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Impact of Cooking Time on the Physicochemical and Nutritional Properties of *Macrotermes subhyalinus* and *Imbrasia obscura*

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Abstract

Insects are considered as an important source of essential nutrients because of their nutritional value which in turn is related to proteins, lipids, and mineral elements. In order to optimise the nutritional quality of insects, there is a need to identify processing and cooking methods that will result in higher retention of quality nutrients. Several researchers have investigated the effect of cooking methods on the nutritional quality of edible insects. The effect of cooking time on physico-chemical and nutritional parameters of *Macrotermes subhyalinus* Rambur and *Imbrasia obscura* Butler was evaluated in this study. *M. subhyalinus* échantillons were fried and grilled at a temperature of 150˚C at intervals of 3, 6, 9, and 12 minutes. *I. obscura* was initially boiled at 93.4˚C for 6, 9, 12, and 15 minutes. Then, *I. obscura* which had been boiled for six minutes at 93.4˚C was fried for 3, 6, 9, and 12 minutes, respectively, at 150˚C. The analysis used the pre-levered samples from those various times. The results obtained for *M. subhyalinus* and *I. obscura* respectively demonstrate that these two insects comprise primarily proteins (36.83 and 59.04 g/100g DM), lipids (54.24 and 18.67 g/100g DM), and total mineral content (5.87 and 7.82 g/100g DM). With increased cooking time, physical-chemical and nutritional indicators decreased significantly ($p < 0.05$). When the insects were fried and toasted, the total mineral content increased, but only the lipids increased considerably ($p < 0.05$). Fry for 3 to 6 minutes and toast for 3 to 6 minutes are treatments for *M. subhyalinus* that better conserve nutrients. To preserve the nutritional value, scalding *I. obscura* for 6 minutes and combining it with frying it for 3 minutes are highly advised.

Keywords

Entomophagy, Insects, Processing, Nutritional Value

1. Introduction

Due to the fact that edible insects are not included in national economic data on food consumption, the contribution of edible insects to food and nutrition security, as well as the battle against poverty, is underappreciated in Cameroon [1] [2] [3]. In most cases, insect usages and commercialisation remain informal. Though insect consumption seems to be innovative, it is rather a reintroduction of this food product in our feeding habits. Several studies show that edible insects were so popular at the time of our ancestors [2] [3]. A survey conducted in the Adamawa and East regions of Cameroon showed that insects such as *I. obscura* and *M. subhyalinus* are of great interest in the food habits of the local population [4]. These insects are mainly fried, toasted, grilled, scalded, and roasted. Many authors [3] [4] [5] reported that the cooking method affects proteins, fats, carbohydrates, total minerals, and *in vitro* digestibility of proteins of *I. obscura* and *M. subhyalinus*. It was reported that the method and cooking temperature considerably modify the content of certain nutrients in pork and beef meats [6] [7] [8]. Nevertheless, studies of the influence of culinary treatments on the content and quality of nutrients of edible insects are less known, especially for the two insects mentioned above. In the Adamawa and East regions of Cameroon, *M. subhyalinus* is generally consumed fried or toasted and *I. obscura* is either scalded or scalded and fried [5]. During various processing treatments, several chemical reactions happen [9] and can affect the texture of insects, and modify their physicochemical and nutritional properties [5] [10] found that the application of heat treatments to *M. subhyalinus* and *I. obscura* reduced the microbial load to the recommended values by AFNOR norm. Moreover, frying and toasting resulted in the reduction of nutritive and nutritional parameters from 5% to 64% for *M. subhyalinus* [5]. On the other hand, scalding, the combined process of scalding and frying reduces nutritional parameters from 5% to 30% for *I. obscura* [5]. However, according to data gathered by [5] from the populations of the East and Adamawa areas of Cameroon, the cooking time varies from person to person. These values range from 3 to 20 minutes. It is, therefore, known that for a given heating treatment, the breadth of its effect on the reduction of the nutritional parameters is a function of time. The study of the variations of the different parameters with respect to the cooking time of *M. subhyalinus* and *I. obscura* becomes a necessity. Therefore, the goal of this study is to determine how cooking time affects many factors, including protein digestibility, protein content, lipids, and total minerals.

