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ORIGINAL PAPER

Effect of drying processes in the chemical, physico-chemical, techno-functional and antioxidant properties of flours obtained from house cricket (*Acheta domesticus*)

Raquel Lucas-González[1] · Juana Fernández-López[1] · José A. Pérez-Álvarez[1] · Manuel Viuda-Martos[1]

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Abstract
The aims of this study were determine (1) the chemical composition (2) the physico-chemical properties (3) the fatty acid profile (4) the techno-functional and (5) the antioxidant properties of flours obtained from house cricket (*Acheta domesticus*) using two different methods of drying. In thermal drying cricket flour (TDCF) and lyophilized cricket flour (LCF) high content of protein (62.68–67.48%, respectively) and fat (24.91–19.32% respectively) was found. This content was higher than found in several cereal or pseudocereal flours such as wheat, oat or quinoa. Both types of flours showed good techno-functional properties (water and oil holding capacity, Swelling capacity, emulsion and foam capacity and stability) with higher values in LCF than TDCF. The values obtained for techno-functional properties were similar to those found for several flours obtained from cereal or pseudocereal of fruits coproducts. In LCF and TDFC the main fatty acid detected were linoleic, oleic and palmitic acids. LCF showed stronger radical scavenging (7.18–2.82 mg Trolox equivalent/g, respectively), reducing (0.24–0.15 Trolox equivalent/g, respectively) and chelating capacity (43.78–32.23 µg EDTA/g, respectively) than TDCF. Due to the protein and fat content, the good techno-functional and antioxidant properties the flours obtained from house cricket could be used as food ingredient in the development of novel foods.

Keywords Cricket flours · Techno-functional · Antioxidant · Fatty acid · Lyophilized

Introduction

Since the prehistory to the present, edible insects have been used as food source in numerous different cultures around the world. Actually, it is probable that 1900 species of insects are consumed by more two billion people in around 80 countries across Asia, Africa and America [1] whilst in Europe, the consumption of insects was null due to regulatory issues. Nevertheless, the Novel Foods Regulation (regulation 2015/2283), which entered into force on January 2018, approved the use of all insect-based food by the European Food Safety Authority (EFSA), after which it could be officially commercialized in all European Union Member States.

✉ Manuel Viuda-Martos
mviuda@umh.es

[1] IPOA Research Group, Agro-Food Technology Department, Escuela Politécnica Superior de Orihuela, Miguel Hernández University, Orihuela, Alicante, Spain

Insects are progressively seen as a potentially important source of protein which is obtained at very low cost. Apart, due to its composition could be used to complement of other conventional sources of proteins such as meat without overburdening the environment [2]. Additionally, the edible insects are more efficient in terms of feed conversion, greenhouse gas emissions, water and soil use and edible mass compared to most domestic breeding animal species [1]. Therefore, in very short term, the consumption of insect-based food will be the best option in response to overpopulation and environmental pressure caused by meat production [3]. As reported Zielińska et al. [4], the most commonly consumed insects are: beetles (family *Coleoptera*) (31%), caterpillars (family *Lepidoptera*) (18%) and bees and ants (family *Hymenoptera*) (14%). Following these are grasshoppers, locusts and crickets (family *Orthoptera*) (13%), cicadas, and true bugs (family *Hemiptera*) (10%), termites (family *Isoptera*) (3%), and other orders (11%). Although it is probable that grasshoppers, locusts, and crickets, make up about 13% of the world insect consumption [1]. Nevertheless, it has been

observed that in western countries the most popular insects use in entomophagy have been mealworms and crickets [5] mainly as result of their nutritional value, taste, and ease of rearing. Several scientific researchers showed that crickets had some of the highest protein contents when compared to other insects as well as high content and quality of fatty acids [6].

