

Original article

Chemical composition, thermal profile and functional properties of grasshopper (*Sphenarium purpurascens* Ch.), cockroach (*Nauphoeta cinerea*) flours and their mixtures

José Manuel Juárez-Barrientos,¹ Jesús Rodríguez-Miranda,^{2*} Emyr Saúl Peña-Marín,³ Berenice Chareo-Benítez,¹ Juan Pablo Alcántar-Vázquez,¹ Emmanuel de Jesús Ramírez-Rivera,⁴ Alejandro Aparicio-Saguilán⁵ & Adriano Gomes da Cruz⁶

1 Instituto de Agroingeniería, Universidad del Papaloapan Campus Loma Bonita, Av. Ferrocarril S/N, Cd. Universitaria, Loma Bonita, Oax C.P. 68400, Mexico

2 Departamento de Ingeniería Química y Bioquímica, Tecnológico Nacional de México/Instituto Tecnológico de Tuxtepec, Tuxtepec, Oaxaca 68350, Mexico

3 Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California (UABC), Ensenada C.P. 21100 Baja California, Mexico

4 Tecnológico Nacional de México /Campus Zongolica, Km. 4 Carretera S/N Tepetitlanapa, 95005 Zongolica, Veracruz, Mexico

5 Instituto de Biotecnología, Universidad del Papaloapan Campus Tuxtepec, Circuito Central 200, Parque Industrial, San Juan Bautista Tuxtepec, Oax C.P. 68301, Mexico

6 Department of Food, Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ), Rio de Janeiro, Rio de Janeiro, Brazil

(Received 19 April 2024; Accepted in revised form 24 June 2024)

Summary The use of insects as food is a hot topic today and the obtaining and comprehensive characterisation of insect meals is relevant since any scientific information represents progress towards the real use of these ‘new foods’. Therefore, the objective of this study was to evaluate the chemical composition of flours obtained from *Sphenarium purpurascens* Ch. and *Nauphoeta cinerea*, identify the main components and know their functional properties and thermal profile in flours and their mixtures to establish their potential applications as ingredients in the food and feed industry. The results revealed that flours and their mixtures can be used to increase the nutritional value of foods, especially thanks to their high protein content (35%–38%); in addition, their potential uses are numerous and range from baking, snacks, drinks and meat substitutes thanks to their techno-functional and thermal properties. Regarding the thermal profile, this study presents results above 250 °C that have not been reported before for these insects and relate to the decomposition of acetylglucosamine units and the evaporation of low molecular weight volatile products that have not been reported for the flours of these insects. This study represents an advance in terms of the use of insects, pending attention to issues such as innocuity.

Keywords insect flours, *Nauphoeta cinerea*, novel foods, *Sphenarium purpurascens* Ch.

Introduction

Currently, scientists and technologists are making numerous efforts to achieve the goal called ‘zero hunger’; however, until 2021 there were still 828 million people in the world in conditions of malnutrition and since the COVID-19 pandemic, 150 million more undernourished people were added (FAO, 2022; Vale-Hagan *et al.*, 2023). Associated with the above, intensive animal production systems have a high

demand for raw materials to obtain feed for various agricultural branches (Bimbo, 2012). This pressure represents a burden on the environment by generating large amounts of greenhouse gases (Kowalski *et al.*, 2022). This poses a complex problem, since, if there is no widespread awareness, a significant deficit is expected not only in food for human consumption but also in feed. Therefore, a more reliable, sustainable and resistant protein production system is required to address the side effects of the current crisis that global food security is experiencing (Vale-Hagan *et al.*, 2023), but in addition to producing new sources of nutrients, it is important to learn how to use them (Kowalski

*Correspondent: E-mail: jesrodmir@gmail.com, jesus.rm@tuxtepec.tecnm.mx

et al., 2022), for which it is necessary to know its composition, characteristics and behaviour.

In the fields of food, nutrition and environmental sciences, edible insects have become a hot topic during the last decade. Several studies have shown that insects could play a role in the food supply chain, either as feed or food, due to the various advantages that could lead to a more sustainable food system (Benes *et al.*, 2022; Vale-Hagan *et al.*, 2023). Studies carried out on the nutritional composition of insects report a high content of energy, fat, fibre, minerals, vitamins and mainly proteins with levels like those of fish and meat (Veldkamp *et al.*, 2012). In addition, insects have short life cycles, do not require large spaces to be cultivated and have a low water requirement and their diet can consist of low-cost waste (Van Huis *et al.*, 2013; Gahukar, 2016).

The use of insects, whether for human consumption or to produce animal feed, is not widespread in Western countries as consumers tend to reject insects and insect-based food products (Nowak *et al.*, 2016; Benes *et al.*, 2022) but it has been found that rejection is reduced if the insects are used in a form in which they are not directly perceived by the consumer, for example in the form of extracts, concentrates or flour. Insect flours are characterised by a significantly higher content of proteins, ash, fats, and total and insoluble dietary fibre compared to other flours such as wheat flour, and their use contributes to increasing the nutritional value of foods by being used as an additive (Kowalski *et al.*, 2022). However, edible insects are considered 'novel foods' according to Regulation (EU) 2015/2283 and to occupy a place on the market they require being included in the Union list of authorised novel foods.

