Article

FOOD SCIENCE AND TECHNOLOGY INTERNATIONAL

Assessment of chemical composition and antioxidant properties of defatted flours obtained from several edible insects

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Abstract

The aims of this study were determined the chemical composition and the antioxidant properties of defatted flours obtained from several commercially available edible insects such as *Acheta dosmesticus*, *Tenebrio molitor, Zophobas morio*, and *Rhynchophorus ferrugineus* to establish their utilization as ingredient in the development of new food products. The proximate composition of flour was determined using AOAC methods while for antioxidant capacity, four different methodologies were employed (DPPH, ABTS, FIC, and FRAP). The total phenolic content and the tannin content were also determined. All flours analyzed had a high protein content with values ranging between 64.17 and 72.55 g/100 g flour. With regard to the antioxidant activity, *R. ferrugineus* showed the highest values for DPPH, ABTS, and FRAP assays with values of 2.03, 4.93, and 8.46 mg Trolox equivalent/g flour, respectively. For FIC assay, *A. dosmesticus* and *T. molitor* had the highest values 0.47 and 0.48 mg EDTA equivalent/g flour. Defatted flours obtained from edible insects analyzed could have several applications as ingredients to the development new foods due to its good nutrient content and as a functional food for the prevention of oxidation.

Keywords

Edible insects, flours, antioxidant, bioactive compounds, defatted

Date received: 5 June 2020; accepted: 24 August 2020

INTRODUCTION

Worldwide, there are a large number of researches focused on the search for various nonconventional sources of proteins, which could help to improve the nutritional value of several food products at low price. In this way, the demand for relatively inexpensive sources of proteins, which could be incorporated in to value-added food products is increasing. Edible insects are attracting growing interest in the food industry due to their potential to serve as an alternative protein source (Zielińska et al., 2018). The reason to introduce this kind of food in western countries is that in 2050, the world habitants are calculated roughly in more than 9000 million of people, which represents an additional 50% more of food. Edible insects are an alternative source of protein compared to domestic animals-based foods, and they show additional benefits that include the use of less rearing land, a high rate of reproduction, and high feed conversion efficiency (Klunder et al., 2012). Additionally, edible insects can avoid deforestation for pasture use, present a high efficiency on water and soil use and edible mass compared to

Food Science and Technology International 27(5) 383–391

DOI: 10.1177/1082013220958854
journals.sagepub.com/home/fst
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conventional livestock and they are responsible for a relatively low emission of greenhouse gases and ammonia (Poma et al., 2017). Nevertheless, it should be noted that, in most western countries, the use of insects as a food product is usually considered as a primitive practice causing disgust depending on the anatomical part of the insect ingested (Jensen and Lieberoth, 2019). Nonetheless, consumers would be more receptive to the consumption of these products as long as they cannot distinguish anatomical parts. The addition of edible insects in everyday consumer products such as cookies, pasta, or bakery products where they are not perceptible, instead of incorporating them in to the diet, and linking them with well-known flavors are some strategies to confront with neophobia or the poor sensory characteristics of these products (Megido et al., 2016).

One way to start eating edible insects in the diet or using them in the development of novel foods is obtaining flour from them. These flours could be used as a product for food fortification for numerous reasons. First of all, these flours have a high content in protein, which show a great biological value with a high-quality amino acid profile and a high level of digestibility. Furthermore, edible insects are a great source of a diversity of minerals such as: copper, iron, magnesium, manganese, phosphorous, selenium, and zinc and vitamins like riboflavin, pantothenic acid, biotin, or folic acid (Ramos-Elorduy et al., 2012; Rumpold and Schlüter, 2013). However, in order to avoid possible lipid oxidation processes of these flours, which are rich in polyunsaturated fatty acids, it is necessary to carry out a previous defatted process to increase the chemical stability and increase their shelf life. On the other hand, the flours obtained from commercially available edible insects and invertebrates represent a potential source of antioxidant ingredients. These antioxidant properties are related, as mentioned by Di Mattia et al. (2019), with several factors such as their taxonomy, eating habits, the life cycle (e.g. egg, larva, pupa, or adult), insect pre-processing before to study (e.g. use of the entire edible insect vs. several parts are removed), or the way in which the insects were treated (heat and mechanical managements). The negative part of consuming insects is the possibility of allergies. Actually, the prevalence of insect food allergy in Europe is not known. However, there are some reports on food allergy to insects in Asia (Broekman et al., 2017).