Nevertheless, it should be borne in mind that the rejection of edible insects, mainly when whole served, had been influenced by many factors, such as unpleasant characteristics, disagreeable sensory properties, cultural and societal situation, personal issues, individual beliefs, and health concerns. However, as mentioned Schösler et al. [3] the consumers would be willing to eat them in a less visible form, as food ingredient, in adapted products indistinguishable from familiar ones. One way for introducing insects as ingredients in the food production is as flour. However, it is important to note that the utilization of edible insects in the food industry is highly dependent on understanding the deep changes could take place during the flour development process which will influence its nutritional and sensorial characteristics. Thus, bioactive compounds with high added value such as polyunsaturated fatty acid, several minerals and vitamins could be lost. Additionally, flours with a brown color due to maillard reactions or flours with bitter flavors due to protein denaturation could be obtained. Thus, the aims of this study were determine: (1) the chemical composition, (2) the physic-chemical properties, (3) the techno-functional, (4) the fatty acid profile, and (5) the antioxidant properties of flours obtained from house cricket (*Acheta domesticus*) using two different process, to set their applications as potential ingredient in the development of new food products.

Materials and methods

Material and sample preparation

House crickets (*A. domesticus*) were purchased from Insect Side (Elche, Spain). The samples (3000 live crickets) were place in a freezer set at − 30 °C for 24 h immediately receiving them. After that, the crickets were hand separated in two batches of 1500 samples.

To obtain the flours, two different procedures were carried out. In the first methodology crickets were dehydrated in a convection oven at 60 °C/12 h. In the second procedure the samples were lyophilised in a freeze dryer for 24 h. Then, a grinder mill and sieves were used to obtain flours with a particle size of less than 0.417 mm. The two flours obtained were thermal dried cricket flour (TDCF) and lyophilised cricket flour (LCF).

Chemical composition

The chemical composition of TDCF and LCF was carried out by standard methods of AOAC [7] to analyzed proteins (920.152), fat (963.15), ash (940.26) and moisture (925.09) content. The conversion factor for calculation of protein from nitrogen content was 6.25 while the solvents used for fat extraction was *n*-hexane.

Physico-chemical properties

The pH was measured in a suspension resultant from mixing 2 g of sample analyzed with 20 mL of ultrapure water during 10 min, using a Crison pHmeter (Model 507, Crison, Barcelona, Spain). The water activity (aw) was determined using a hygrometer Novasina Sprint TH-500 at 25 °C. The objective color (CIE L^*, a^*, and b^*) of the samples analyzed was determined using a colorimeter Minolta CM-700 with illuminant D_{65}, SCI mode and an observer angle of 10°. The CIE$L^*a^*b^*$ coordinates determined were: lightness (L^*), redness (a^*, coordinate red/green), and yellowness (b^*, coordinate yellow-blue) and the psychophysical parameters h_{ab} (hue) and C^*_{ab} (chroma) which were calculated as follows:

$$h_{ab} = \text{arctg}\frac{b^*}{a^*} \quad C^*_{ab} = \sqrt{a^{*2} + b^{*2}}.$$

Techno-functional properties

The methodology described by Robertson et al. [8] was used to determine the water holding capacity (WHC) and oil-holding capacity (OHC) as well as swelling capacity (SWC) of flour samples. WHC and OHC were expressed as g of water or oil, respectively, held per g of sample. On the other hand, SWC was expressed as mL of volume increase per g of sample. The emulsifying activity and emulsion stability were also analyzed following the recommendations of Vázquez-Ovando et al. [9]. Emulsion capacity was expressed as the mL of the emulsified layer volume of the entire volume in the centrifuge tube. Emulsion stability was calculated as volume of the remaining emulsified layer/original emulsion volume layer in the tube.

In addition, foam capacity (FC) and foam stability (FS) were analyzed following the method described by Tsutsui [10]. Foam capacity was reported as:

$$\text{FC (\%)} = \frac{\text{Volumen after agitation} - \text{Volumen prior agitation}}{\text{Valumen prior agitation}} \times 100.$$

For the determination of Foam stability, the samples were allowed to stand for 30 min at room temperature and the

remaining foam volume was measured. The following formula was used to calculate FS:

$$\text{FS}\ (\%) = \frac{\text{Residual foam volume}}{\text{Total foam volume}} \times 100.$$

