(s)*
Aguilera et al., 2021	Spain	Beetle (*Phyllophaga rugosa*) Caterpillar (*Nudaurelia melanops*)	Lyophilisation	Powder (10%)	Cupcakes	Highest colour for caterpillar cupcake	10% Beetle and caterpillar enrichment	(Aguilera et al., 2021)
Pauter et al., 2018	Poland	Cricket	N/A	Powder (2, 5 and 10%)	Muffin	↓L*, and hardness for all substitutions ↑Protein and fat contents with increasing substitution	5% cricket powder enriched muffin	(Pauter et al., 2018)
Çabuk, (2021)	Turkey	Grasshopper (*Locusta migratoria*) Mealworm (*Tenebrio molitor*)	N/A	Powder (15%)	Muffin	↓Specific volume, L*, and hardness for ↑Protein and fat contents	15% mealworm enriched muffin	(Çabuk, 2021)
Ouma et al., (2022)	Kenya	Walker caterpillar (*Gonimbrasia zambesina*)	Oven drying	Powder (5, 10, 15 and 20%)	Muffin	↓Colour and texture for all substitution as compared to the control ↑Protein, fibre and fat contents with increasing substitution	5% walker caterpillar powder enriched muffins	(Ouma, Muriithi, & Anyango, 2022)
Zielińska et al., 2021	Poland	Mealworm (*Tenebrio molitor)* Crickets (*Gryllodes sigillatus)*	Lypholization	Powder (2, 6 10%)	Muffin	↓Hardness for all substitutions except for the 10% cricket powder enriched muffins ↑Protein and fat contents with increasing substitution except for the 2 and 6% mealworm and cricket powder enriched muffins respectively	10% cricket and cricket powder enriched muffins	(Zielińska, Pankiewicz, & Sujka, 2021)
Akande et al. (2020)	Nigeria	Mulberry Silkworm (*Bombyx mori*) African palm weevil larvae (*Rhynchophorus phoenicis*)	Boiled	Paste	Pie	↑Appearance for African palm weevil larvae	150g mulberry silkworm and African palm weevil larvae paste enriched pie	(Akande, O. A., Falade, Badejo, & Adekoya, 2020)
Gurdian et al. (2022)	USA	Crickets (*Acheta domesticus*)	Microwave drying	Powder (6.9%)	Pita chips	↑ crunchiness for Italian treated pita chips	6.9% cricket powder pita chips seasoned with Italian-style herb seasoning	(Gurdian, Torrico, Li, & Prinyawiwatkul, 2022)
Indriani et al. (2020)	Thailand	Bombay locusts (*Patanga succincta L.*)	Freeze drying	Powder (10, 20, 30%)	Cake	↓Specific volume, hardness, L* crumb and L* crust as compared to the control ↑Protein contents with increasing substitution ↑Fat contents with increasing concentration except for the 20% enriched cake	↓Overall liking with increasing substitution	(Indriani, Bin Ab Karim, Nalinanon, & Karnjanapratum, 2020)
Vlahova-Vangelova et al. (2022)	Bulgaria	Crickets (*Acheta domesticus*)	N/A	Powder (5, 10%)	Cake	↓Specific volume, and L* as compared to the control	5% cricket powder-enriched sponge cake	(Vlahova-Vangelova, Balev, Kolev, Dinkova, & Stankov, 2022)
Ho et al. (2022)	USA	Crickets (*Acheta domesticus*)	N/A	Powder (7%)	Brownies	↓Firmness for all substitutions as	N/A	(Ho et al., 2022)

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Table 1 (*continued*)

Authors, Year	*Country of study*	*Edible insects and their larvae used*	*Pre-treatment method used*	*Form of insect used for enrichment/ substitution*	*Bakery Product*	*Findings*	*Acceptable substitution*	*Reference(s)*
						compared to the control ↑Protein and fat content as compared to control		
Biró et al. (2020)	Hungary	Cricket (*Acheta domesticus*)	N/A	Powder (5, 10, 15%)	Biscuits	↑Hardness for all substitutions as compared to the control ↓L* for all substitutions as compared to the control ↑Protein, fats and fibre content as compared to control	5% cricket powder-enriched biscuits	(Biro et al., 2020)
Xie et al. (2022)	China	Mealworm (*Tenebrio molitor*)	N/A	Powder (5, 10, 15, 20%)	Biscuits	↑Hardness for all substitutions except 20% substitution ↓L* for all substitutions as compared to the control ↑Protein, fats and fibre content as compared to control	5, 10, 15% mealworm powder-enriched biscuits	(Xie, Yuan, Fu, An, & Deng, 2022)
Bas & El (2022)	Turkey	Cricket (*Acheta domesticus*)	N/A	Powder (10, 15, 20%)	Biscuits	↓Hardness for all substitutions	Up to 20%	(Bas & El, 2022)
Zielińska & Pankiewicz (2020)	Poland	Mealworm (*Tenebrio molitor*)	Lyophilization	Powder (15, 20, 30%)	Biscuits (shortcake)	↑ Apparent density for all substitutions except 15% substitution ↑Proteins with increasing substitutions	N/A	(Zielinska & Pankiewicz, 2020)
Ortolá et al., (2022)	Spain	Mealworm (*Tenebrio molitor*) Buffalo worm (*Alphitobius diaperinus*)	N/A	Powder (12.7, 16.8 20, 25%)	Biscuits	↑Hardness for all substitutions except 25% substitution of the Buffalo worm ↑Proteins and fats content with increasing substitutions ↓L* for all substitutions as compared to the control	N/A	(Ortolá, Martínez-Catalá, Yuste Del Carmen, & Castelló, 2022)
Akande et al. (2020)	Nigeria	Mulberry silkworm pupae (*Bombyx mori*) Locust (*Schistocerca gregaria*)	Oven drying	Powder (15%)	Biscuits	↑Colour for Mulberry silkworm pupae biscuits ↓Crispness for all substitution ↑Fat content for the silkworm pupae powder enriched high-energy biscuits	15% Mulberry silkworm pupae and locust powder-enriched biscuits	(Akande, A. O., Jolayemi, Adelugba, & Akande, 2020)

N/A- Not Assessed and L*- Lightness colour

provision, which could be utilised in new product development. The extraction and application of fat from edible insect in bakery products has been explored. In fact, Cheseto et al. (2020) extracted fat from the desert locust *Schistocerca gregaria* and the African bush-cricket *Ruspolia differens* and incorporated the fat into cookies (Cheseto et al., 2020). The authors found that edible oils extracted from the insects had higher concentrations of omega-3 fatty acids, flavonoids, and vitamin E compared to oils extracted from plant origins (sesame and olive). Enrichment of the cookies with edible insect oil especially those from desert locust *Schistocerca gregaria* resulted in significant increase in the ash and protein content compared to their plant-based oil enriched cookies (Cheseto et al., 2020). New areas of research could prioritise the optimisation of oil extraction from these fat-rich edible insects using green technologies.