Currently, there are three safe species according to the European Food Safety Authority (EFSA), which are the yellow mealworm larvae (*Tenebrio molitor*), migratory locust (*Locusta migratoria* L.) and house cricket (*Acheta domestica* L.). Despite the legal difficulties, it is important to highlight that the legislation does not hinder the research or development of experimental products with insects. On the contrary, the information generated regarding their characteristics, composition and nutritional and environmental benefits generates that the use of insects gains more space in the food and feed sector (Benes *et al.*, 2022). Therefore, the objective of the present study was to evaluate the chemical composition of flours obtained from two species of insects: grasshopper (*Sphenarium purpurascens* Ch.) and cockroach (*Nauphoeta cinerea*), identify the main components and know their functional properties and thermal profile in flours and their mixtures to establish their potential applications as ingredients in the food and feed industry.

Materials and methods

Obtaining insect flour

Grasshopper flour (*Sphenarium purpurascens* Ch.) was obtained from insects purchased in the market of the city of Oaxaca de Juárez, Mexico, from a wild collection. The insects were frozen and transferred to the laboratory of the Universidad del Papaloapan. They were subsequently washed, drained (three washing cycles to eliminate impurities related to the collection) and placed on aluminium trays to be dried at 55 °C for 48 h in a drying oven (FA-65B, Ecoshell, PHARR, TX, USA). They were subsequently ground in a grinding mill (KCG0702ER, KitchenAid, Benton Harbor, MI, USA) and sieved to 250 µM, and the resulting flour was stored in hermetically sealed bags in the freezer until use.

Cockroach flour (*Nauphoeta cinerea*) was obtained from organisms cultured at the Juárez Autonomous University of Tabasco. For the breeding and fattening of the cockroaches, a 70-L plastic box without a lid was used, with conditioned cardboard shelters. 50 males and 50 females were used for the beginning of breeding. Three cm of Vaseline was placed around the entire perimeter of the upper part of the plastic box to prevent the escape of the insects. The cockroaches were fed to satiety using a diet formulated with 30% protein and 9% lipids. Water was provided constantly in a 200-mL plastic container with marbles, to increase the surface area and prevent the nymphs from drowning. Adult cockroaches (3 months) were harvested, frozen (−20 °C), dried at 60 °C for 12 h in an oven (FA-65B, Ecoshell, USA), ground in a grinding mill (KCG0702ER, KitchenAid, USA), sieved at 250 µM and stored in sealed freezer bags until use.

Chemical composition

The following parameters of insect flour were analysed: ash content (AOAC 923.03) and protein content (AOAC 950.36). The protein content was calculated by applying a conversion factor of 5.60 (Janssen *et al.*, 2017); fat content (AOAC 935.38) and water content (AOAC 925.10). The carbohydrate content was calculated by difference. Analyses were performed in triplicate.

Functional properties

The grasshopper flour (*Sphenarium purpurascens* Ch.), cockroach flour (*Nauphoeta cinerea*) and mixture (50:50) were analysed. Water absorption capacity (WAC) and water solubility capacity (WSC): the WAC and WSC were determined according to the methodology reported by Rodríguez-Miranda *et al.* (2012). Oil absorption capacity (OAC): the OAC

was determined according to the methodology reported by Beuchat (1977). Swelling power (SP): the SP was determined according to Sathe *et al.* (1982). Emulsifying capacity (EC): the EC was determined according to the methodology reported by Rodríguez-Miranda *et al.* (2012). Foaming capacity (FC) was performed according to Bencini (1986), and apparent density (DA) was performed according to Juárez-Barrientos *et al.* (2017).

Thermal profile

The grasshopper flour (*Sphenarium purpurascens* Ch.), cockroach flour (*Nauphoeta cinerea*) and mixture (50:50) were analysed. The thermal properties of the flours were determined using a differential scanning calorimeter (DSC Q 2000, TA Instruments, 109 Lukens Drive, New Castle, DE 19720, USA) calibrated with indium ($T_0 = 156.4$ °C, $DH = 28.4$ J/g). The cell was purged with nitrogen gas (99.99% purity) and calibrated for its baseline using a standard of pure indium. Samples of 2 mg were placed on hermetically sealed aluminium pans (40- μ L) and heated from 25 °C up to 400 °C with a heating rate of 5 °C/min. Curves of heat flow (Wg^{-1}) versus temperature were obtained and processed by TA Instruments Universal Analysis software, and the curves were analysed for the peak temperature (°C) and enthalpy (ΔH J/g).

Data analysis

Statistical analysis was carried out using Statistica 13.0 (StatSoft, Kraków, Poland). A one-way ANOVA was used at the significance level $P \leq 0.05$. When the Levene test indicated significant differences, a post-hoc least significant difference (LSD) Fisher's test was performed. The results were presented as mean \pm standard deviation.

Results and discussion

Chemical composition

The proximal chemical analysis revealed that the flours have a percentage of proteins in a range of 35.92% to 38.24%, with cockroach flour having a higher content compared to grasshopper; however, the difference was not statistically significant ($P > 0.05$). Grasshopper flour presented a significantly higher percentage ($P < 0.05$) of ash, and no differences were observed in the content of lipids and carbohydrates, as shown in Table 1. It is interesting to note that the protein content found in this study for both insects is lower than that reported in studies published by other authors who present values from 46.5 ± 0.8 to $75.56 \pm 0.8\%$ for grasshopper (*S. purpurascens* Ch.)

Table 1 Chemical composition of grasshopper (*S. purpurascens*) and cockroach (*N. cinerea*) flours.