Fatty acid composition

Cricket oil was extracted following the methodology described by Pellegrini et al. [11]. The oil was obtained from 15 g of lyophilized or air dry samples using 60 mL of *n*-hexane, by means of an ultrasonic extraction during 45 min at 20 °C. After this time, the samples were centrifuged at 2470*g* for 10 min at 4 °C. The supernatant was collected and the solvent was removed through a rotary vacuum evaporator. Fatty acid identification was obtained by transesterification of fats with methanol, producing fatty acids methyl esters (FAMEs) as described by Golay and Moulin [12]. The FAMEs were analyzed on an Agilent 6890 gas chromatography equipped with a flame ionization detector (FID) and a DB-23 capillary column (30 m, 0.25 µm film, 0.25 mm internal diameter; Agilent Technologies). The injector and detector temperatures were set at 250 and 270 °C, respectively. The temperature program was as follows: initial temperature 60 °C for 1 min after injection, rate of 10 °C/min from 60 to 130 °C, and rate of 3 °C/min from 130 to 170 °C finally, at 10 °C/min from 170 to 230 °C and hold 5 min. The carrier gas was helium with a column inlet pressure fixed at 20 psi. The injection volume was 0.5 µL with a split ratio of 1:20. Response factors were calculated using a reference fat (BCR-164) (Fedelco Inc., Madrid, Spain). Fatty acids were identified by comparing retention times with those of FAME standards (Supelco 37 Component FAME Mix, Bellefonte, PA, USA), Tritridecanoin was used as an internal standard. All analyses were performed in triplicate and results were expressed as g/100 g of oil.

Antioxidant activity

Sample preparation

Extracts were prepared according to the method described by Lucas-Ortega et al. [13]. Thus, 1 g of TDCF or LCF samples were homogenized with a mixture (10 mL) of methanol–water (80:20, v/v) in an Ultra-Turrax at 12,000 rpm for 1 min. Then, the samples were centrifuged at 5000*g* for 10 min at 4 °C and the supernatants were collected in flasks. The pellet was homogenized with a mixture (10 mL) of acetone–water (70:30, v/v) in an Ultra-Turrax at 12,000 rpm for 1 min. Again, the samples were centrifuged at 5000*g* for 10 min at 4 °C and the supernatants were mixed with the other supernatant. This mixture obtained was evaporated in rotary evaporator and the solids were re-suspended in 5 mL of methanol. The extract was filtered through a 0.45 µm Millipore filter (Millipore Corporation, Bedford, USA) and kept at − 20 °C until analysis.

DPPH radical scavenging assay

DPPH radical scavenging assay was done following the method described by Brand-Williams et al. [14]. The results were expressed as mg Trolox equivalents per gram of cricket flour.

Ferric reducing antioxidant power

Ferric reducing antioxidant power (FRAP) was evaluated by means of method proposed by Oyaizu [15]. The results were expressed as mg Trolox equivalents per gram of cricket flour.

Ferrous ion-chelating ability assay

Ferrous ions chelating activity (FIC) was determined by means of the method described by Carter [16]. The results were expressed as µg Ethylenediaminetetraacetic acid (EDTA) per gram of cricket.

Statistical analysis

Statistical analysis and comparisons among means were carried out using the statistical package SPSS 19.0 (SPSS Inc., Chicago, IL). All experiments were carried out in triplicate and data are reported as mean ± standard deviation. The differences of mean values among chemical composition, physic-chemical, techno-functional and the antioxidant properties were analyzed by one-way analysis of variance (ANOVA). Tukey's post hoc test was applied for comparison of means, while differences were considered significant at $p < 0.05$.

Table 1 Chemical composition of flours obtained from house cricket (*Acheta domesticus*)

	Moisture	Fat	Proteins	Ash
LCF	1.49 ± 0.27^{a}	19.32 ± 1.23^{b}	67.48 ± 1.01^{a}	4.36 ± 0.13^{a}
TDCF	1.64 ± 0.25^{a}	24.91 ± 2.29^{a}	62.68 ± 0.85^{b}	4.73 ± 0.16^{a}

Values followed by the same letter in the same column did not show statistically significant differences according to Tukey's HSD post hoc test ($p > 0.05$). Values expressed as g/100 g