Thus, the aims of this study were to determine the chemical composition and antioxidant properties of defatted flours obtained from several commercially available edible insects to establish their applications as potential ingredient in the development of new food products.

MATERIAL AND METHODS

Material and sample preparation

House crickets (*Acheta dosmesticus*), mealworms (*Tenebrio molitor*), and superworms (*Zophobas morio*) were acquired from "la grilleria" (Valencia, Spain); red palm weevil (*Rhynchophorus ferrugineus*) was obtained from "Fundacion Palmeral de Elche" (Elche, Spain). After reception, the samples (1000 live crickets, 1000 mealworms, 1000 superworms, and 500 red palm weevil) were placed in a freezer at −30 °C for 24 h. Then, the samples were freeze dried for 24 h. After this, a grinder mill and sieves were employed to achieve different edible insect flours.

To remove oils, the flours were mixed with hexane in the ratio of 1:5 (w/v) and then they were left in an ultrasound bath without temperature control for 1 h. Then, the samples were centrifuged at $6500 \times g$ for 15 min at 10 °C and the supernatants were collected in flasks. The flour fraction that remains in the tube was mixed with hexane (1:5 w/v) and shaken actively for 2 min and then they were left for 1 h in an ultrasound bath. For a second time, the samples were centrifuged at $6500 \times g$ for 15 min at 10 °C. Residual hexane was removed from the flours by evaporation at 45 °C overnight. The four flours obtained (Figure 1) were *A. dosmesticus* flour (ADF), *T. molitor* flour (TMF), *Z. morio* flour (ZMF), and *R. ferrugineus* flour (RFF).

Chemical composition

The chemical composition (fat, ash, protein, and moisture content) of edible insect flours was analyzed using the pertinent AOAC methodologies (AOAC, 2016).

Edible insect extracts

Extracts from edible insects flours were prepared according to the method described by Lucas-Gonzalez et al. (2018) with some modifications. Therefore, 1 g of edible insect flour was mixed with 10 mL of methanol–water (80:20, v/v) in a homogenizer Ultra-Turrax at 12,000 r/min for 4 min. Later, the mixture was centrifuged at $5000 \times g$ for 8 min at 5 °C and the supernatants were collected in flasks. The pellet was homogenized with 10 mL of acetone–water (70:30, v/v) in a homogenizer UltraTurrax at 12,000 r/min for 4 min. Again, the samples were centrifuged at $5000 \times g$ for 8 min at 5 °C. The supernatants of the two phases were mixed in a round-bottomed flask and evaporated until dryness using a rotary evaporator R-205 (Büchi, Flawil, Switzerland) under reduced pressure (<0.1 bar) at 40 °C. The solids were re-suspended in 7 mL of methanol. Then, these extracts were filtered through a 0.45 μm filter and kept at −30 °C until analysis.