2. Materials and Methods

Sources and Collection of Insects

I. obscura and *M. subhyalinus* (images are presented in Figure 1) were collected early in the morning in Garoua-Boulai (5˚53'00"N, 14˚33'00"E) East region of Cameroon in July 2020 for the first sample. The sample second was collected in Ngaoundere 3 subdivision (7˚19'39"N, 7˚19'39"E) Adamawa region, Cameroon, in the month of June of the same year.

Preparation of Insects

The different treatment methods applied (Figure 2 and Figure 3) on these insects are the most used, as mentioned by the population consuming the insects in the Adamawa and East regions of Cameroon [5]. Wings and other impurities of selected *M. subhyalinus* were removed while the digestive tract of *I. obscura* was emptied by exerting pressure using the fingers from the head to the abdomen end. These insects were then washed using distilled water before processing. A batch of insects weighing 250 g was used for each treatment. The cooking temperature for scalding was set at 93.5˚C ± 0.5˚C, and frying and grilling were done at 150˚C ± 0.5˚C. Sampling was done withing specific and regular time intervals of 0, 3, 6, 9, and 12 min for toasting and frying of *M. subhyalinus*, 0, 6, 9,

(A) (B)

Figure 1. Photograph of *Imbrasia obscura* (A) and *Macrotermes subhyalinus* (B).

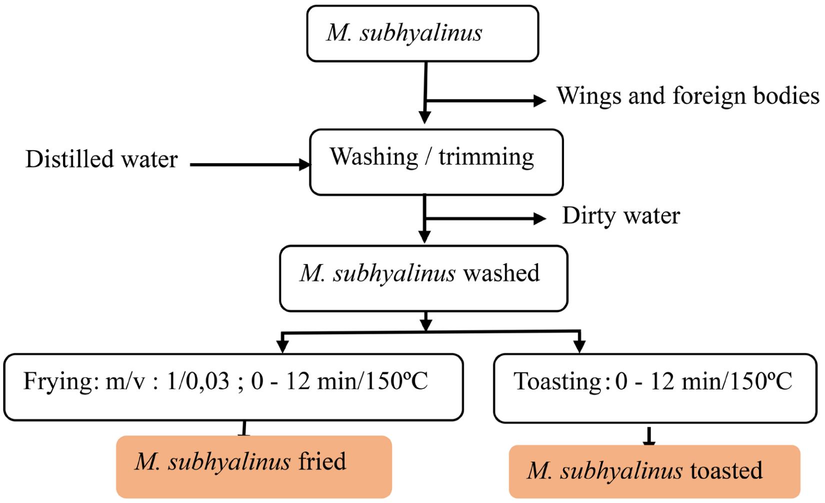

Figure 2. Cooking kinetic of *M. subhyalinus*.