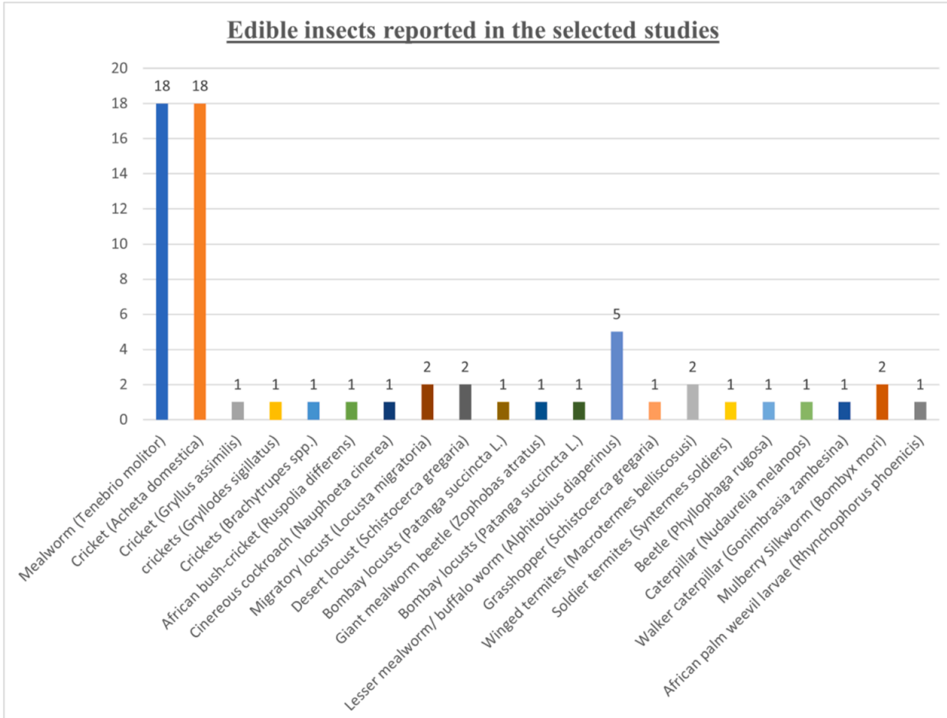

Fig. 2. The number of edible insects and their larvae reported in the selected studies.

The ash content of edible insect powders varies with processing method. Ash content refers to the inorganic matter of a food material produced after burning in a furnace at high temperatures (Ismail, 2017) and represents the mineral content of the edible insect and their larvae which are predominantly phosphorous, calcium, potassium and sodium (Djouadi et al., 2022). The ash content of most of the edible insects especially for those processed by freeze-drying, blanching, oven drying and microwave drying were consistently similar and ranged from 2.95–4.6 g/100 g (Aguilera et al., 2021; Althwab et al., 2021; Fombong et al., 2021; González et al., 2019; Haber et al., 2019; Lucas-González et al., 2019). These values compare well with the ash content of powder from commonly consumed legumes/pulses including fava bean, green pea and yellow pea that had ash content of 3.40, 2.76 and 3.52 g/100 g respectively (Millar et al., 2019). Consequently, edible insects and legumes, which constitute alternative protein sources could be substituted or combined with each other in food product development. Even though the use of roasting method on palm weevil larvae processing resulted in ash content of 1.05 g/100 g (Adepoju and Ayenitaju, 2021), the value was higher than ash content of 0.96 g/100 g reported for commercial strong-wheat powder (Millar et al., 2019).

Nutritional composition of bakery products enriched with edible insect powders

The enrichment of bakery products with edible insects impacts the nutritional profile (González et al., 2019). Bakery products include bread, cakes, muffins and cookies (Guiné, 2022). Due to factors including cost, ease of preparation and convenience, and shelf-life bakery products globally are a commonly consumed staple foods (Kourkouta et al., 2017). The basic ingredients for most gluten-containing bakery products are refined wheat flour and water, which is considered energy-dense and nutrient-poor. The nutritional composition, protein, fat, fibre and ash of bakery products can be improved with the addition of powder from edible insects. Each is discussed in turn below.

Effect of edible insect powder enrichment of bakery products on the protein content

Bawa et al. (2020) enriched bread with 10% freeze-dried cricket powder and recorded 20% magnitude increase in the protein content for the enriched bread when compared to its non-enriched counterparts. In a similar study involving bread enrichment with 10 and 20% cricket (*Gryllus assimilis*) powder substitution, a magnitude increase of 28.8 and 62.8% in the protein content of the enriched bread compared to their control non-enriched counterpart was reported (da Rosa Machado and Thys, 2019). For whole wheat bread enrichment with cricket powder (10, 15, 20, 25 and 30%), increased protein content of the enriched breads with increased edible insect powder substitution was observed as expected (Mafu et al., 2022). A magnitude increase of 17.1, 28.2, 31.0, 39.2 and 39.4% was recorded respectively for the 10, 15, 20, 25 and 30% cricket powder-enriched whole wheat bread (Mafu et al., 2022). In this review, bread enrichment with 10% cricket powder generally resulted in protein increase in the magnitude range of 17.1–28.8%. However, one study that enriched bread with cricket powder at substitutions of 2, 6 and 10% resulted in substantial increases of 52, 79 and 85.5% in protein concentration respectively compared to their non-enriched counterpart (Kowalczewski et al., 2021). These were quite higher compared to those (17.1–28.8%) reported earlier for the 10% cricket powder-enriched breads and could be attributed to the processing method used for the edible insect powder production. The limitation of that study however is that the cricket (*Acheta domesticus*) powder was commercially produced and lacks information on the type of processing method used for its production (Kowalczewski et al., 2021).

Bread enrichment with 5 and 10% mealworm (*Tenebrio molitor*) powder resulted in protein increase by magnitude of 17.3 and 30.3% respectively compared to their control non-enriched counterpart (Garcia-Segovia et al., 2020). Bread enrichment with mealworm powder at 5 and 10% substitution resulted in similar magnitude increase in the protein content (15.5 and 22.9%) respectively compared to their non-enriched counterparts (Roncolini et al., 2019). Bread enrichment with 5 and 10% lesser mealworm (*Alphitobus diasperinus*) powder

Table 2
Pre-treatment methods and the protein, fat and ash content of edible insect powder available in the studies selected for this review.