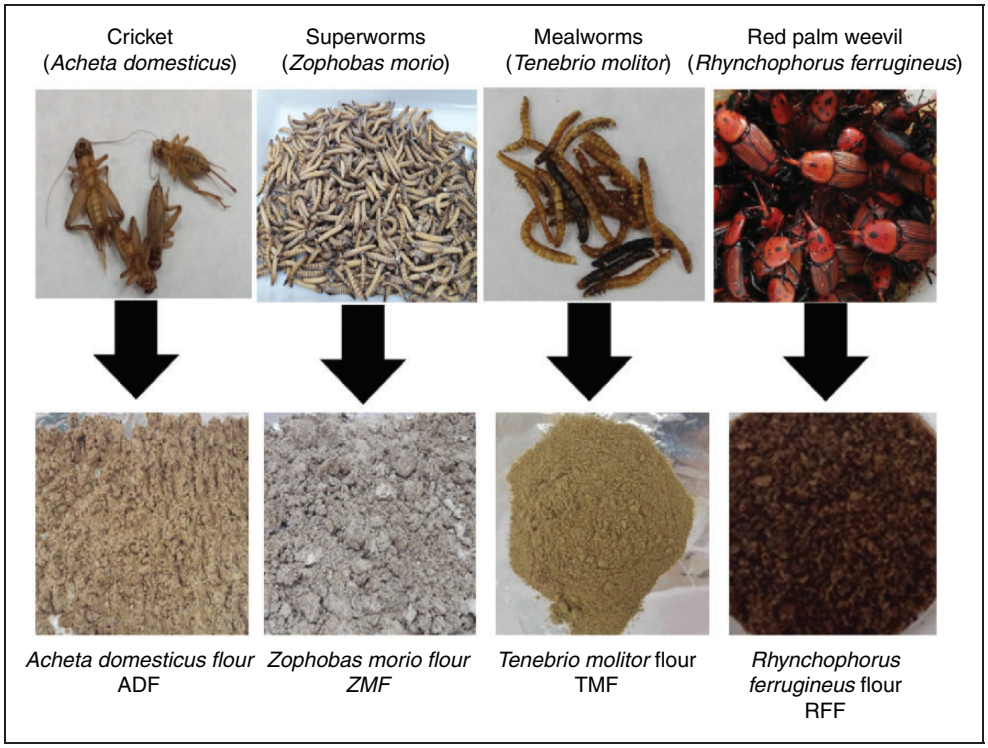

Figure 1. The flours obtained from edible insects such as *Acheta dosmesticus*, *Tenebrio molitor*, *Zophobas morio*, and *Rhynchophorus ferrugineus*.

Total phenol, total flavonoid, and tannin content

The total phenolic content (TPC) of edible insect flours was determined using the Folin–Ciocalteu's reagent (Singleton and Rossi, 1965). The results were expressed as g Gallic Acid equivalent (GAE)/100 g dry sample. The tannin content (TC) was estimated using the vanillin–HCl in methanol assay (Price et al., 1978). The results were expressed as mg Catechin equivalent (CE)/100 g dry sample.

Antioxidant activity

DPPH· assay. The DPPH free radical scavenging capacity was determined by the method described by Brand-Williams et al. (1995) using the stable radical DPPH. Results were expressed as mg Trolox equivalent (TE)/g sample.

Ferric-reducing antioxidant power. Ferric-reducing antioxidant power (FRAP) was determined following the recommendations of Oyaizu (1986). The results were expressed as mg Trolox equivalent/ g sample.

Ferrous ion chelating capacity. Ferrous ion chelating assay (FIC) was measured by inhibiting the formation of Fe^{2+}–ferrozine complex following the methodology reported by Mahdavi et al. (2017). The results were expressed as mg EDTA equivalent/g sample.

ABTS assay. The radical cation (ABTS·+) scavenging activity was determined using the methodology described by Gullón et al. (2015). The results were expressed as mg Trolox equivalent/g sample.

Statistical analysis

All experiments were carried out in triplicate and data were reported as mean ± standard deviation. The data collected for chemical composition, TPC, TC, and antioxidant capacity were analyzed by one-way analysis of variance. To discover whether there were significant differences ($p < 0.05$) between the levels of the main factor, contrasts between means were made using the Tukey's test. The statistical analyses were made using Statgraphics 5.1 for Windows (Statistical Graphics Corp., Rockville, MD).

The protein content, TPC, and TC were compared with the values obtained for antioxidant capacity through Pearson's correlation test. For that, a low correlation was considered for *r*-values comprising between ±0.1 and ±0.3; a moderate correlation was achieved with *r*-values ranging between ±0.3 and ±0.7. Finally, a strong correlation was considered for

r-values higher than ±0.7. The variables were considered not correlated for values of *r* lower than ±0.1 (Pellegrini et al., 2018).

RESULTS AND DISCUSSION

Chemical composition

The proximal composition of defatted flours obtained from several edible insects is presented in Table 1. With reference to the protein content, the flour obtained from ADF showed the highest ($p < 0.05$) values followed by the flours obtained from RFF and ZMF with no statistically significant differences ($p > 0.05$) between samples. Finally, TMF showed the lowest protein values ($p < 0.05$). Similarly, for fat content, ZMF had the highest ($p < 0.05$) values followed by the flours obtained from TMF and ADF with no statistically significant differences ($p > 0.05$) between samples. The flour obtained from RFF had the lowest ($p < 0.05$) fat content. With reference to moisture, all samples showed a low moisture content with no statistical differences ($p > 0.05$) between ADF and RFF and between TMF and ZMF. However, TMF and ZMF showed higher moisture content ($p < 0.05$) than ADF and RFF. The ash content had values ranging between 2.66 and 4.77 g/100 g flour with statistically significant differences ($p < 0.05$) between all defatted flour analyzed.