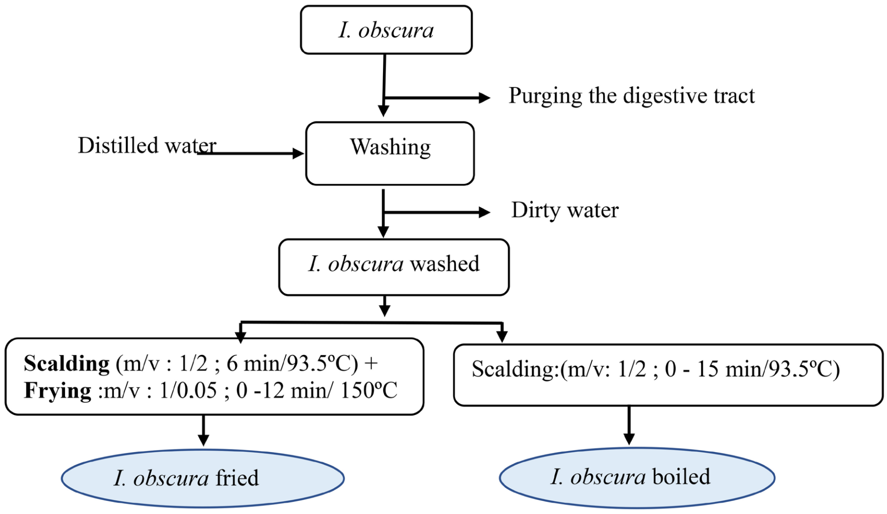

Figure 3. Cooking kinetics of *I. obscura*.

12, 15 min for scalding of *I. obscura* and 0, 3, 6, 9 and 12 min for the frying of *I. obscura*. The time used for the first sampling represents the minimum cooking time and the maximum cooking time is that of the last sampling The physicochemical analyses performed the so treated samples were the moisture, protein, carbohydrate, lipids and total mineral content whereas the proteins digestibility and the energy density as well as described below. Raw sample was considered as control.

Physicochemical and Nutritional Analyses

Moisture content was determined by the method described by [11]. Total mineral content were evaluated by [12] method; total fat content was done using Soxhlet as described by [13], while total nitrogen was determined after mineralisation of samples according to the Kjeldahl method [14] and assessment was done by the colorimetric technique of [15], protein content was calculated by multiplying the nitrogen content by the conversion factor of nitrogen to protein (6.25). The total carbohydrate content was determined by subtracting the water, proteins, lipids, and ashes from 100% of dry matter. The energetic density was calculated from the values of total proteins, fats and carbohydrate by applying the conversion into energy using the formula given by [16]. The method of [17] was used to determine the *in vitro* protein digestibility.

Statistical Analyses

Experiments were done in triplicate and data expressed as mean ± standard-deviation. Similarly, increasing or reducing percentage of different parameters with respect to the crude sample was calculated. Analysis of variance (ANOVA) was used to compare the means of the different treated samples. The Duncan multiple range test was applied to classify means when there was a significant difference at 5% using Statgraphics Centurion. The principal component analysis was investigated how variables related to one another and how samples varied. The plotting of curves was done using Sigma plot 11 software.

3. Results and Discussion

Table 1 shows the findings from the nutritional and physicochemical content of raw samples of *M. subhyalinus* and *I. obscura.*

The effects of cooking on total minerals, carbohydrates, moisture content, and *in vitro* protein digestibility on raw, fried, and roasted *M. subhyalinus*, scalded and roasted *I. obscura* were investigated.

Variation of Moisture Content of *M. subhyalinus* and *I. obscura* during Cooking

The moisture content significantly differed ($p < 0.05$) between raw samples of *I. obsura* (57.28%) and *M. subhyalinus* (52.47%). Results obtained while cooking the two insect samples are presented in Figure 4 and show that cooking has an influence ($p < 0.05$) on the moisture content.

Frying and toasting *M. subhyalinus* and the combined process of scalding and frying *I. obscura* significantly reduced the amount of water present during cooking. For fried and grilled *M. subhyalinus*, the correlation between cooking time and the outcome was negative ($r = -0.91$) and ($r = -0.90$), respectively. Additionally,

Table 1. Physicochemical and nutritional composition of *M. subhyalinus* and *I. obscura*.

Parameters	Water content (%)	Crude proteins (Nx6.25)	Crude fats (g/100 de MS)	Ashes (g/100 de MS)	Total carbohydrates (g/100 de MS)	*In vitro* protein digestibility (%)	Energy densities (Kcal/g)
M. subhyalinus	52.47 ± 0.94	36.83 ± 0.44	54.24 ± 0.01	5.87 ± 0.10	3.04 ± 0.36	86.65 ± 0.54	3.07 ± 0.06
I. obscura	57.28 ± 0.43	59.04 ± 0.46	18.67 ± 0.26	7.82 ± 0.53	14.45 ± 0.74	85.20 ± 0.36	1.97 ± 0.04