LCF lyophilized cricket flour, *TDCF* thermal dried cricket flour

Results and discussion

Chemical composition

The chemical composition of LCF and TDCF is shown in Table 1. In both samples analyzed a high content of protein and fat was found. As regards the protein content, the samples obtained from LCF showed higher values [67.48 g/100 g dry weight (dw)] than samples obtained from TDCF (62.68 g/100 g dw) with statistically differences ($p < 0.05$) between them. In general terms, the values obtained were in agreement with van Huis [17] who mentioned that the protein content vary between 7 and 91% dw depending on the insect species, with most insects containing around 60%. The protein values obtained in this work were higher than those reported by Osimani et al. [18] for cricket powder or small crickets obtained from producers located in The Netherlands with values of 59.46 and 51.82 g/100 g dw or by González et al. [19] who reported protein values of 56.58 g/100 g dw for house cricket flour. However, Kamau et al. [20] reported a protein content of adult crickets obtained from Nairobi, Kenya of 65.85 g/100 g dw.

Although edible insects are being seen typically as a source of protein, several species are rich in appreciated oils that might be used directly or indirectly, as ingredient, to improved several parameters such as texture, flavor and digestibility of numerous foods [21]. Thus, fat signifies the second largest portion of the nutrient composition of edible insects. The fat values of LCF and TDCF analyzed are shown in Table 1. The samples obtained from TDCF showed higher fat values (24.91 g/100 g dw) than samples obtained from LCF (19.332 g/100 g dw) with differences statistically significant ($p < 0.05$) between them. These values were very similar than those reported by Williams et al. [22] in adult house crickets (22.10 g/100 g) and higher than reported by the same authors for nymph house crickets (14.40 g/100 g) or Ramos-Elorduy Blasques et al. [23] in adult house crickets from Mexico with values of 22.08 g/100 g. For moisture and ash content (Table 1) no statistical differences were found ($p > 0.05$) between LCF and TDCF samples analyzed.

The values obtained for proteins and fat of house cricket flours (LCF and TDCF) were higher than those reported for quinoa flours with values comprised between 11.62 and 13.66 g/100 g for proteins or 4.87 and 6.48 g/100 g for fats [11] or for several cereals such as wheat, maize, rice, barley, sorghum, oats, millet or rye with values comprised between 7.50 and 16.89 g/100 g for proteins or 1.16 and 6.90 g/100 g for fats [24].

These results suggested that the huge variability could proceed from extrinsic factors like feed and ecology which are probable to affect final composition. Additionally, other parameters such as the development stage of the edible insects (i.e., eggs, larvae, pupae, or adults), insect processing previous to analysis (i.e., assessment of whole insect vs insect with some parts remove), the way in which they are processed (thermal and mechanical treatments) as well as variations in measuring methods could also affect their chemical composition [25, 26].

Physico-chemical

The physico-chemical properties of TDCF and LCF are presented in Table 2. TDCF and LCF were characterized by slightly acidic pH (6.31–6.48, respectively) with no statistical differences between them ($p > 0.05$). To know the pH value is important information because it can determine in which type of food matrix they could be added, without affecting their technological behavior [27]. Thus, potential food ingredient with pH values close neutrality, such as those obtained in this work, will be more suitable for application to some neutral food matrices such as meat products.

Water activity is one of the principal factors that could affect on microbial growth. In this work no statistical differences were found ($p > 0.05$) between both TDCF and LCF for this parameter. The low values obtained indicate that the samples would be self-stable from a microbiological point of view.

Color of foodstuff is very important quality from the consumer point of view. Thus, the potential ingredients added to foods to improve their techno-functional, antioxidant and

Table 2 Physico-chemical properties of flours obtained from house cricket (*Acheta domesticus*)

Sample	pH	Aw	Color parameters				
			L^*	a^*	b^*	C^*	h
LCF	6.48 ± 0.07^a	0.166 ± 0.007^a	64.58 ± 0.88^a	3.50 ± 0.09^a	14.03 ± 0.33^a	14.46 ± 0.33^a	76.01 ± 0.35^a
TDCF	6.31 ± 0.04^a	0.172 ± 0.012^a	41.62 ± 0.61^b	3.79 ± 0.11^a	7.42 ± 0.36^b	8.34 ± 0.37^b	62.93 ± 0.55^b