Author	*insect*	*Pre-treatment*	*Nutrition composition of insect powder used (dry weight)*			*Reference*
			Protein (g/100g)	*Fat (g/100g)*	*Ash (g/100g)*	
Gantner et al. (2022)	Mealworm (*Tenebrio molitor*)	N/I	61.0	21.5	-	(Gantner, M. et al., 2022)
Osimani et al. (2018)	Cricket (*Acheta domesticus*)	N/I	48.87	28.75	3.50	(Osimani et al., 2018)
de Oliveira et al. (2017)	Cinerous cockroach (*Nauphoeta cinerea*)	Oven drying	63.59	23.29	4.63	(de Oliveira et al., 2017)
Mihaly Cozmuta et al. (2022	Cricket (*Acheta domesticus*)	N/I	67.21	18.39	3.75	(Mihaly Cozmuta et al., 2022)
	Yellow mealworm (*Tenebrio molitor*)		46.54	35.46	4.88	
da Rosa Machado & Thys (2019)	Cricket powder (*Gryllus assimilis*)	N/I	62.76	20.96	3.19	(da Rosa Machado & Thys, 2019)
Khuenpet et al. (2020)	larval-stage mealworm (*Tenebrio molitor*)	Freeze drying	41.22	32.76	3.57	(Khuenpet et al., 2020)
Althwab et al. (2021)	Migratory locust (*Locusta migratoria*)	Blanched, oven drying	51.97	23.15	2.95	(Althwab et al., 2021)
González et al. (2019)	Cricket (*Acheta domesticus*)	Freeze drying	56.58	27.08	4.02	(González et al., 2019)
	Black soldier fly (*Hermetia illucens*)		45.09	35.82	4.25	
	Mealworm (*Tenebrio molitor*)		48.82	30.69	4.25	
Roncolini et al. (2020	Lesser mealworm (*Alphitobius diaperinus*)	N/I	58.40	26.25	5.38	(Roncolini, Andrea et al., 2020)
Roncolini et al. (2019)	Mealworm (*Tenebrio molitor*)	N/I	51.71	27.69	3.65	(Roncolini, A. et al., 2019)
Gaglio et al. (2021)	Mealworm (*Tenebrio molitor*)	N/I	54.1	29.4	-	(Gaglio et al., 2021)
	Buffalo worm (*Alphitobius diaperinus*)		59.6	28.7	-	
Bartkiene et al. (2022)	Cricket	N/I	62.6	26.5	3.8	(Bartkiene et al., 2022)
Haber et al. (2019)	Grasshopper (*Schistocerca gregaria*)	Microwave drying	35.3	13.3	3.9	(Haber et al., 2019)
	Defatted Grasshopper (*Schistocerca gregaria*)		39.1	1.8	4.0	
Kowalski et al. (2022)	Mealworm (*Tenebrio molitor*)	N/I	49.89	29.64	3.65	(Kowalski et al., 2022)
	Buffalo worm (*Alphitobius diaperinus*)		55.67	14.02	5.22	
	cricket (*Acheta domesticus*)		62.51	8.37	3.39	
Mafu et al., 2022	Cricket (*Acheta domesticus*)	Tray drying	55.11	22.83	4.80	(Mafu et al., 2022)
Ouma et al. (2022)	Walker caterpillar (*Gonimbrasia zambesina*)	Oven drying	59.33	14.87	3.46	(Ouma et al., 2022)
Zielińska et al. (2021)	Mealworm (*Tenebrio molitor*)	Freeze drying	54.29	28.01	0.95	(Zielińska et al., 2021)
	Cricket (*Gryllodes sigillatus*)		71.5	14.82	0.95	
Wendin et al. (2021)	Mealworm (*Tenebrio molitor*)	Oven drying	53.6	33.9	-	(Wendin et al., 2021)
Aleman et al. (2022)	Cricket (*Acheta domesticus*)	N/I	60.7	13.4	3.9	(Aleman et al., 2022)
Djouadi et al. (2022)	Mealworm (*Tenebrio molitor*)	Microwave Drying	51.2	20.0	3.4	(Djouadi et al., 2022)
Aguilera et al. (2021)	Mealworm (*Tenebrio molitor*)	Freeze drying	45.7	40.6	3.9	(Aguilera et al., 2021)
	Cricket (*Acheta domesticus*)		57.7	25.9	4.6	
	Beetle (*Phyllophaga rugosa*)		39.4	17.7	4.5	
	Caterpillar (*Nudaurelia melanops*)		41.1	33.0	4.0	
	Ant (*Oecophylla smara-Digna*)		30.6	50.1	2.4	
	Locust (*Locusta migratoria*)		58.8	17.9	5.5	
Indriani et al. (2020)	Bombay locusts (*Patanga succincta L.*)	Freeze drying	78.7	1.2	3.3	(Indriani et al., 2020)
Vlahova-Vangelova et al. (2022)	Cricket (*Acheta domesticus*)	N/I	63.64	14.43	-	(Vlahova-Vangelova et al., 2022)
Biró et al. (2020)	Cricket (*Acheta domesticus*)	N/I	67.8	18.2	-	(Biro et al., 2020)
Xie et al. (2022)	Mealworm (*Tenebrio molitor*)	N/I	43.5	25.3	3.5	(Xie, Yuan, et al., 2022)
Zielińska & Pankiewicz (2020)	Mealworm (*Tenebrio molitor*)	Freeze drying	54.6	29.47	3.89	(Zielinska & Pankiewicz, 2020)
Ortolá et al. (2022)	Mealworm (*Tenebrio molitor*)	N/I	54.1	-	-	(Ortolá et al., 2022)
	Buffalo worm (*Alphitobius diaperinus*)		59.6	-	-	
Akande et al. (2020)	Mulberry silkworm pupae (*Bombyx mori*)	Oven drying	60.7	23.5	0.9	(Akande, A. O. et al., 2020)
	Locust (*Schistocerca gregaria*)		43.2	15.2	2.1	
Sriprablom et al. (2022)	Mealworm (*Tenebrio molitor*)	N/I	51.11	32.89	3.48	(Sriprablom et al., 2022)
	Giant mealworm beetle (*Zophobas atratus*)		51.08	34.64	3.23	

N/I- Not Indicated

resulted in protein content increase by magnitude of (12.7 and 24%) respectively compared to their control non-enriched counterpart (Garcia-Segovia et al., 2020). Bread enrichment with locust (*Locusta migratoria*) (1, 3 and 5%) resulted in protein increase by a magnitude of (5.1, 11.7, and 18.8%) respectively when compared to their non-enriched counterpart (Althwab et al., 2021).

The enrichment of biscuits with cricket powder (2, 6 and 10%) resulted in magnitude increase of (22.1, 34.2 and 41%) for protein content respectively (Smarzynski et al., 2021). In the case of cricket-enriched cookies, enrichment with 10% cricket resulted in protein content increase by a magnitude of 40.2% (Bawa et al., 2020). Cookies enrichment with 5, 7.5, 10% cricket powder resulted in protein increase by a magnitude of 56.2, 67.2 and 70.7% respectively (Aleman et al., 2022). Ouma et al. (2022) enriched wheat muffins enriched with *Gonimbrasia zambesina*, walker caterpillar powder (5%, 10%, 15% and 20% substitution levels) and recorded increased protein content by 22.8, 30.3, 37.7 and 42.4% magnitude. Awobusuyi et al. (2020) reported on cookies enriched 5, 10 and 15% winged termites (*Macrotermes bellicosusi*) had an increase in the protein content by a magnitude of 71.2, 35.9, 51.4 and 37.1%.