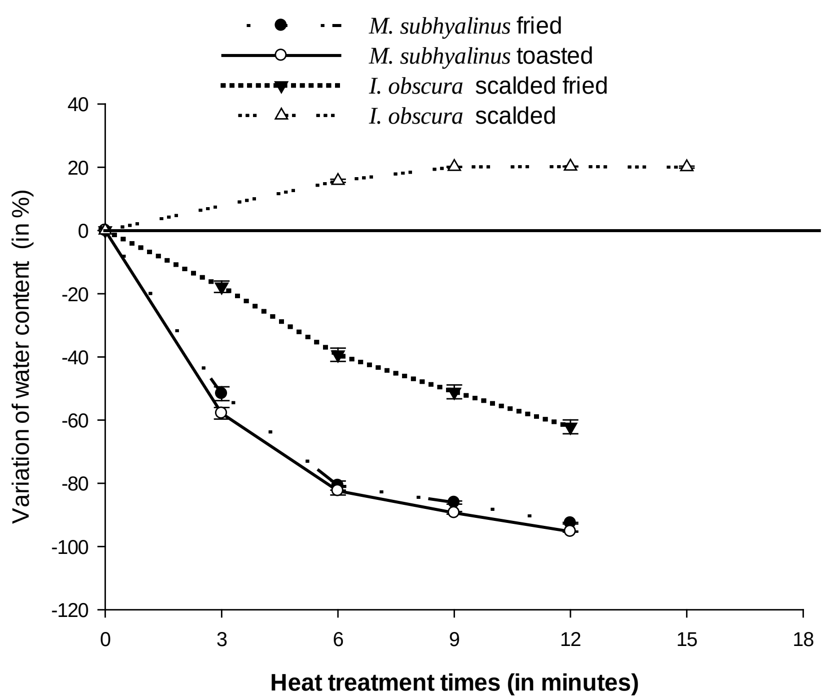

Figure 4. Evolution of moisture content of *M. subhyalinus* and *I. obscura* with respect to the cooking method.

there was a significant difference ($p < 0.05$) between the water content and cooking time for all *M. subhyalinus* treatments. In contrast, scalding *I. obscura* allowed for a considerable ($p < 0.05$) increase in water during the first nine minutes of cooking, after which the moisture content became constant. The correlation ($r = 0.89$) between the moisture content and the scalding time of *I. obscura* is positive. The reduction of the moisture content at the end of 3, 6, 9 and 12 minutes for *M. subhyalinus* during frying (51.67%, 80.74%, 86.11% and 92.63%) is significantly ($p < 0.05$) higher than that of *I. obscura* (20.81%, 41.53%, 52.90% and 63.55%). These results show that insects obtained after cooking for 9 min and 12 min are good for long time storage. On the microbiological aspect, these low moisture contents could limit the development of microorganisms [18]. The effect of moisture content increase observed during scalding in this study is contrary to the works of [19] who found that boiling of rabbit meat for 5, 15 and 40 min enhanced the reduction of the water content by 12.03%, 11.66% and 12.98% respectively. This difference can be explained by the structure of proteins and their capacity to absorb and retain water. However, the reduction of the moisture content observed during frying and toasting is similar to the study of [19] in which frying of rabbit meat for 2, 4 and 6 min led to a reduction of humidity from 49.92%, 96.56% and 98.88%, respectively. These results show that boiling has less influence on the moisture content of insects compared to frying.

Variation of the Protein Content of *M. subhyalinus* and *I. obscura* during Cooking

The raw samples of *I. obscura* had higher protein content than the raw samples of *M. subhyalinus* (**Table 1**). The heat treatments by frying and toasting *M. subhyalinus* then fried and scalded *I. obscura* carried out in the course of this study enhanced an increase in protein content during the first 6 minutes of cooking, compared to the crude sample. After 6 min, a significant lost in protein content was observed. **Figure 5** shows the differences in protein concentration depending on the type and length of treatment.