The main component of the defatted flours obtained from edible insects is proteins. In general, the protein values obtained in this study were in agreement with those reported by van Huis (2016) who mentioned that the protein content varies between 7% and 91% dry weight depending on the insect species, with most insects containing around 60%. Similarly, Xiaoming et al. (2010) analyzed the protein content present in several edible insect species. These authors informed that the protein content was in the range of 13–77% by dry matter, reflecting the large variability of tested species. Zielińska et al. (2015) informed that edible insects have a high protein content, which varies between 20% and 76% of dry weight, depending on the type of insect analyzed and the life cycle in which it is found. However, it should be borne in mind that data on the amount of protein in flours that can be extracted from insects previously dried, milled, defatted, and suspended in aqueous solutions had a great variability. Several factors such as the solid/water ratio, pH, and temperature play an important role (Zhao et al., 2016).

Nonetheless, the protein content of the defatted flours from edible insects obtained in this work indicates that these flours could be used in the food industry as a potential source of protein in the development of novel foods. Therefore, there are recent studies where the flours obtained from several insects are utilized as ingredients to improve the protein content of the food products. Thus, González et al. (2019) used insects' flour obtained from *Hermetia illucens*, *A. domesticus*, and *T. molitor* as protein-rich ingredient for bakery products. These authors reported that the protein content in bread increased between 9.66% and 28.55%. Azzollini et al. (2018) used flour obtained from *T. molitor* at two concentrations, 10% and 20%, for elaborated cereal snacks and assessed the nutritional properties as a function of the different processing techniques used during fabrication. These authors reported that the addition of *T. molitor* flour increased the protein content and improved the snack digestibility. The second largest component of insect nutrient composition is fat. This fat has a high content of polyunsaturated fatty acids, like linoleic acid, α-linolenic acid, or several ω-3. The fact is that, in general, the oils obtained from insects are liquid at room temperature. This property makes them an ideal candidate to be used as ingredients in several food products such as emulsions, frying oils, food lubricants, etc. (da Silva Lucas et al., 2020). In this work, although part of the fat content has been eliminated, a small part remains. This low fat content can provide these polyunsaturated fatty acids to foods in this type of flour and it may be used as an ingredient.

Table 1. Chemical composition of defatted flours obtained from some edible insects.

Sample	Proteins	Fat	Ash	Moisture
ADF	72.55 ± 0.21a	4.49 ± 0.16b	4.77 ± 0.04a	4.95 ± 0.19b
RFF	68.18 ± 1.56b	2.42 ± 0.05c	2.66 ± 0.04d	4.99 ± 0.02b
TMF	64.17 ± 0.31c	4.67 ± 0.07b	3.04 ± 0.24c	6.29 ± 0.71a
ZMF	67.56 ± 0.70b	5.29 ± 0.19a	3.55 ± 0.03b	6.58 ± 0.11a

Values expressed as g/100 g dry matter (mean values).
Values followed by the same letter within the same column are not significantly different ($p > 0.05$) according to Tukey's multiple range test.
ADF: *Acheta dosmesticus* flour; TMF: *Tenebrio molitor* flour; ZMF: *Zhophobas morio* flour; RFF: *Rhynchophorus ferrugineus* flour.

Total phenol and tannin content

The TPC and TC of different extract solutions of defatted flours obtained from some edible insects are presented in Table 2. The TPC varied from 1.09 to 3.83 g GAE/100 g sample. The flour obtained from RFF showed the highest ($p < 0.05$) TPC followed by the flour obtained from TMF. The flours obtained from ADF and ZMF had the lowest values ($p < 0.05$) with no statistically significant differences ($p > 0.05$) between them. With regard to the TC, again the flour obtained from RFF showed the highest ($p < 0.05$) values followed by the flour obtained from TMF. ZMF had the lowest TC ($p < 0.05$). The TPC could be used as an important indicator of antioxidant capacity of a foodstuff and they may be utilized as an initial screen for several products when proposed as a natural source of antioxidants in the development of new foods (Viuda-Martos et al., 2011). Nevertheless, it should be noted that the TPC depends on several factors such as the part of the product used to obtain the extract, the method used to obtain the flours, and the solvents or the methodology employed to measure. Several previous studies have described the presence of phenolic compounds in edible insects and in extracts obtained from them. Nevertheless, the accessible data for the phenolic content of defatted flours obtained from edible insects analyzed in this work are scarce. Several authors found polyphenolic compounds in flours or extracts obtained from numerous insects. Thus, Navarro del Hierro et al. (2020) reported that the phenolic content of lyophilized flours obtained from *A. domesticus* and *T. molitor* using different extraction methods and solvents ranged between 0.3 and 5 g GAE/100 g for *A. domesticus* and 0.8 and 3.8 g GAE/100 g for *T. molitor*. These values were, in general, higher than those values obtained in this work. Similarly, Di Mattia et al. (2019) studied the TPC of defatted flours obtained from edible insects and invertebrates. These authors informed that the TPC varied between 0.125 and 0.496 g GAE/100 g sample. In another study, Kunatsa et al. (2020) analyzed the TPC of edible insects (*Macrotermes facilger* and *Henicus whellani*) from Zimbabwe. These authors reported values of 7.77 and 9.77 g GAE/100 g sample for *M. facilger* and *H. whellani*, respectively. This great variability depends on several factors and thus Di Mattia et al. (2019) informed that insects characterized by vegetarian dietary habit showed a high content of phenolic compounds than those characterized by a carnivorous habit.