Values followed by the same letter in the same column did not show statistically significant differences according to Tukey's HSD post hoc test ($p > 0.05$)

LCF lyophilized cricket flour, *TDCF* thermal dried cricket flour

antimicrobial properties should not significantly affect the color of the product and influence negatively on the perception that consumers have about it. The color coordinates of TDCF and LCF are shown in Table 2. The lightness (L^*) value of TDCF was lower ($p < 0.05$) than LCF. The value of lightness (L^*) of LCF was similar than those corresponding to powder obtained from freeze dried house cricket from Kenia ($L^* = 65.50$) [28]. However, TDCF had lower L^* values which were similar than those reported by González et al. [19] in flour obtained of freeze dried house cricket from Spain ($L^* = 39.32$). These L^* values of TDCF indicate that the samples are darker due to protein rich products when are thermally processed may show non-enzymatic browning [29]. For redness coordinate (a^*) there was not statistical differences ($p > 0.05$) between both samples analyzed. As regard to yellowness coordinate (b^*), again the values obtained for TDCF were lower ($p < 0.05$) than LCF. This result indicated that TDCF was less yellow than LCF. For hue angle and Chroma values, LCF samples showed higher values ($p < 0.05$) than TDCF samples.

Techno-functional properties

Techno-functional properties (water holding capacity, oil holding capacity, swelling capacity, emulsion capacity, emulsion stability, foam capacity and foam stability) of TDCF and LCF are shown in Table 3. LCF showed higher values ($p < 0.05$) for water holding (3.82 g water/g sample), oil holding capacity (2.86 g oil/g sample) and swelling capacity (7.34 mL/g sample) than TDCF which showed values of WHC, OHC and SWC of 2.25 g water/g sample, 1.91 g oil/g sample and 3.90 mL/g sample, respectively. The values obtained were higher than those reported by Kim et al. [30] in house cricket flour obtained by spray-dried with values of water holding and oil holding capacity of 2.6 and 1.75 g of water and oil, respectively, held per g of sample. The values obtained for WHC and OHC of house cricket flours (LCF and TDCF) were higher than those reported for quinoa flours with values comprised between 1.41 and 1.66 g water/g sample for WHC or 0.89 and 1.04 g oil/g sample for OHC. However, the SWC was lower than showed the quinoa flours [11].

The difference in protein structure and the presence of different hydrophilic carbohydrates might be responsible for variation in the water holding capacity of the flours [31]. In the same way, the differences in oil holding capacity could be possible due to the different conformational characteristics, surface hydrophobicity or lipophilicity of the proteins [32]. Emulsifying capacity is a molecule's ability to act as an agent that facilitates solubilization or dispersion of two immiscible liquids, and emulsion stability is the ability to maintain the integrity of an emulsion [27]. LCF had better emulsifying capacity and emulsion stability ($p < 0.05$) than TDCF (Table 3). The values obtained for LCF were higher than those reported by Ndiritu et al. [28] for powder obtained from freeze-dried house cricket from Kenia (26.83%) or Kim et al. [30] in spray-dried house cricket flour (39.2–45%). The differences between the emulsion activities and emulsion stabilities are related to the amphiphilicity of the protein surface, protein contents (soluble and insoluble), and other components such as carbohydrates which could aid stabilize the emulsion by increasing the viscosity of the system [33]. On the other hand, thermal treatment of the sample could expose previously inaccessible amino acids in the parent protein. Release of these surface-stabilizing residues can increase hydrophobic interactions and thus, facilitating emulsion formation [34].

As regards to foam capacity and foam stability (Table 3) the results obtained showed that LCF had better foam capacity and foam stability ($p < 0.05$) than TDCF. Foaming properties are dependent on the proteins and some other components, such as carbohydrates, present in the flours [35]. Thus, as mentioned Kinsella [36] the capacity of a protein to act as a foaming agent depends on several factors such as: (1) its rate of migration to the air/water interface, (2) its capacity to unfold and rearrange at the interface, and (3) the physical characteristics of the interfacial film produced. An increased surface hydrophobicity due to heat-induced denaturation would favor the FC by improving the adsorption at the air/water interface [34].