Frying and toasting resulted in an increase in protein content of *M. subhyalinus* and scalding *I. obscura* samples during the first 6 minutes of cooking of 3.45%, 5.64% and 5.77% respectively. These results contradict the findings of [19] who reported the reduction in protein content during rabbit meat scalding and frying. According to [19], losses in protein content of boiled rabbit meat during 5, 15 and 40 min were 2.51%, 7.75% and 17.78%, respectively. Hydrolysis of proteins and the drainage of sarcoplasmic proteins could explain the higher protein losses of boiled meat for 15 to 40 min than meat boiled for 5 min compared to raw proteins. These differences may also be explained by the nature of the substrate and protein structure involved. The increase of protein losses is associated to the increase of frying time as described by [20]. The losses of protein content in this study happened with the increase of cooking time, and the loss due to frying is greater compared to boiling. Another possible reason is that, frying at high temperature (150˚C ± 3˚C) might have caused more important

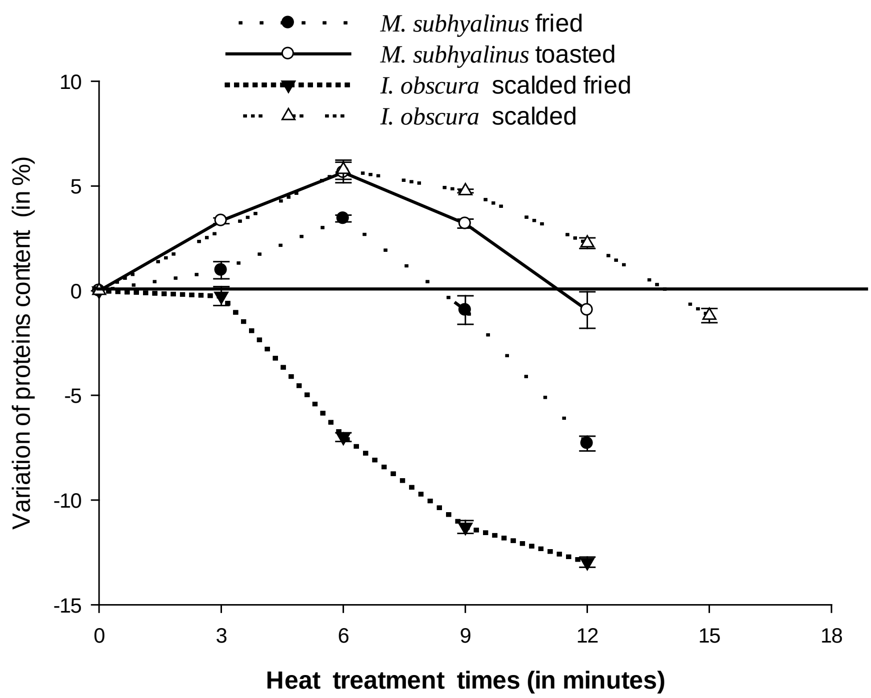

Figure 5. Evolution of the protein content for *M. subhyalinus* and *I. obscura* with respect to cooking time.

and rapid denaturation compared to boiling at low temperature, by so doing leading to losses of greater water molecules [21]. The oil absorption during frying or protein diffusion in oil used may be another reason of the slight reduction in protein content during frying as compared to boiling.