Chemical composition (%)	Sample	
	<i>S. purpurascens</i> flour	<i>N. cinerea</i> flour
Protein	35.92 \pm 2.34 ^a	38.24 \pm 1.31 ^a
Fats	7.98 \pm 1.20 ^a	8.56 \pm 1.43 ^a
Ash	12.35 \pm 0.01 ^a	5.79 \pm 0.10 ^b
Carbohydrates	43.74 \pm 3.31 ^a	47.41 \pm 0.45 ^a

Means \pm standard deviation, different superscripts in the same row indicate significant differences ($P < 0.05$).

(Ramos-Elorduy *et al.*, 1997; Melo-Ruíz *et al.*, 2015; Torruco-Uco *et al.*, 2019; Contreras *et al.*, 2020; Ibarra-Herrera *et al.*, 2020; Ganguly & Moreno, 2021; Reyes-Herrera *et al.*, 2022; Téllez-Morales *et al.*, 2022; Rivas-Vela *et al.*, 2023) and 63.59 ± 0.46 for cinereous cockroach (*N. cinerea*) (de Oliveira *et al.*, 2017). These differences in protein content within the same species can be explained in part by factors such as geographic area (Rivas-Vela *et al.*, 2023) seasonality (Ssepuyua *et al.*, 2019), sex, environment (temperature, day length, humidity, light intensity), stage of life and diet (Ibarra-Herrera *et al.*, 2020). In this regard, Reyes-Herrera *et al.* (2022) reported this effect and established that a diet richer in protein is not reflected in a higher percentage of it in the chemical composition of the insect. On the other hand, the variability in the results reported and those found in this study may be related to an extrinsic factor, such as the method used to estimate protein content. In this sense, it is important to highlight that insects have a significant amount of chitin, which is present in the exoskeleton and contains nitrogen. Failure to consider the nitrogen content of chitin may lead to an overestimation of protein percentage (Ibarra-Herrera *et al.*, 2020) if the Kjeldahl method is used since this method determines the total nitrogen content and uses a conversion factor to estimate the protein content. In this regard, in the majority of studies (70%) where protein content is reported, a conversion factor of 6.25 is used (generally applied for meat products or generic foods) for both *S. purpurascens* (Ganguly & Moreno, 2021; Rivas-Vela *et al.*, 2023) and *N. cinerea* (de Oliveira *et al.*, 2017). In 30% of previously published studies, a factor of 5.60 or 5.33 is applied (Contreras *et al.*, 2020; Ibarra-Herrera *et al.*, 2020; Reyes-Herrera *et al.*, 2022). The factor of 5.60 used in this study was established by Janssen *et al.* (2017), who recommend using 5.60 for adult insects and 4.76 for larvae, intending to avoid overestimation of the real protein content in edible insects.

Although the protein values found in this study were lower than those reported by other authors, the

Table 2 Functional properties of grasshopper (*S. purpurascens*) and cockroach (*N. cinerea*) flours and their mixtures.

Property	<i>S. purpurascens</i> flour	Mixture	<i>N. cinerea</i> flour
Water absorption capacity (WAC) (g/g)	10.10 ± 0.37 ^a	9.45 ± 0.90 ^a	9.93 ± 0.11 ^a
Water solubility index (WSI) (%)	16.78 ± 0.35 ^{ab}	15.80 ± 0.78 ^a	17.89 ± 0.83 ^b
Oil absorption capacity (OAC) (oil g/g)	9.29 ± 0.33 ^a	9.02 ± 0.41 ^a	8.89 ± 0.44 ^a
Emulsifying capacity (EC) (%)	1.71 ± 0.54 ^a	1.74 ± 0.57 ^a	4.55 ± 0.66 ^b
Apparent density (AD) (g/cm ³)	0.65 ± 0.01 ^b	0.74 ± 0.01 ^a	0.56 ± 0.01 ^a
Foaming capacity (FC) (%)	5.63 ± 0.47 ^a	8.55 ± 0.03 ^b	10.72 ± 0.17 ^c

Means ± standard deviation, different superscripts in the same row indicate significant differences ($P < 0.05$).

protein contribution is still considerable and the addition, even in small proportions, of these insect flours mixed with other flours conventionally used to obtain foods and feeds can increase its nutritional value considerably (de Oliveira *et al.*, 2017; Contreras *et al.*, 2020). Another important aspect of grasshopper and cockroach flours is the low-fat content (7.98%–8.56%), which makes them a practical raw material that is easy to process, when compared to flours that are difficult to process such as mealworm flour (*Tenebrio molitor*) and black soldier fly (*Hermetia illucens*) with a content of 20.0% and 21.1% fat, respectively (Bußler *et al.*, 2016).

Functional properties

The samples do not present significant differences ($P < 0.05$) between the samples in WAC and OAC, with an average value of 9.83 and 9.07 g/g, respectively (Table 2). This is because no significant differences were found in the protein and carbohydrate content ($P < 0.05$) since the composition of the protein will affect the water and lipid retention functionality of the samples (Gravel & Doyen, 2020; López-Gómez *et al.*, 2024). Both properties are crucial for texture in foods and are considered essential functionalities for food applications, especially for the development of food texture (Mishyna *et al.*, 2021; López-Gómez *et al.*, 2024). Therefore, a high WAC is related to the presence of a high proportion of soluble proteins and a greater exposure of polar amino acids, appropriate for soups, bakery or pasta (de Paiva Gouvêa *et al.*, 2023; López-Gómez *et al.*, 2024). On the contrary, a high OAC is probably due to the availability of non-polar amino acids or a high lipid content, desirable in meat emulsions and dairy products (Ghribi *et al.*, 2015; López-Gómez *et al.*, 2024).