Tannins have a biological and pharmacological activity, which includes antioxidative, antibacterial, antiviral, cardioprotective, antitumor, anti-inflammatory, and immune-modulatory (Kumari and Jain, 2012). With regard to the phenolic content, tannins also have been detected in edible insects. Thus, the results achieved in this study were higher than those described by Omotoso and Adesola (2018) who analyzed the TC of four edible insects namely, *Cirina forda*, *Periplanata americana*, *Rhynchophorus phoenicis*, and *Zonocerus variegatus*. These authors reported that the TC values were 0.61, 0.54, 0.72, and 1.13 mg/100g for *R. phoenicis, C. forda, Z. variegatus*, and *P. americana*, respectively. On the other hand, Chakravorty et al. (2016) mentioned that the TC of *Oecophylla smaragdina* and *Odontotermes* sp., two common species of edible insects used as food in India were 496.67 and 615.0 mg/100 g, respectively. These values were higher than those obtained in this study.

Antioxidant activity

The results of antioxidant capacity using DPPH, FRAP, FIC, and ABTS assays are summarized in Table 3. In DPPH assay, the antioxidant capacities of defatted flours obtained from several edible insects tested varied from 0.24 to 2.03 mg Trolox equivalent/g flour. The flour obtained from RFF showed the highest ($p < 0.05$) values followed by the flour obtained from TMF. No statistically significant differences ($p > 0.05$) were found ADF and ZMF, which had the lowest antioxidant activity values measure with this method.

In FRAP assay, again the flour obtained from RFF had the highest ($p < 0.05$) values (8.46 mg Trolox equivalent/g flour). ADF and TMF had the lowest

Table 2. Total phenolic and tannin content of defatted flours obtained from some edible insects.

Sample	ADF	RFF	TMF	ZMF
TPC[a]	1.09 ± 0.12c	3.83 ± 0.08a	1.95 ± 0.09b	1.15 ± 0.19c
TC[b]	4.21 ± 0.09c	9.45 ± 0.10a	5.89 ± 0.07b	3.92 ± 0.07d

Values followed by the same letter within the same row are not significantly different ($p > 0.05$) according to Tukey's multiple range test.
[a]Values expressed as g Gallic Acid equivalent (GAE)/100 g dry matter (mean values).
[b]Values expressed as mg Catechin equivalents/100 g dry matter.
ADF: *Acheta dosmesticus* flour; TMF: *Tenebrio molitor* flour; ZMF: *Zhophobas morio* flour; RFF: *Rhynchophorus ferrugineus* flour.

Table 3. Antioxidant activity of defatted flours obtained from several edible insects measured with four different methodologies: DPPH, ABTS, FRAP, and FIC.

Sample	DPPH	FRAP	FIC	ABTS
ADF	0.24 ± 0.02c	2.82 ± 0.18c	0.47 ± 0.04a	1.26 ± 0.12c
RFF	2.03 ± 0.01a	8.46 ± 0.13a	0.39 ± 0.03b	4.93 ± 0.38a
TMF	0.76 ± 0.14b	3.08 ± 0.18c	0.48 ± 0.01a	3.12 ± 0.25b
ZMF	0.27 ± 0.03c	3.67 ± 0.02b	0.32 ± 0.06b	1.43 ± 0.08c

For DPPH, FRAP, and ABTS assays values expressed as mg Trolox equivalent/g flour. For FIC assay values expressed as mg EDTA equivalent/g flour.
Values followed by the same letter (a–b) within the same column are not significantly different ($p > 0.05$) according to Tukey's multiple range test.
ADF: *Acheta dosmesticus* flour; TMF: *Tenebrio molitor* flour; ZMF: *Zhophobas morio* flour; RFF: *Rhynchophorus ferrugineus* flour; FRAP: ferric-reducing antioxidant power; FIC: ferrous ion chelating capacity.