Sriprablom et al. (2022) reported on cookies enriched with 10, 20 and 30% mealworm (*Tenebrio molitor*) and giant mealworm beetle (*Zophobas atratus*) each and recorded a significant increase in the protein, fat and ash. They reported significant magnitude increase of (15.2, 26.6, and 36.2%) and (15.1, 27.7, 37.0%) for proteins of mealworm and giant mealworm enriched respectively. Cheseto et al. (2020) compared cookies enriched with 300 mL desert locust (*Schistocerca gregaria*) oil, african bush-cricket (*Ruspolia differens*) oil, olive oil and sesame oil in terms of their nutritional value. The authors reported protein content of 8.8% and 7.75% compared to protein values of 7.5% and 7.5% recorded for protein content of olive oil and sesame oil-enriched cookies respectively.

The higher protein content of the edible insect powder-enriched bakery products highlight its prospect for use as nutritional intervention to address protein-related malnutrition. This remains a prevailing phenomenon in several low and middle-income countries where access to muscle meat is a challenge due to cost as this could provide an affordable and sustainable source of protein.

Effect of edible insect powder enrichment of bakery products on the fat content

Bawa et al. (2020) enriched bread with 10% freeze-dried cricket powder and reported a magnitude increase of almost 17.3% for the fat content respectively for the enriched bread when compared to its non-enriched counterparts. In a similar study involving bread enrichment with 10 and 20% cricket (*Gryllus assimilis*) powder substitution, a magnitude increase of 51.5% and 73.3% respectively for the lipids content compared to their control non-enriched counterpart was reported (da Rosa Machado and Thys, 2019). Bread enriched with cricket powder at substitution of 2, 6 and 10% resulted in substantial increases in fat, fibre and ash content of (18.8, 37.1 and 51.3%) respectively compared to their non-enriched counterpart (Kowalczewski et al., 2021). In the case of whole wheat bread enrichment with cricket powder (10, 15, 20, 25 and 30%), increased the fat content of the enriched breads by magnitude of 16.87%, 12.20%, 23.46%, 34.70% and 39.81% (Mafu et al., 2022).

Bread enrichment with mealworm powder at 5 and 10% substitution resulted in a magnitude increase in the fat content by 81.3 and 91.9% respectively compared to their non-enriched counterparts (Roncolini et al., 2019). Bread enrichment with locust (*Locusta migratoria*) (1, 3 and 5%) resulted in fat increase by a magnitude of (6.2, 14.8 and 22.4%) respectively when compared to their non-enriched counterpart (Althwab et al., 2021).

The enrichment of biscuits with cricket powder (2, 6 and 10%) resulted in magnitude increase of 9.3%, 12.5% and 16% for fat content respectively (Smarzyński et al., 2021). In the case of cricket-enriched cookies, enrichment with 10% cricket resulted in a decrease in fat content increase by a magnitude of 5.47% when compared to their non-enriched counterpart (Bawa et al., 2020).

Ouma et al. (2022) enriched wheat muffins enriched with *Gonimbrasia zambesina*, walker caterpillar powder (5%, 10%, 15% and 20% substitution levels). The fat content of the enriched muffins increased by a magnitude of 3.1%, 6.0%, 8.5% and 11.6%. Cookies enrichment with 5, 7.5 and 10% cricket powder resulted in reductions in the fat content by a magnitude of (6.8, 10.7, 15.7%) (Aleman et al., 2022). Awobusuyi et al. (2020) reported on cookies enriched 5, 10 and 15% winged termites (*Macrotermes belliscosusi*) had an increase in the protein, fat, ash and dietary fibre. Their study resulted in significant magnitude increase of 35.9, 43.3 and 49.3% for fat respectively (Awobusuyi et al., 2020).

Sriprablom et al. (2022) reported on cookies enriched with 10, 20 and 30% mealworm (*Tenebrio molitor*) and giant mealworm beetle (*Zophobas atratus*) each and recorded a significant increase in the fat content. They reported significant magnitude increase in the fat content by (6.7, 13.6, 16.5%) and (0.5, 10.9, 14.8%) respectively for mealworm and giant mealworm enriched respectively. The enrichment of crackers with mealworm (*Tenebrio molitor*) (6%) resulted in a decreased magnitude of (12.6%) for the fat content compared to their non-enriched counterpart (Djouadi et al., 2022). In an enrinchment of muffins with cricket powders at 2, 5 and 10% substitution levels, Pauter et al. (2018) reported magnitude increase of 0.8, 3.8 and 7.4% for fat content (Pauter et al., 2018). Çabuk (2021) reported an increase in the fat content of a muffin enriched with grasshopper (*Locusta migratoria*) and mealworm (*Tenebrio molitor*). They reported an increased magnitude of (14.4%) for fat contents for grasshopper muffin and (14.6%) for fat contents for mealworm muffin (Çabuk, 2021).

In a mealworm (*Tenebrio molitor*) and crickets (*Gryllodes sigillatus*) enrichment in muffins at 2, 6, 10% substitution, the fat content of the enriched muffin in wet and dry weight increased (Zielińska et al., 2021). Wendin et al. (2021) incorporated mealworm (*Tenebrio molitor*) into pâtés and reported an increase of (10.9, 20.2%) for fat at 10 and 30% replacement respectively. There was an increase in the fat content of biscuits enriched with mealworm (*Tenebrio molitor*) at 5, 10, 15 and 20% substitutions (Xie et al., 2022). Bas & El (2022) reported that fat content decreased by magnitude of 2.4% for biscuits enriched by cricket (*Acheta domesticus*) powder (Bas and El, 2022). In mulberry silkworm pupae (*Bombyx mori*) and locust enriched high-energy biscuits, Akande et al. (2020) the mulberry silkworm pupae had the highest fat content followed by the skimmed milk biscuits.

Effect of edible insect powder enrichment of bakery products on the fibre content

Bawa et al. (2020) enriched bread with 10% freeze-dried cricket powder and reported a magnitude increase of almost 81.8% for fibre content for the enriched bread when compared to its non-enriched counterparts. The significantly higher fibre content reported for the enriched bread could be due to the presence of chitin in the exoskeleton of the cricket insect and its powder (Bresciani et al., 2022). Bread enriched with cricket powder at substitution of 2, 6 and 10% resulted in substantial increases in fibre content of 17.5, 33.8 and 41.2% respectively compared to their non-enriched counterpart (Kowalczewski et al., 2021). Bread enrichment with locust (*Locusta migratoria*) (1, 3 and 5%) resulted in fibers increase by a magnitude of 18.9, 34.8 and 45.9% respectively when compared to their non-enriched counterpart (Althwab et al., 2021). In the case of cricket-enriched cookies, enrichment with 10% cricket resulted in fibre content increase by a magnitude of 84.4% (Bawa et al., 2020).