These results are superior to those reported by Torruco-Uco *et al.* (2019) and Villaseñor *et al.* (2022b) in *S. purpurascens* in WAC (1.75–2.75 g/g) and OAC (2–2.79 g/g), Haber *et al.* (2019) in *Schistocerca gregaria* (WAC: 1.37 g/g and OAC: 1.21 g/g) and Aguilera *et al.* (2021) in *Acheta domesticus* (WAC:

3.20 g/g and OAC: 2.19 g/g), as well as what was reported in WAC in other insects such as yellow worm (*T. molitor*, protein isolate (3.95 g/g) and flour (1.29 g/g)) and the desert locust (*Schistocerca gregaria*) protein isolates and flours (2.18 and 2.31 g/g, respectively) (Zielińska *et al.*, 2018; Villaseñor *et al.*, 2022a).

The maximum WSI was found in the *N. cinerea* flour at 17.89%, with significant differences ($P < 0.05$) being found with the mixture where the lowest value was found at 15.80% (Table 2). These differences may be because solubility depends on the amino acid composition and quaternary structure of the proteins, as well as on pH and temperature. Grossmann & Weiss (2021) mention that many insect protein fractions have low solubility, and some specific fractions may have solubility characteristics suitable for use in food applications. Therefore, a high solubility would be suitable for formulating beverages with properties like those of milk (de Paiva Gouvêa *et al.*, 2023). These results are similar to those reported by Torruco-Uco *et al.* (2019) from 12.33% to 17.13%.

N. cinerea flour showed the highest values of EC (4.55%) and FC (10.72%) (Table 2). In EC, no significant differences ($p < 0.05$) were found between the mixture and the *S. purpurascens* flour, while in FC, significant differences were found between the samples ($P < 0.05$) (Table 2). These differences are because these properties depend on the amphiphilic characteristics of the protein present in the samples, which will determine the interactions at the oil–water and air–water interfaces (Mishyna *et al.*, 2021; López-Gómez *et al.*, 2024), and in this case, the *N. cinerea* samples could contain a greater number of proteins with amphiphilic characteristics. A higher EC is desirable to produce semi-solid foods such as meat analogues, in the format of sausages or hamburgers (Talens *et al.*, 2022; de Paiva Gouvêa *et al.*, 2023; López-Gómez *et al.*, 2024). Gravel & Doyen (2020) found that insect proteins are more suitable for stabilising oil–water interfaces, being at the same EC level as other proteins, such as whey and soy proteins. However, Grossmann & Weiss (2021) and Gravel &

Doyen (2020) mention that insect proteins have low foaming capacity and low foam stability.

A significantly ($P < 0.05$) higher value of AD (0.74 g/cm^3) was found in the mixture (Table 2). The AD is the property that relates the dough to the volume occupied by the flour, including the volume of the particles and the spaces available between them, important in determining the packaging or packaging and handling system of the material, which is why it seeks to obtain low AD values so that the products do not lose volume during storage (Torruco-Uco *et al.*, 2019). The value found is higher than that reported in *S. purpurascens* by Torruco-Uco *et al.* (2019) 0.51 g/cm^3 and in *Acheta domesticus* by Aguilera *et al.* (2021) 0.31 g/cm^3 .

In SP, no significant differences ($P > 0.05$) were found between the samples (Fig. 1) with increasing temperature (70–90 °C), while at 60 °C, significant differences ($P < 0.05$) were found between the *S. purpurascens* and *N. cinerea* samples. This is likely due to protein–chitin interactions in the swelling layer during heating, as well as protein–lipid interactions from two insect samples. However, these results are superior to those reported by Torruco-Uco *et al.* (2019).

Thermal profile

In the thermal analysis of the flours (grasshopper, cockroach and the mixture [50:50]), three zones are identified with five endothermic events. In the first zone, two peaks (peak 1 and peak 2) were identified between 46 and 147 °C. The second zone presented a

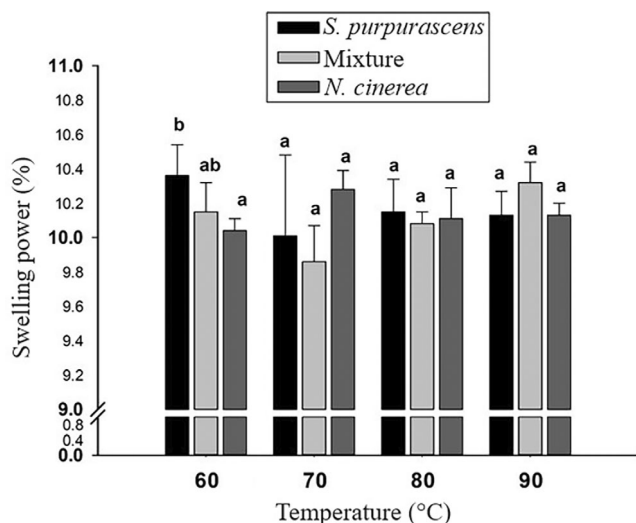


Figure 1 Swelling power of grasshopper (*S. purpurascens*) and cockroach (*N. cinerea*) flours and their mixtures.