Table 4. Pearson's correlation coefficients between the different antioxidant assays (DPPH, ABTS, FRAP, and FIC) and the protein, total phenolic, and tannin content.

Pearson's correlation coefficients							
	Proteins	TPC	TC	DPPH	FRAP	FIC	ABTS
Proteins	1	0.862	0.632	0.525	0.651	0.234	0.637
TPC		1	0.857	0.906	0.959	0.231	0.924
TC			1	0.873	0.909	0.409	0.934
DPPH				1	0.965	0.688	0.925
FRAP					1	0.556	0.835
FIC						1	0.841
ABTS							1

TPC: total phenolic content; TC: tannin content; FRAP: ferric-reducing antioxidant power; FIC: ferrous ion chelating capacity.

antioxidant activity values measure with FRAP method with no statistical differences ($p > 0.05$) between them. For FIC assay, ADF and TMF had the highest ferrous chelating capacity with no statistical ($p > 0.05$) differences between them. Likewise, no statistically significant differences ($p > 0.05$) were obtained between RFF and ZMF samples, which presented the lowest values. Finally, in ABTS assay, the flour obtained from RFF had the highest ($p < 0.05$) values followed by the flour obtained from TMF. No statistically significant differences ($p > 0.05$) were obtained between ADF and ZMF, which had the lowest antioxidant activity values measure in this method.

Table 4 shows the correlation coefficients (r) between the antioxidant properties assessment with DPPH, ABTS, FRAP and FIC assays, TPC, TC, and protein content of flours obtained from edible insects. Thus, the correlations Proteins–DPPH, Proteins–FRAP, and Proteins–ABTS showed a moderate correlation (r lower than 0.7 and higher than 0.3) with r values of 0.525, 0.651, and 0.637 respectively, whilst the correlations Protein–FIC assay had a low correlation (r lower than 0.3) with a r-value of 0.234. In the same way, high correlations were found between TPC–DPPH, TPC–FRAP, and TPC–ABTS with r-values of 0.906, 0.959, and 0.924; however, a low correlation was obtained between TPC and FIC ($r = 0.231$). Similarly, the correlations between TC–DPPH, TC–FRAP, and TC–ABTS were higher with r-values ranging between 0.873 and 0.934. When the correlation between assays was analyzed, a positive correlation was found. Particularly, DPPH–ABTS, DPPH–FRAP, and FRAP–ABTS showed a strong correlation with r-values higher than 0.7, whilst between DPPH and FIC, ABTS and FIC, and FRAP and FIC there was a correlation moderate with r values comprising between 0.3 and 0.7. These results showed that flours obtained from edible insects had comparable activity in all determinations.

Lipid oxidation is the major concern of the food industry since this process causes severe changes in products such as: the appearance of unpleasant odors and flavors, decrease in the product shelf-life, significant changes in texture and color and, therefore, a decrease in the nutritional value of food (Alamed et al., 2009). If oxidation is analyzed from a point of

view of human health, reactive oxygen species (ROS) like superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical ($^{\bullet}OH$), are constantly created in cellular metabolism, which could be particularly harmful to cell components at elevated concentrations (Najafian and Babji, 2012). Oxidative stress is associated with cellular toxic processes that could provoke several pathologies such as carcinogenesis, cardiovascular diseases, stroke, arthritis, and aging (Rahal et al., 2014). Antioxidants are a group of compounds that have the function of inhibiting and/or reducing effects caused by the deleterious action of free radicals and nonradical reactive species (Barbosa et al., 2010). However, it should be borne in mind that it is very difficult to measure the antioxidant capacity of a compound using one single methodology due to the antioxidant mechanism, in biological matrices, being so complex and numerous different factors playing a role in these mechanisms (Huang et al., 2005). For that reason, in this work four different methodologies with different antioxidant mechanisms were used.