Awobusuyi et al. (2020) reported on cookies enriched 5, 10 and 15% winged termites (*Macrotermes belliscosusi*) had an increase in the dietary fibre. Their study resulted in significant magnitude increase of 37.12, 19.41 and 36.15% for dietary fibre respectively (Awobusuyi et al., 2020).

Effect of edible insect powder enrichment of bakery products on the ash content

Bawa et al. (2020) enriched bread with 10% freeze-dried cricket powder and reported a magnitude increase of almost 18.5% for the ash content for the enriched bread when compared to its non-enriched counterparts. Bread enriched with cricket powder at substitution of 2, 6 and 10% resulted in substantial increases in ash content of 40.5%, 42.4% and 45.3% respectively compared to their non-enriched counterpart (Kowalczewski et al., 2021). Bread enrichment with 5 and 10% mealworm (*Tenebrio molitor*) powder resulted in ash content increase by magnitude of 31 and 36.5% respectively compared to their control non-enriched counterpart (García-Segovia et al., 2020). Bread enrichment with mealworm powder at 5 and 10% substitution resulted in a magnitude increase in the ash of 7.5% and 23.4% respectively compared to their non-enriched counterparts (Roncolini et al., 2019). Bread enrichment with locust (*Locusta migratoria*) (1, 3 and 5%) resulted in ash increase by a magnitude of 6.9%, 27.7% and 51.8% respectively when compared to their non-enriched counterpart (Althwab et al., 2021). Bread enrichment with 5 and 10% lesser mealworm (*Alphitobus diasperinus*) powder resulted in ash content increase by magnitude of 24 and 38.3% respectively compared to their control non-enriched counterpart (García-Segovia et al., 2020).

The enrichment of biscuits with cricket powder at 2, 6 and 10%

resulted in magnitude increases of 41, 16 and 25.2% for ash content respectively (Smarzyński et al., 2021). In the case of cricket-enriched cookies, enrichment with 10% cricket resulted in ash content decreased by 22.7% respectively (Bawa et al., 2020). Cookies enrichment with 5, 7.5 and 10% cricket powder resulted in ash content by a magnitude of 3.44, 10.34 and 13.79% respectively (Aleman et al., 2022).

Awobusuyi et al. (2020) reported on cookies enriched 5, 10 and 15% winged termites (*Macrotermes belliscosusi*) had an increase in the ash content. Their study resulted in significant magnitude increase of 51.4, 57.5 and 59.5% ash respectively (Awobusuyi et al., 2020). Sriprablom et al. (2022) reported on cookies enriched with 10, 20 and 30% mealworm (*Tenebrio molitor*) and giant mealworm beetle (*Zophobas atratus*) each and recorded a significant increase in the ash. They reported significant magnitude increase of 6.3, 14.4 and 19.0% for ash content of mealworm (*Tenebrio molitor*) and (11.3, 14.4, 18.6%) for giant mealworm beetle (*Zophobas atratus*). The enrichment of crackers with 6% mealworm (*Tenebrio molitor*) resulted in a 12.8% increase in ash content (Djouadi et al., 2022). In an enrinchment of muffins with cricket powders at 2, 5 and 10% substitution levels, Pauter et al. (2018) reported magnitude increases of 9, 24.8 and 39.4% in ash content(Pauter et al., 2018). In a mealworm (*Tenebrio molitor*) and crickets (*Gryllodes sigillatus*) enrichment in muffins at 2, 6 and 10% substitution, the ash content of the enriched muffin in wet and dry weight increased (Zielińska et al., 2021). There was an increase in the ash content of biscuits enriched with mealworm (*Tenebrio molitor*) at 5, 10, 15 and 20% substitutions (Xie et al., 2022). Bas & El (2022) reported an increase in the ash content of biscuits enriched by cricket (*Acheta domesticus*) powder by magnitude of 35.8%. In mulberry silkworm pupae (*Bombyx mori*) and locust enriched high-energy biscuits, Akande et al. (2020) reported high values for ash content for both the insect-enriched biscuits.

Physical assessment of bakery products enriched with insect

The physical properties of powder developed from edible insect impact on the physical parameters of the bakery products that have insect powder as an ingredient. Measureable parameters include specific loaf volume, loaf crust/crumb lightness colour, crumb hardness, cohesiveness, springiness and gumminess.

Effect of edible insect enrichment of enriched bakery products on the specific volume

Specific volume of bakery products including bread is an important indicator of the technological performance of the processes involved in the product development (Ananingsih et al., 2013). Bread with appreciable specific volume to the commercial baker is associated with higher profitability as it resonates with consumers acceptability appeal.

Bawa et al. (2020) enriched bread with cricket (*Acheta domesticus*) powder (5, 10 and 15%) and investigated its effect on the quality profile. The authors reported decreased specific volume (3.8, 8.5 and 23.0%) compared to their control non-enriched counterpart. The specific volume of the 5% enriched bread was however not significantly different from the control bread. In a similar study (González et al., 2019) where 5% cricket (*Acheta domesticus*) powder was used in bread enrichment, there was reduction in the specific volume by a magnitude of 2.25%. The use of 10 and 20% cricket powder (*Gryllus assimilis*) in bread enrichment resulted in decreased specific volume of 17.3% and 12.4% respectively (da Rosa Machado and Thys, 2019). Bresciani et al. (2022) enriched wheat bread with cricket powder (at 10%, and 20% levels) and reported a significant decrease in the specific volume of the bread loaves by magnitude of 3.9% and 8.8% respectively. Bread enriched with 5% black soldier fly larvae (*Hermetia illucens*) and yellow mealworm (*Tenebrio molitor*) powder resulted in reduced specific volumes of 42.7% and 13.3% (González et al., 2019). Several other bakery products including cookies, biscuits/crackers and muffins have been enriched with edible insects and their effect on the qualities of the products reported. Increased enrichment of the cookies with cricket powder (5, 10 and 15%) resulted in reductions of specific volume 2.1%, 4.1% and 11.3% respectively (Bawa et al., 2020).

In this review, the specific volume of most of the edible insect powder-enriched bakery products especially bread decreased with increasing edible insect powder substitution. The plausible rationale behind this observation includes that chitin fibre from edible insect powder interfere and impairs gluten development during kneading resulting in dough with lower stickiness and resistance and poor gas retention (Struck et al., 2018).

Effects of bakery product enrichment with edible insect powder on its lightness colour

Loaf colour especially that of the crumb impacts on the acceptability of its organoleptic attributes. Factors including ingredient composition such as edible insect powder, baking temperatures and duration affects the overall lightness colour (L*) attributes of bakery products.