peak (peak 3) between 210 and 238 °C. Finally, the third zone presented two peaks (peak 4 and peak 5) between 299 and 320 °C (Fig. 2a). In Figure 2b, two endothermic peaks are seen for the cockroach flour and the mixture and only one endothermic peak for the grasshopper flour. The first peak of cockroach flours and the mixture, according to the temperature at which the event is observed, corresponds to the fusion of lipids, which according to Knothe & Dunn (2009) can occur in the range of 9.49–41.43 °C for individual fatty acids, but the melting temperature can be raised, depending on the interaction of the lipids in the food matrix. The second endothermic peak corresponds to protein denaturation. In the case of the mixture, it is presented at a temperature of 106.45 °C, and for the cockroach flour, it is located at 110.16 °C. These denaturation temperatures are above those reported by Contreras *et al.* (2020) (81 °C) and Baigts-Allende *et al.* (2021) (76 °C for wasp larvae, 82 °C for jumil and 94 °C for black soldier fly larvae). However, the protein denaturation temperature depends on the type of proteins present in insects since when there are highly stable protein conformations, the denaturation temperature increases and there may even be extended peaks up to 130 °C that are related to a second protein fraction (Baigts-Allende *et al.*, 2021). In the case of grasshopper flour, there is only one endothermic peak at 147.12 °C, which is similar to what was found by Torruco-Uco *et al.* (2019) who report a single peak in an interval of 131.01–163.07 °C and different from what was reported by Contreras *et al.* (2020) who found two peaks, one at 72.2 °C, related to protein denaturation, and the second at 103.15 °C, related to the formation of the protein–lipid complex. In this study, the endothermic peak at 147.12 °C in grasshopper flour is attributed to protein denaturation and formation of the protein–lipid complex, which occurs in food matrices during processing (generally due to high temperatures) and depending on the nature of the raw material, will result in different types of interactions that can be hydrogen bonding, electrostatic bonding, covalent bonding, hydrophobic bonding and van der Waals bonding, which determine the stability of the structures and affect the thermal, functional, nutritional properties and some characteristics such as the flavour and texture of the food (Alzagat & Alli, 2002). The difference between the peak found in this study and the two peaks reported by Contreras *et al.* (2020) can be attributed to differences in the composition of insects that result in different intermolecular interactions and different structures in the formation of the protein–lipid complex.

In Figure 2c, only one endothermic peak is seen between 210 and 238 °C for the three flour samples. This peak may be related to the vaporisation of water from the chitin structure since the samples analysed

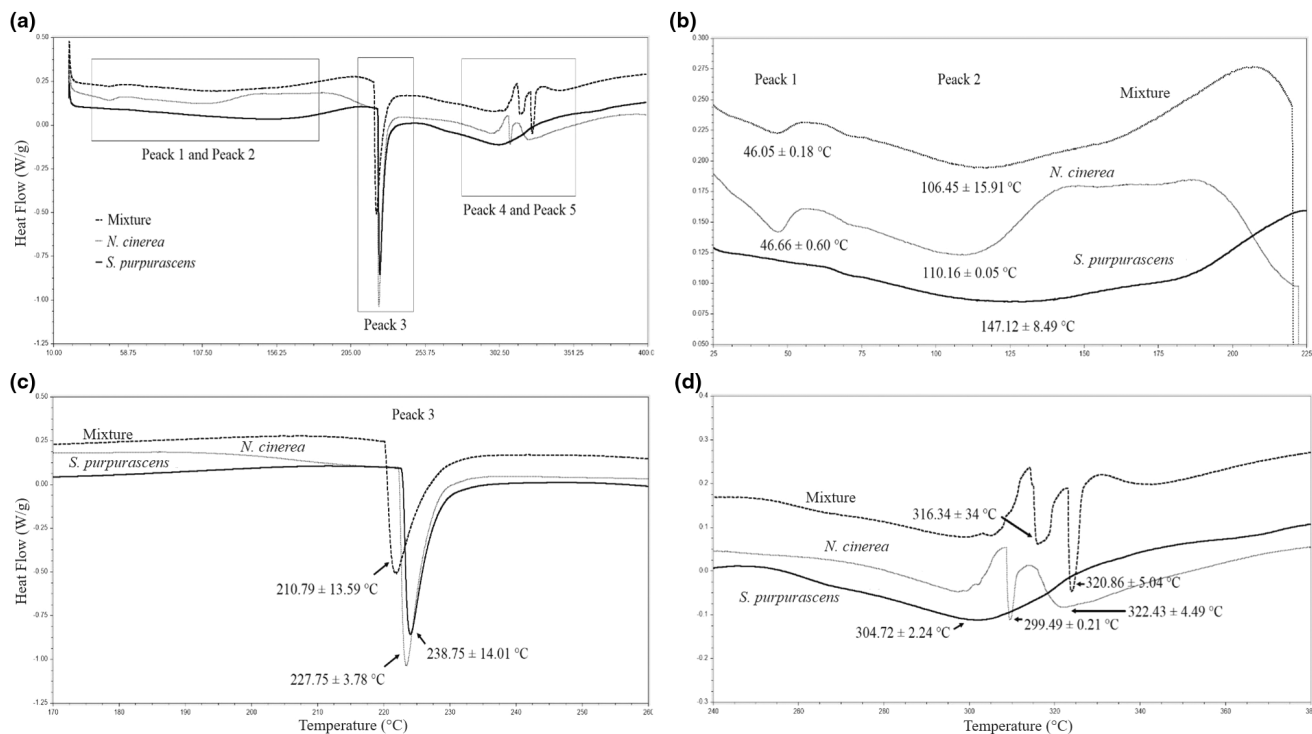


Figure 2 Thermal properties of grasshopper (*S. purpurascens*) and cockroach (*N. cinerea*) flours in a temperature range of (a) 10–400 °C, (b) 25–225 °C, (c) 170–260 °C and (d) 240–380 °C.