Actually, the scientific attention has been focused on the use of natural products with antioxidant properties to protect tissues and food products from damage by free radicals. Thus, edible insect flours with a high content of proteins, have received particular attention because of studies that have reported that these flours are highly efficient antioxidants and they show free radical scavenging capacity for decreasing the toxic effects of chemical agents. In this way, Zielińska et al. (2017a) analyzed the antioxidant potential of some edible insects using free radical-scavenging capacity, ion chelating capacity, and reducing power assays. These authors reported that the highest anti-radical capacity against 2,2-diphenyl-1-picrylhydrazyl radical was achieved for baked cricket (*Gryllodes sigillatus*) hydrolysate with an IC_{50} value of 10.90 μg/mL and that against ABTS radical was the highest for raw *T. molitor* hydrolysate with an IC_{50} value of 5.3 μg/mL. Locust (*Schistocerca gregaria*) hydrolysate had the highest Fe^{2+} chelation capacity with a IC_{50} value of 2.57 μg/mL. Similarly, Zielińska et al. (2017b) assessed the antioxidant capacity of extracts obtained of edible insects *Amphiacusta annulipes*, *Z. morio*, *Agnetina annulipes*, and *Locusta migratoria* after in vitro gastrointestinal digestion using DPPH, ABTS+, FIC, and FRAP assays. Insects that demonstrated the highest antioxidant activities in each antioxidant assay were *A. annulipes* in DPPH assay with values of 19.1 μg/mL; *Z. morio* in ABTS assay with values of, 4.6 μg/mL; and *A. annulipes* in FIC and FRAP assays with values of 58.82% and 0.652 μg/mL, respectively. Di Mattia et al. (2019) analyzed the capacity of several extracts, obtained by 12 commercially edible insects, to show an antioxidant effect in vitro. These authors found that extracts of grasshoppers, silkworm, and crickets with values of 2.55, 2.48, and 2.37 mmol TE/100 g, respectively showed the highest values of antioxidant capacity, measured with ABTS assay. On the other hand, the extracts obtained from grasshoppers, African caterpillars, and cricket with values of 2.12, 1.88, and 1.81 mmol Fe^{2+}/100 g, respectively display the highest FRAP values.

The antioxidant mechanisms through which proteins exercise this activity are not completely understood; nevertheless, it is known that the amino acid content as well as the sequence of the resulting peptides have a significant role in their antioxidant activity (Sarmadi and Ismail, 2010). In this regard, Serpen et al. (2012) informed that moderate heat treatments may raise the antioxidant capacity of several proteins as a result of changes in their tertiary and quaternary structures. In scientific literature, there are several works that inform that hydrophobic and aromatic amino acids, as well as histidine, methionine, tyrosine, lysine, and cysteine, improve the force of antioxidant peptides through proton-donation capacity, electron-donation capacity, or by radical scavenging capacity (Da Rocha et al., 2018; Najafian and Babji, 2012). With respect to this, Liu et al. (2016) reported that peptides with a low molecular weight such as methionine and lysine showed more amino acids exposed to interact with free radicals and this increases their antioxidant effect.

With regard to proteins, the action mechanism set in motion by the antioxidant activity of phenolic and tannins is still not clearly understood. Tannins have the ability to act as both primary antioxidants (e.g. donate hydrogen atom or electrons) and secondary antioxidants. Additionally, these compounds showed the capacity to chelate metal ions like Fe^{+2}, which interfere with the Fenton reaction and in that way, delay the oxidation process (Karamac et al., 2006). The inhibition of lipid peroxidation by tannin constituents can act via the inhibition of cyclooxygenase (Zhang et al., 2004). In the case of phenolic compounds, several mechanisms have been proposed such as a direct hydrogen atom transfer, a single electron transfer, a sequential proton loss-electron transfer, or metal chelating activity (Klein and Lukeš, 2007; Mayer and Rhile, 2004; Rojano et al., 2008).

CONCLUSIONS

Defatted flours obtained from *A. dosmesticus*, *T. molitor*, *Z. morio*, and *R. ferrugineus* could have several applications as ingredients in the development new foods due to its good nutrient content and as a functional food for the prevention of oxidation. However, in order for the consumption of insects and products derived from them to be generalized worldwide, three

major hurdles must be overcome. First of all, it must be ensured that the consumption of insects is safe through the use of insect farms where the feeding, growth, control of diseases of insects is assured. Secondly, the neophobic problems against entomophagy must be overcome in those countries where insect consumption is not widespread. Finally, analyze and determine the possible allergy problems that could be generated by the consumption of insects.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

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

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