Bawa et al. (2020) enriched bread with cricket (*Acheta domesticus*) powder (5, 10 and 15%) and reported that L* values decreased by a magnitude of (4.2, 12.1 and 14.1%) respectively. A general decrease in the lightness colour (L*) values as the cricket powder substitution increased was observed and were all significantly different from the control bread. In a similar study (González et al., 2019) where 5% cricket (*Acheta domesticus*) powder was used in bread enrichment, there was reduction in the L* values of the bread crumb by a magnitude of 9.50% of the enriched bread. The use of 10 and 20% cricket powder (*Gryllus assimilis*) in bread enrichment resulted in decreased L* (7.5% and 14.6%) for the crust and crumb (25.8% and 35.4%) respectively (da Rosa Machado and Thys, 2019). Kowalczewski et al. (2021) evaluated the colour profile of crumb from bread enriched with 2%, 6% and 10% cricket (*Acheta domesticus*) powder. Similar to the earlier observations, the authors observed a dose-response reduction in L* by 16.4, 27.3 and 33.2% for the 2%, 6% and 10% cricket (*Acheta domesticus*) powder-enriched bread respectively. Mafu et al. (2022) recently enriched whole wheat bread with cricket powder (10, 15, 20, 25 and 30%) and reported increase in bread crust L* by magnitude of 6.6, 2.5 and 6.1%. However, there was reduced bread crust L* by a magnitude of 1.7% and 4.9% for the whole wheat bread enriched with 25 and 30% cricket powder respectively. In the case of the bread crumb, L* decreased by magnitudes of 7.9, 12.4, 16.9, 17.2 and 20.6% for the 10, 15, 20, 25 and 30% cricket powder-enriched whole wheat bread. Bread enriched with 5% black soldier fly larvae (*Hermetia illucens*) and yellow mealworm (*Tenebrio molitor*) powder resulted in reduced L* by magnitude of 14% and 8.8% respectively (González et al., 2019). Bread crumb L* values decreased by magnitude of (7.9% and 12.0%) and (5.0% and 4.5%) respectively for the 5% and 10% *Alphitos diasperinus* and *Tenebrio molitor* enriched bread (García-Segovia et al., 2020). Increased enrichment of the cookies with cricket powder (5, 10 and 15%) resulted in reductions of L* of 17.2%, 28.2% and 30.1% respectively (Bawa et al., 2020).

Zielińska et al. (2021) enriched muffins with 2%, 6% and 10% cricket (*Gryllodes sigillatus*) and mealworm (*Tenebrio molitor*) powders. The L* colour of the 2% Mealworm (*Tenebrio molitor*) and cricket (*Gryllodes sigillatus*) powder-enriched bread increased by 5.3% and 1.1% respectively. Muffin enrichment with 6 and 10% Mealworm (*Tenebrio molitor*) and cricket (*Gryllodes sigillatus*) powders reduced the L* colour by (16.3% and 26.7%) and (5.8% and 12.9%). Biro et al. (2020) enriched oat biscuit with cricket powder (5, 10 and 15%) and reported Oat biscuit lightness L* values reduced by 8.3%, 15.4% and 21.1% respectively.

Ardoin et al. (2021) in a recent study enriched crackers with cricket powder in 5%, 10%, 15% and 20% substitutions. Lightness L* colour decreased with increasing cricket substitution. The magnitude decrease were 9.8%, 19.5%, 32.0% and 32.8% respectively for the 5%, 10%, 15%

and 20% cricket powder-enriched crackers. Powder from *Tenebrio molitor* larvae have been used in enriching (2, 6, 10, 15 and 20%) crackers with the authors reporting a general decrease in the lightness colour (L*) of in magnitude ranging from 3.1% −38.5% (Djouadi et al., 2022).

Cookies enriched with crickets (*Acheta domesticus*) also recorded a 5.9%, 10.4% and 15.9% magnitude reduction for L* for the 5%, 10% and 15% formulations respectively (Aleman et al., 2022). In a study by Awobusuyi et al. (2020) that enriched cookies with cricket powder, the authors reported a magnitude decrease of 2.3, 5.9 and 12.9% respectively for L* for the for the 5%, 10% and 15% cricket-enriched cookies respectively. A study by Sriprablom et al. (2022) reported a decrease for the L* (Sriprablom et al., 2022). Ortolá et al. (2022) enriched biscuits with powder from *Tenebrio molitor* and *Alphitobius diaperinus* powders (0, 13, 17, 20, and 25%). The L* decreased by magnitude in the range of 7.7–23.1%. Xie et al. (2022) enriched biscuits with mealworm powders at (5, 10, 15 and 20%) substitution. The lightness decreased in magnitude by 21.7, 26.7, 35.5 and 37.9% respectively for the 5, 10, 15 and 20% mealworm powder-enriched biscuits.

In this review, there was a general decrease in the lightness colour of the bakery products as the edible insect powder substitution increased. This could be attributed to the increased Maillard reaction as a result of the reaction between bioactive compounds and biomolecules including protein and carbohydrate from the edible insect powder which are released during baking (Ribas-Agusti et al., 2017).

Effects of bakery product enrichment with edible insect powder on textural attributes

The textural attributes of bakery products include parameters such as hardness and chewiness which are mainly determined using an objective Texture analyser (Amoah et al., 2020). These parameters influence consumers liking of the products. For example, bread with higher hardness could negatively resonate with the sensory perceptions of outcome in older adults with dysphagia and dentition challenges. Consequently, the right substitution level of edible insect powder should be utilised in bakery products formulation to deliver products with appealing textural attributes. The effect of bakery product enrichment with edible insect powder on the hardness and chewiness has been highlighted below.