are not completely anhydrous since bound water persists and cannot be eliminated in the drying process of obtaining the flours. This peak is located in an area of higher temperature than that reported by Liu *et al.* (2010) who identify the evaporation of water from chitin between 99 and 113 °C, but mention that the peaks can extend up to 162 °C. In this regard, it is important to mention that in the study by Liu *et al.* (2010), samples of purified chitin were analysed, and in the case of this study, the water vaporisation event of chitin could be moved to higher temperatures due to the interaction of this component with other components within the food matrix. Finally, in Figure 2d, two endothermic peaks are observed for the cockroach flour and the mixture and a single peak for the grasshopper flour in the range of 304–322 °C. These peaks are related to the decomposition of acetylglucosamine units and the evaporation of low molecular weight volatile products that form during depolymerisation (Liu *et al.*, 2010) and with some residues of proteins and chitin pigments (Ben Seghir & Benhamza, 2017). It is worth mentioning that the studies reported at temperatures above 250 °C for the thermal behaviour of chitin have been with purified chitin since insects with all their complete components, only analyses from 30 to 180 °C (Torruco-Uco *et al.*, 2019),

30 a 250 °C (Contreras *et al.*, 2020) and de 20 a 180 °C (Baigts-Allende *et al.*, 2021) have been reported, leaving the temperature zone above 250 °C unexplored, in the case of the flour of these whole insects. According to the overall results of the functional and thermal properties, the flour mixtures can be recommended for the preparation of sauces and dressings.

Conclusions

The findings confirm the feasibility of using insect flour as an alternative protein source. The differences observed in terms of the reported values may be multifactorial; however, it is necessary to emphasise the use of the appropriate conversion factor to avoid overestimating the protein content. The thermal profile showed novel information above temperatures previously reported by other authors, in which the understanding of a major component in insects such as chitin is expanded. These results open a whole field to explore the behaviour of chitin in the protein matrix of flours and its effect on the development of new products or the preparation of sauces and dressings. The flours obtained can be added as an ingredient in a wide range of food products to increase their nutritional value and improve physical properties.

However, it is advisable to carry out more safety studies to ensure compliance with international legislation in the future and eventually develop products considering consumer acceptance through sensory analysis.

Acknowledgments

The authors thank the academic Vice-rector of the Universidad del Papaloapan M.C Héctor López Arjona for the facilities provided for the development of the project.

Author contributions

José Manuel Juárez-Barrientos: Conceptualization; investigation; writing – review and editing; formal analysis; supervision; methodology; data curation; validation; software. **Jesús Rodríguez-Miranda:** Writing – review and editing; writing – original draft; supervision; methodology; formal analysis; validation; data curation; software; conceptualization. **Emyr Saúl Peña-Marín:** Writing – review and editing; writing – original draft; methodology; formal analysis. **Berenice Chareo-Benítez:** Writing – original draft; investigation; methodology; data curation. **Juan Pablo Alcántar-Vázquez:** Writing – original draft; writing – review and editing. **Emmanuel de Jesús Ramírez-Rivera:** Writing – original draft; writing – review and editing; formal analysis; data curation; software; validation. **Alejandro Aparicio-Saguilán:** Writing – original draft; writing – review and editing; software; methodology. **Adriano Gomes da Cruz:** Writing – original draft; writing – review and editing; formal analysis; methodology.

Funding information

Funding provided by Consejo Nacional de Ciencia y Tecnología (CONACyT), México, for the support granted through the resources of ‘Ciencia de Frontera 2023’ with the project CF-2023-I-167.

Disclosure of interest

The authors declare that there is no conflict of interest.

Ethical statement

The authors confirm that the study did not involve experimentation on human or animal subjects.

Peer review

The peer review history for this article is available at <https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.17339>.

Data availability

Data will be made available on request.