Fatty acid profile

The fatty acids profile of oils obtained from house cricket (*A. domesticus*) flours are shown in Table 4. The oil yield

Table 3 Techno-functional properties of flours obtained from house cricket (*Acheta domesticus*)

	WHC	OHC	SWC	EC	ES (%)	FC (%)	FS (%)
LCF	3.82 ± 0.09^a	2.86 ± 0.10^a	7.34 ± 0.21^a	58.87 ± 0.49^a	95	100	75
TDCF	2.25 ± 0.29^b	1.91 ± 0.12^b	3.90 ± 0.17^b	42.14 ± 0.53^b	90	86	65

Values followed by the same letter in the same column did not show statistically significant differences according to Tukey's HSD post hoc test ($p > 0.05$)

LCF lyophilized cricket flour, *TDCF* thermal dried cricket flour, *WHC* water holding capacity, *OCH* oil holding capacity, *SWC* swelling capacity, *EC* emulsion capacity, *ES* emulsion stability, *FC* foam capacity, *FS* foam stability

Table 4 Fatty acids profile of oils obtained from house cricket (*Acheta domesticus*) flours identified by means of GC (mean ± standard deviation)

ID	LCF	TDCF
C14:0	0.53 ± 0.01^{eB}	1.05 ± 0.03^{fA}
C16:0	20.51 ± 0.16^{bB}	22.20 ± 0.13^{cA}
C16:1c7	0.90 ± 0.13^{dB}	5.38 ± 0.08^{eA}
C17.0	ND	0.26 ± 0.04^{gA}
C18:0	12.95 ± 0.08^{cA}	7.07 ± 0.11^{dB}
C18:1c9	19.57 ± 0.17^{bB}	33.52 ± 0.17^{aA}
C18:2c9,12	44.98 ± 0.21^{aA}	30.18 ± 0.22^{bB}
C20:0	0.55 ± 0.03^{eA}	0.34 ± 0.01^{gB}
SFA	34.54 ± 0.11^{A}	30.92 ± 0.13^{B}
MUFA	20.47 ± 0.12^{B}	38.90 ± 0.13^{A}
PUFA	44.98 ± 0.12^{A}	30.18 ± 0.22^{B}

Fatty acids, % of total fatty acids. Lower-case letter refers to the comparison of the different compounds in the same samples while upper-case letter refers to the comparison of the same compound between the different cricket flours samples; results followed by the same lower/upper-case letter are not significantly different according to Tukey's HSD post hoc test ($p > 0.05$)

ND no detected

obtained for LCF and TDCF was different. Thus, LCF had a yield value of 19.32% while for TDCF was recovered an oil yield of 24.91%. In the same way, TDCF showed higher content ($p < 0.05$) of oleic acid (C18:1n-9) and palmitic acid (C16:0) than LCF; while LCF had higher amount ($p < 0.05$) of oleic acid (C18:1n-9) and stearic acid (C18:0) than TDCF. In LCF the main fatty acid detected ($p < 0.05$) was linoleic acid (C18:2n-6) which was followed by oleic acid (C18:1n-9) and palmitic acid (C16:0) with no statistical differences ($p > 0.05$) between them. In TDCF the main fatty acids detected were oleic acid (C18:1n-9) > linoleic acid (C18:2n-6) > palmitic acid (C16:0) > stearic acid (C18:0) with statistical differences ($p < 0.05$) between them. In both LCF and TDCF, small amounts of myristic acid (C14:0), margaric acid (C17:0) and arachidic acid (C20:0) were also found. These results were in agreement than those reported by Paul et al. [37] who found that the main fatty acids present in oils obtained from cricket were linoleic acid, palmitic acid and oleic acid. Tzompa-Sosa et al. [38] also observed a similar trend in the fatty acid composition of crickets feeds with carrot and chicken mash. These authors reported that oils obtained from cricket contain 31.80%, 30.23% and 24.81% of linoleic acid, oleic acid and palmitic acid, respectively. It is important to notice than the variances in fatty acid profile of whole insects might be dependent on numerous factors such as: life cycle, feed pattern and feed used, inter-tissue differences within an organism, uncommon features of specific insect species, and environmental conditions as mentioned Raksakantong et al. [39].