Bawa et al. (2020) enriched bread with cricket (*Acheta domesticus*) powder (5, 10 and 15%) and reported that hardness and chewiness increased by magnitude of (3.0, 12.7, and 16.5%) and (7.3, 12.0 and 38.0%) respectively for the 5, 10 and 15% cricket-enriched breads respectively compared to their control non-enriched counterparts. However, the hardness and chewiness of the 5% enriched bread was however not significantly different from the control bread. In a similar study (González et al., 2019) where 5% cricket (*Acheta domesticus*) powder was used in bread enrichment, bread hardness and chewiness increased by 18.8% and 14.9% respectively. The use of 10 and 20% cricket powder (*Gryllus assimilis*) in bread enrichment resulted in hardness and chewiness increase by (53.9%, 63.4%) and (46.8% and 57.3%) respectively for the 10% and 20% cricket powder-enriched breads (da Rosa Machado and Thys, 2019). Mafu et al. (2022) enriched whole wheat bread with cricket powder (10, 15, 20, 25 and 30%) and reported that hardness and chewiness increased by a magnitude of (5.5, 4.6, 29.1, 42.3 and 46.3%) and (13.8, 26.2, 30.1, 47.6 and 32.2%) compared to their non-enriched counterpart. Bresciani et al. (2022) enriched cricket powder (at 10%, and 20% levels) with wheat bread and reported increased crumb hardness in the magnitude of 11.8 and 31.8% respectively. Bread enriched with 5% black soldier fly larvae (*Hermetia illucens*) and yellow mealworm (*Tenebrio molitor*) powder resulted increased hardness by magnitude of (88.6% and 10.5%) and chewiness (82.2% and 1.9%) respectively (González et al., 2019). Bread hardness reduced by (18.5% and 10.6%) and (31.8% and 23.8%) respectively for the 5% and 10% *Alphitos diasperinus* and *Tenebrio molitor* powder enriched breads. Similarly, chewiness following enrichment with 5% and 10% *Alphitos diasperinus* and *Tenebrio molitor* powders reduced by (24.6% and 15.5%) and (35.9% and 32.3%) respectively (García-Segovia et al., 2020). Increased enrichment of the cookies with cricket powder (5, 10 and 15%) resulted hardness of the cookies increased by 5.9%, 7.5% and 32.7%. Powder from *Tenebrio molitor* larvae have been used in enriching (2, 6, 10, 15 and 20%) crackers with the authors reporting a general decrease in the hardness by magnitude ranging from 14.3%- 68.8% (Djouadi et al., 2022). Zielińska et al. (2021) enriched muffins with 2%, 6% and 10% cricket (*Gryllodes sigillatus*) and mealworm (*Tenebrio molitor*) powders. Mealworm (*Tenebrio molitor*) powder enrichment with muffins resulted in decreased hardness compared to the control. Hardness reduced by 24.6%, 15.2% and 11.5%. When the cricket powder was used for the enrichment, hardness reduced by 19.0%, 44.2% and 0%. Chewiness reduced by 34.9%, 31.9% and 15.1% for the Mealworm (*Tenebrio molitor*) powder (2, 6 and 10%)-enriched muffins compared to the control. Cricket-enriched muffins had chewiness reduced by 29.9% and 42.5% for the 2 and 6% enriched muffins but the 10% enriched muffins increased chewiness by 3.9%. Biro et al. (2020) enriched oat biscuit with cricket powder (5, 10 and 15%) and reported increased hardness as the enrichment increased compared to the control biscuit. This trend was similarly observed for the cricket-enriched breads. Hardness of the cricket-enriched oat biscuit increased by 2.7%, 13.4% and 12.8% respectively.

Ardoin et al. (2021) in a recent study enriched crackers with cricket powder in 5%, 10%, 15% and 20% substitutions. The authors expectedly reported increasing cracker hardness as the level of cricket powder substitution increased. Hardness increased by 20.2%, 21.6%, 4% and 43.0% for the 5%, 10%, 15% and 20% cricket powder-enriched crackers.

Cookies enriched with crickets (*Acheta domesticus*) also recorded a 5.9%, 10.4% and 15.9%. For hardness, this study also reported a magnitude reduction of 27.7%, 53.5% and 74.8% for the 5%, 10% and 15% formulations respectively (Aleman et al., 2022). A study by Awobusuyi et al. (2020) reported a magnitude decrease of 19.1%, 12.8% and 11.7% for the 5%, 10% and 15% cricket-enriched cookies respectively. A study by Sriprablom et al. (2022) reported an increase in hardness for the substitution of the two insects (*Tenebrio molitor* and *Zophobas atratus*) (Sriprablom et al., 2022). Akullo et al. (2018) studied the crunchiness of winged termites (*Macrotermes bellicosus*) insect powder incorporated into crackers. The authors recorded a 10.5% magnitude decrease for crunchiness (Akullo et al., 2018).

In another study that studied the individual effects of incorporating 15% grasshopper (*Locusta migratoria*) and 15% mealworm (*Tenebrio molitor*) into muffins, it was observed that, hardness recorded a magnitude decrease of 35.04% for the mealworm substitution and 38.21% for the grasshopper substitution respectively (Çabuk, 2021). Zielińska et al., 2021, in their recent study determined the chemical composition, physical parameters, sensory acceptance, and biological properties of muffins enriched with different levels of cricket (*Gryllodes sigillatus*) and mealworm (*Tenebrio molitor*) powders. The formulations were 2%, 6% and 10% for each insect. They recorded a decrease in hardness for the 6% and 10% substitutions as compared to the control for both insect-enriched muffins. The 6% substitution recorded a magnitude change of 16.29% for hardness whiles the 10% substitution recorded a magnitude change of 26.7% for mealworm. The cricket also a magnitude decrease of 6.8% and 13.9% for the 6% and 10% substitutions respectively (Zielińska et al., 2021).

Ortolá et al. (2022) enriched biscuits with powder from *Tenebrio molitor* and *Alphitobius diaperinus* powders (0, 13, 17, 20, and 25%). Biscuits hardness increased with increased substitution in a magnitude range from 32.8 to 51.3% except for the 25% *Alphitobius diaperinus* powder which recorded no change in hardness (Ortola, Martinez-Catala, Yuste Del Carmen, and Castello, 2022). Xie et al. (2022) enriched biscuits with mealworm powders at (5, 10, 15 and 20%) substitution. Hardness increased by 6.1%, 9.4% and 5.3% except the 20% mealworm powder-enriched biscuits, which recorded reduced hardness by magnitude of 23.01%. Chewiness increased by 28.2%, 35.5% and 38.5% except for the 20% mealworm powder-enriched cookie, which recorded a decreased chewiness by magnitude of 16.0%.

In this review, there was a general increase in hardness of most of the baked products especially bread when enrichment was particularly done with cricket powders. Interestingly, a contrary observation was made when enrichment was carried out using edible insect powder from mealworms. This highlight the point that the nature of the insect imparts on the functionality of the dough and the finished baked products. The rationale for the observed phenomenon could be attributed to the fact that cricket and locust contributed higher magnitude increase in fibre content (chitin) to their enriched bakery products, which affects the gluten network dough in the dough compared to the mealworm powder. Also, the relatively lower hardness associated with the mealworm enriched products could be attributed to the fact that it contained several hydrophilic amino acids that have good water retention property in the dough matrix (Wouters et al., 2016).

Consumer perceptions and sensory properties and purchase intent of insect-enriched bakery products

Consumers demand nutrient-dense baked foods that looks and tastes good but the healthiness of the ingredients and nutrition profile as well as food origin and environmental impact also influence purchase (Wilkinson et al., 2018). Several studies (Alemu et al., 2017; Herbert and Beacom, 2021; Orkusz et al., 2020; Wilkinson et al., 2018) that investigated perceptions of consumers regarding the consumption of edible insects revealed that food neophobia associated with insect consumption could be reduced if the edible insect is processed into powder and incorporated into bakery products.