References

- Aguilera, Y., Pastrana, I., Rebollo-Hernanz, M. *et al.* (2021). Investigating edible insects as a sustainable food source: nutritional value and techno-functional and physiological properties. *Food & Function*, **12**, 6309–6322.
- Alzagat, A.A. & Alli, I. (2002). Protein-lipid interactions in food systems: a review. *International Journal of Food Sciences and Nutrition*, **53**, 249–260.
- Baigts-Allende, D., Doost, A.S., Ramirez-Rodrigues, M. *et al.* (2021). Insect protein concentrates from Mexican edible insects: structural and functional characterization. *LWT*, **152**, 112267.
- Ben Seghir, B. & Benhamza, M.H. (2017). Preparation, optimization and characterization of chitosan polymer from shrimp shells. *Journal of Food Measurement and Characterization*, **11**, 1137–1147.
- Bencini, M.C. (1986). Functional properties of drum-dried chickpea (*Cicer arietinum* L.) flours. *Journal of Food Science*, **51**, 1518–1521.
- Benes, E., Biró, B., Fodor, M. & Gere, A. (2022). Analysis of wheat flour-insect powder mixtures based on their near infrared spectra. *Food Chemistry: X*, **13**, 100266.
- Beuchat, L.R. (1977). Functional and electrophoretic characteristics of succinylated peanut flour protein. *Journal of Agricultural and Food Chemistry*, **25**, 258–261.
- Bimbo, A.P. (2012). Fish meal and oil. In: *The Seafood Industry: Species, Products, Processing, and Safety* (edited by G.L. Ankenman, J. George, J. Flick & E.M. Roy). Pp. 348–373. New Delhi, India: Blackwell Publishing Ltd. <https://doi.org/10.1002/9781118229491.ch26>
- Bubler, S., Rumpold, B.A., Jander, E., Rawel, H.M. & Schlüter, O.K. (2016). Recovery and techno-functionality of flours and proteins from two edible insect species: meal worm (*Tenebrio molitor*) and black soldier fly (*Hermetia illucens*) larvae. *Heliyon*, **12**, e00218.
- Contreras, J.B., Oseguera, T.M.E., Garcia, M.L. *et al.* (2020). Physicochemical study of nixtamalized corn masa and tortillas fortified with “chapulin” (grasshopper, *Sphenarium purpurascens*) flour. *CyTA Journal of Food*, **18**, 527–534.
- FAO, IFAD, UNICEF, WFP, WHO. (2022). The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO. Retrieved from <https://doi.org/10.4060/cc0639en>
- Gahukar, R.T. (2016). Edible insects farming: efficiency and impact on family livelihood, food security, and environment compared with livestock and crops. In: *Insects as Sustainable Food Ingredients* (edited by A.T. Dossey, J.A. Morales-Ramos & M.G. Rojas). Pp. 85–111. New York: Academic Press. <https://doi.org/10.1016/B978-0-12-802856-8.00017-X>
- Ganguly, A. & Moreno, J.M.P. (2021). A preliminary study on the juvenile stages of *Tenebrio molitor* Linnaeus, 1758 (Coleoptera: Tenebrionidae) and *Sphenarium purpurascens* Charpentier, 1842 (Orthoptera: Pyrgomorphidae) as exploitable nutraceutical resources. *International Journal of Tropical Insect Science*, **41**, 2247–2253.
- Ghribi, A.M., Gafsi, I.M., Blecker, C., Danthine, S., Attia, H. & Besbes, S. (2015). Effect of drying methods on physico-chemical and functional properties of chickpea protein concentrates. *Journal of Food Engineering*, **165**, 179–188.
- Gravel, A. & Doyen, A. (2020). The use of edible insect proteins in food: challenges and issues related to their functional properties. *Innovative Food Science and Emerging Technologies*, **59**, 102272.
- Grossmann, L. & Weiss, J. (2021). Alternative protein sources as technofunctional food ingredients. *Annual Review of Food Science and Technology*, **12**, 93–117.