Table 5 Antioxidant properties of flours obtained from house cricket (*Acheta domesticus*)

	DPPH (mg TE/g)	FRAP (mg TE/g)	FIC (μg EDTA/g)
LCF	7.18 ± 0.12^{a}	0.24 ± 0.02^{a}	43.78 ± 0.42^{a}
TDCF	2.82 ± 0.06^{b}	0.15 ± 0.02^{b}	32.23 ± 0.44^{b}

Values followed by the same letter in the same column did not show statistically significant differences according to Tukey's HSD post hoc test ($p > 0.05$)

LCF lyophilized cricket flour, *TDCF* thermal dried cricket flour, *TE* Trolox equivalent

The high percentage of the fatty acids detected in oils obtained from both LCF and TDCF were unsaturated fatty acids (UFA). In LCF around, 45% of the total content was polyunsaturated fatty acids (PUFA) and a 21% of monounsaturated fatty acids (MUFA) whilst saturated fatty acids (SFA) represented the left 34%. In TDCF approximately 30% were PUFA, 39% MUFA and 31% SFA. The polyunsaturated to saturated fatty acid (P/S) ratio is one of the most important indicators of lipid composition in a healthy diet and it is suggested to consume diet with a P/S ratio near to 1 [37]. In this work LCF showed a P/S ratio of 1.30 while TDCF had a P/S ratio of 0.98. Diets with a high P/S ratio (≥ 3) could lead to the development of various diseases, among which are several tumors. On the other hand, diets with a low P/S ratio (≤ 0.33) could have an atherogenic capacity [40].

Antioxidant properties

To evaluate the antioxidant capacity of a single compound, an extract or a product there are different methods, but none of these may be considered as official. In fact, as mentioned Prior et al. [41] not a single substance, but a mixture of them with a different mechanism of action could contributes to conferring the antioxidant capacity of a foodstuff. For this reason, it is very important to use several tests, rather than relying on a single analysis to evaluate and contrast the antioxidant capacity. Thus, Table 5 shows the results for the antioxidant capacity of extracts obtained from LCF and TDCF determined with FRAP, DPPH and FIC assays. The cricket flours analyzed with DPPH assay showed different degrees of scavenging ability. Therefore, LCF presented the stronger ($p < 0.05$) radical scavenging effect than TDCF. In the FRAP assay, as occurs with DPPH assay, The LCF samples had higher ($p < 0.05$) ferric reducing capacity than TDCF samples (Table 5). Ferrous ion (Fe^{2+}), frequently found in food products, is well known as an active pro-oxidant agent. In this way, numerous bioactive compounds had the capacity to chelate these pro-oxidant agents and, therefore, reduce or avoid the free radical formation. Again, The LCF samples

showed higher ($p < 0.05$) ferrous chelating capacity than TDCF samples (Table 5).

The antioxidant activity showed by both LCF and TDCF could be attributed to the high content in proteins. As informed Elias et al. [42], one interesting property of proteins presents in foods is their capacity to inhibit oxidation reactions, e.g., acting as agents with antioxidant capacity. Thus, action mechanisms by which proteins can act as antioxidant agents could be due to: (1) their ability to donate protons, (2) the ability to chelate metal ions, (3) by eliminating radicals [43]. As mentioned Liu et al. [44], this could be attributed to the peptides with a low molecular weight have more amino acids exposed to interact with free radicals and this improves their antioxidant effect. In the group of the small peptides there are amino acids such as lysine and methionine, which provide higher oxidation resistance.

Conclusion

The flours obtained from house crickets have a great potential, to be used as functional ingredients in the development of new foods for food processing industry. TDCF and LCF can be considered a good source of proteins and fats. Additionally, due to their techno-functional properties, mainly its high water retention capacity, emulsifying capacity and swelling capacity, these flours have possible uses in the food industry as ingredients especially in products in which hydration, viscosity development and freshness preservation is required, such as various bakery products or certain cooked meat products. Nevertheless, further studies are necessary to assess the effect of house cricket flour on microbiological stability and sensorial properties of products which cricket flour is added.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human participants or animals performed by any of the authors.

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