The sensory attributes of baked products impacts on the liking and purchasing intent of consumers. Powders from *Acheta domesticus, Gryllus assimilis, Hermetia illucens, Locusta migratoria, Tenebrio molitor* and *Alphitobus diasperinus* have been added to bread and other bakery products (Table 1) (Althwab et al., 2021; Bawa et al., 2020; Gantner et al., 2022; Garcia-Segovia et al., 2020; Mafu et al., 2022; Osimani et al., 2018). Bread enriched with *Acheta domesticus* powder (5%, 10%, and 15%) had increased liking for its taste and appearance up to 10% as there was no significant difference between the bread and its "control" unsubstituted counterpart. The overall acceptability of the control bread and the enriched breads up to 10% substituted was not different (Bawa et al., 2020). In terms of sensory, there was no difference in the overall liking of the control and the 10% cricket powder-enriched bread (Mafu et al., 2022). The plausible rationale behind the varying perceptions amongst the panellists could be due to the attributed to the fact that even though edible insect powder enrichment synergistically could enhance the organoleptic appeal of the bread, at generally higher substitution levels, its fibre from chitin could impair techno-functional properties of the dough and subsequently the baked product (Struck et al., 2018). This could adversely affect the organoleptic appeal of the baked product to the consumer. Thus, food product developers should always ensure a balance between using the right insect substitution levels to obtain optimum organoleptic appeal to consumers.

The incorporation of *Locusta migratoria* powder (1–5%) into bread resulted in a significant increase in the liking of taste of the enriched bread as the substitution increased (Althwab et al., 2021). The opposite was observed for the appearance of the enriched breads. Bread enriched with *Tenebrio molitor* powder (5 and 10%) had a significantly higher liking for its taste and appearance compared to its control counterpart (García-Segovia et al., 2020). The 10% enriched bread recorded a significantly higher overall acceptability compared to the control. In that same study, the authors enriched bread with *Alphitobus diasperinus* (5 and 10%) and reported significantly higher liking for its appearance and taste for the 10% enriched bread compared to the control. The overall acceptability of all the enriched breads were however significantly lower compared to its control.

Edible insect powders from cricket and grasshopper have been incorporated into cookies, biscuit and muffin. Bawa et al. (2020) enriched cookies with cricket powder (5, 10 and 15%). The authors reported that there was no difference in the overall liking of the enriched cookies (5 and 10%) compared to their control counterpart. However, the 10% enriched cookie recorded a significantly lower ranking of its taste attributes by the panellist compared to the control non-enriched counterpart. Castro Delgado et al. (2020), in a similar study, reformulated recipes for use in regular chocolate-chip cookies by substituting 15% and 30% of wheat flour with the same quantity of cricket powder. The authors found that for the chocolate cookies there was increased liking of the appearance, taste and overall liking when 15% cricket powder was substituted. The appealing organoleptic attributes of the insect-enriched cookies could be related to the aromatic and flavour compounds produced by non-enzymatic browning and the increased protein content of the cricket-enriched cookies.

Four different studies enriched cookies with different formulations of cricket and mealworm powders (Ardoin et al., 2021; Biro et al., 2020; Djouadi et al., 2022; Smarzynski et al., 2021). Powder (0%, 5%, 10%, 15%, and 20%) was used in biscuit enrichment (Ardoin et al., 2021). The biscuit generally recorded a significantly lower liking for its colour as enrichment increased compared to its control. However, the 5% enriched biscuit was not different from the control in terms of its overall liking. Smarzyński et al. (2021) enriched biscuit with cricket powder (2, 6 and 10%) and reported decreased liking for its appearance, taste and overall liking as the substitution increased. The 2% formulation was not significantly different in terms of its overall acceptability compared to the control. This pragmatically means that, the 2% cricket-enriched biscuit could compete favourably with commercially produced control types, which may be present on the market. Biro et al. (2020), in a similar study involving cricket powder (5, 10 and 15%) enrichment with biscuit, reported that there was a general decrease in the liking of the colour and overall liking of the enriched biscuits. Interestingly, the 5% enriched biscuits was significantly not different from its control regarding the liking of its colour and overall liking. Crackers enriched with powder from *Tenebrio molitor* larvae (6 and 15%) recorded significantly lower overall liking compared to the control sample. However, that notwithstanding, 70% of the participants indicated that they will be happy to purchase the 6% *Tenebrio molitor* larvae powder-enriched crackers (Djouadi et al., 2022). This could be attributed to the fact that the 15% enrichment resulted in prominent changes in the organoleptic appeal of the *Tenebrio molitor* larvae powder-enriched crackers but not that of the 5% enriched-crackers.

Similar to studies revised above, in a study where 15% mealworm and grasshopper powder was incorporated into muffins, there was a general dislike for the appearance but not the taste (Çabuk, 2021). The 15% grasshopper muffin was prominently disliked for its overall acceptability but the mealworm enriched muffins were liked more than the control. In another study examining 0, 5, 10, 15 and 20% caterpillar powder-enriched wheat muffins only the overall liking of the 5% enriched muffins was not significantly less than control (Ouma et al., 2022). There are trade-offs in improvements in nutritional density and whether the food will have an acceptable appearance and taste and will be eaten.

Perspective and future directions

In this review, it was realised that most studies failed to compare the effect of different pre-treatment method on the nutritional properties of the powder obtained from the edible insect and their larvae. Future research should thus focus on investigating the effect of using different initial processing methods (such as freeze-drying, blanching, oven/microwave drying and roasting) on the functional properties, water activity, protein content and digestibility and the amino acid profile of similar edible insects and their larvae. This potentially will provide insight into the nutritional properties of the powder. It was also observed that concerning the use of the powder for bakery product enrichment, several of the powders obtained from the edible insect and their larvae processing were commercially sourced. Factors regarding trade secret restricted access to full information regarding the processing parameters employed. This subsequently results in establishing poor associations between the effect of processing method employed on the edible insect and its effects on the nutritional properties of the edible insect powder. Lastly, several of the edible insect powder-enriched baked products developed did not have the sensory profile determined and in several instances, the overall acceptability was not determined subjectively. Future studies should ensure that the overall acceptability has been determined as that could give insight into food neophobic tendencies. The effect of pre-treatment methods on the water activity and storability of the edible insect powders should be investigated. Also of interest would be the prevention of oxidation of lipids in stored insect powders. Other gaps that were identified include the lack of information on the feed fed to the insects and the cost involved in the production of the edible insect powders.

Conclusion

The most commonly researched edible insects were crickets, grasshoppers and palm weevil larvae. Commonly used treatment methods for insect processing include freeze drying, oven and microwave drying, blanching and roasting which all involve removal of water and reduction of water activity. The incorporation of insects in bakery products improved the nutritional composition especially the proteins and fat. Bread was the most commonly reported baked product that was enriched with insects. Generally, addition of 10% for bread and up to 5% for cookies/biscuits/muffins was considered acceptable by consumers who were mainly from developed countries. New areas of research should focus on the comparison and costs of harvesting and the initial processing methods on the nutritional properties on the same insect type. The prospects of utilising other underutilised insects for bakery products development for different markets and food sovereignty in Africa should also be explored.

Ethical statement

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Declaration of Competing Interest

The authors declare no conflict of statement.

Data availability

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

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