- Haber, M., Mishyna, M., Martínez, J.I. & Benjamin, O. (2019). The influence of grasshopper (*Schistocerca gregaria*) powder enrichment on bread nutritional and sensorial properties. *LWT*, **115**, 108395.
- Ibarra-Herrera, C.C., Acosta-Estrada, B., Chuck-Hernández, C., Serrano-Sandoval, S.N., Guardado-Félix, D. & Pérez-Carrillo, E. (2020). Nutritional content of edible grasshopper (*Sphenarium purpurascens*) fed on alfalfa (*Medicago sativa*) and maize (*Zea mays*). *CyTA Journal of Food*, **18**, 257–263.
- Janssen, R.H., Vincken, J.P., van den Broek, L.A., Fogliano, V. & Lakemond, C.M. (2017). Nitrogen-to-protein conversion factors for three edible insects: *Tenebrio molitor*, *Alphitobius diaperinus*, and *Hermetia illucens*. *Journal of Agricultural and Food Chemistry*, **65**, 2275–2278.
- This article establishes the correct use of the conversion factor for the estimation of protein content in some insects.
- Juárez-Barrientos, J.M., Hernández-Santos, B., Herman-Lara, E. et al. (2017). Effects of boiling on the functional, thermal and compositional properties of the Mexican jackfruit (*Artocarpus heterophyllus*) seed jackfruit seed meal properties. *Emirates Journal of Food and Agriculture*, **29**, 1–9.
- Knothe, G. & Dunn, R.O. (2009). A comprehensive evaluation of the melting points of fatty acids and esters determined by differential scanning calorimetry. *Journal of the American Oil Chemists' Society*, **86**, 843–856.
- Kowalski, S., Mikulec, A., Mickowska, B., Skotnicka, M. & Mazurek, A. (2022). Wheat bread supplementation with various edible insect flours. Influence of chemical composition on nutritional and technological aspects. *LWT*, **159**, 113220.
- Liu, T., Li, B., Zheng, X. et al. (2010). Effects of freezing on the condensed state structure of chitin in alkaline solution. *Carbohydrate Polymers*, **82**, 753–760.
- This article helped to understand and explain the thermal behaviour of chitin.
- López-Gámez, G., del Pino-García, R., López-Bascón, M.A. & Verardo, V. (2024). From feed to functionality: unravelling the nutritional composition and techno-functional properties of insect-based ingredients. *Food Research International*, **178**, 113985.
- Melo-Ruiz, V., Quirino-Barreda, T., García-Núñez, M., Díaz-García, R., Sánchez-Herrera, K. & Schettino-Bermudez, B. (2015). Grasshoppers *Sphenarium purpurascens* Ch. Source of proteins and essential amino acids. *Journal of Chemistry and Chemical Engineering*, **9**, 472–476.
- Mishyna, M., Keppler, J.K. & Chen, J. (2021). Techno-functional properties of edible insect proteins and effects of processing. *Current Opinion in Colloid & Interface Science*, **56**, 101508.
- Nowak, V., Persijn, D., Rittenschober, D. & Charrondiere, U.R. (2016). Review of food composition data for edible insects. *Food Chemistry*, **193**, 39–46.
- de Oliveira, L.M., da Silva Lucas, A.J., Cadaval, C.L. & Mellado, M.S. (2017). Bread enriched with flour from cinereous cockroach (*Nauphoeta cinerea*). *Innovative Food Science and Emerging Technologies*, **44**, 30–35.
- It is the only article published on the use of cockroach flour as an ingredient.
- de Paiva Gouvêa, L., Caldeira, R., de Lima Azevedo, T. et al. (2023). Physical and techno-functional properties of a common bean protein concentrate compared to commercial legume ingredients for the plant-based market. *Food Hydrocolloids*, **137**, 108351.
- Ramos-Elorduy, J., Moreno, J.M.P., Prado, E.E., Perez, M.A., Otero, J.L. & De Guevara, O.L. (1997). Nutritional value of edible insects from the state of Oaxaca, Mexico. *Journal of Food Composition and Analysis*, **10**, 142–157.
- Reyes-Herrera, A., Pérez-Carrillo, E., Amador-Espejo, G., Valdivia-Nájjar, G. & Ibarra-Herrera, C.C. (2022). Changes in the chemical composition of edible grasshoppers (*Sphenarium purpurascens*) fed exclusively with soy sprouts or maize leaves. *Insects*, **13**, 510.
- Rivas-Vela, C.I., Castaño-Tostado, E., Cardador-Martínez, A., Amaya-Llano, S.L. & Castillo-Herrera, G.A. (2023). Subcritical water hydrolysis for the obtention of bioactive peptides from a grasshopper *Sphenarium purpurascens* protein concentrate. *Journal of Supercritical Fluids*, **197**, 105893.
- Rodríguez-Miranda, J., Hernández-Santos, B., Herman-Lara, E. et al. (2012). Physicochemical and functional properties of whole and defatted meals from Mexican (*Cucurbita pepo*) pumpkin seeds. *International Journal of Food Science and Technology*, **47**, 2297–2303.
- Sathe, S.K., Deshpande, S.S. & Salunkhe, D.K. (1982). Functional properties of lupin seed (*Lupinus mutabilis*) proteins and protein concentrates. *Journal of Food Science*, **47**, 491–497.
- Ssepuyua, G., Smets, R., Nakimbugwe, D., Van Der Borgh, M. & Claes, J. (2019). Nutrient composition of the long-horned grasshopper *Ruspolia differens* Serville: effect of swarming season and sourcing geographical area. *Food Chemistry*, **301**, 125305.
- Talens, C., Llorente, R., Simó-Boyle, L., Odriozola-Serrano, I., Tueros, I. & Ibagüen, M. (2022). Hybrid sausages: modelling the effect of partial meat replacement with broccoli, upcycled Brewer's spent grain and insect flours. *Food*, **11**, 3396.
- Téllez-Morales, J.A., Hernández-Santos, B., Navarro-Cortez, R.O. & Rodríguez-Miranda, J. (2022). Impact of the addition of cricket flour (*Sphenarium purpurascens*) on the physicochemical properties, optimization and extrusion conditions of extruded nixtamalized corn flour. *Applied Food Research*, **2**, 100149.
- Torruco-Uco, J.G., Hernández-Santos, B., Herman-Lara, E., Martínez-Sánchez, C.E., Juárez-Barrientos, J.M. & Rodríguez-Miranda, J. (2019). Chemical, functional and thermal characterization, and fatty acid profile of the edible grasshopper (*Sphenarium purpurascens* Ch.). *European Food Research and Technology*, **245**, 285–292.
- Vale-Hagan, W., Singhal, S., Grigoletto, I., Totaro-Fila, C., Theodoridou, K. & Koidis, A. (2023). Edible insects in mixed-sourced protein meals for animal feed and food: an EU focus. *Food and Humanity*, **1**, 1180–1187.
- This article helps to learn about the main scientific advances in the use of insects as food and complementary proteins in foods.
- Van Huis, A., Van Isterbeeck, J., Klunder, H. et al. (2013). *Edible Insects: Future Prospects for Food and Feed Security (No. 171)*. Rome: Food and Agriculture Organization of the United Nations.
- Veldkamp, T., Van Duinkerken, G., Van Huis, A. et al. (2012). *Insects as a Sustainable Feed Ingredient in Pig and Poultry Diets: A Feasibility Study (Reporte no. 638)*. Lelystad: Wageningen UR Livestock Research.
- Villaseñor, V.M., Enriquez-Vara, J.N., Urias-Silva, J.E. & Mojica, L. (2022a). Edible insects: techno-functional properties food and feed applications and biological potential. *Food Review International*, **38**, 866–892.
- Villaseñor, V.M., Enriquez-Vara, J.N., Urias-Silva, J.E., del Carmen Lugo-Cervantes, E., Luna-Vital, D.A. & Mojica, L. (2022b). Mexican grasshopper (*Sphenarium purpurascens*) as source of high protein flour: techno-functional characterization, and in silico and in vitro biological potential. *Food Research International*, **162**, 112048.
- Zielińska, E., Karas, M. & Baraniak, B. (2018). Comparison of functional properties of edible insects and protein preparations thereof. *LWT*, **91**, 168–174.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1 Supporting Information.