Variation of the Fat Content of *M. subhyalinus* and *I. obscura* during Cooking

Fat contents varied treatment type and cooking time, compared to raw insects in which fat values are 18.67 g/100 of DW and 54.24 g/100 DW respectively for *I. obscura* and for *M. subhyalinus* (**Figure 6**). Oil can be gained by absorption when frying. Fried *M. subhyalinus* and scalded/fried *I. obscura* after 12 min of cooking contributed to observe fat increase of 1.64% and 60.07% respectively. The different absorptions observed between the two insects may have resulted from the difference of hight and the structure (tissue matrix) of these insects which in turn is responsible of their abilities to retain absorbed oil. These results corroborate those of [22], whose experiments with dry pork flesh demonstrated that a significant amount of oil can permeate meat during a straightforward frying. Meanwhile scalding *I. obscura* and toasting *M. subhyalinus* in different cooking times resulted to a significant reduction in the quality of lipids. The lipids loss varied from 2.67%, 8.78%, 12.37% and 13.81% after 6, 9, 12 and 15 min of scalding of *I. obscura*. This reduction may be explained by the melting of fat globules in boiling water. Similar results have been reported by [23] on beef meat. Still, grilling of *M. subhyalinus* revealed fat losses of 1.29%, 3.89% and 4.51% after 6, 9, and 12 min of cooking respectively. This loss may be due to fat

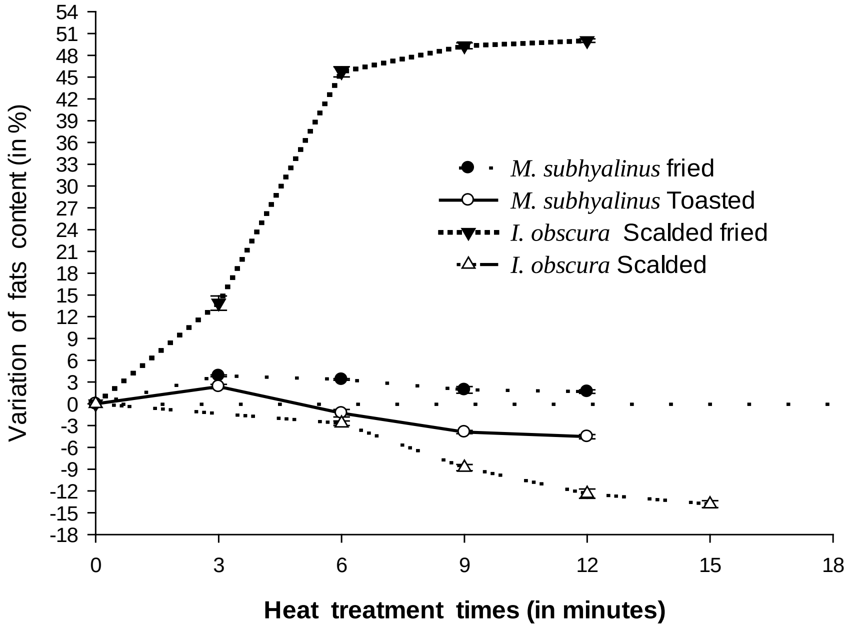

Figure 6. Evolution of fat content for *M. subhyalinus* and *I. obscura* with respect to cooking mode and time.

melting and exudation after tissue contraction, while part of it was lost by thermal decomposition. Similar results have been presented in the works of [24] during grasshopper grilling.

Variation of Ash Content for *M. subhyalinus* and *I. obscura* during Cooking

Results presented in Figure 7 show that ash contents of insects are influenced by cooking methods and time. Ash content of raw *M. subhyalinus* was 5.87 g/100g DM and that of raw *I. obscura* was 7.82 g/100g DM.

A decrease in total mineral content of 9.46% was observed after 9 min of scalding of *I. obscura* and did no longer vary significantly ($p < 0.05$) up to 15 min of cooking. The cooking time was negatively correlated ($r = -0.90$) with the total mineral content. There were losses during scalding and this may be due to the dissolution of minerals in cooking water. These observations are dissimilar to those of [25] who mentioned an increase of ash content during boiling of three species of Nigerian fishes. This difference may be justified by the nature of the matrix substrate. Frying and roasting of *M. subhyalinus* and frying of *I. obscura* increases the amount of minerals in the dry matter. For fried and toasted *M. subhyalinus* and fried *I. obscura*, the correlations between ash contents and cooking duration are positive and, respectively, significant ($r = 0.77$, 0.88, and 0.97). Water lost observed during frying and toasting has favoured minerals concentration in dry matter. Thus, the increase in ash content observed with cooking time. These results are in accordance with those of [26] who found that ash content in raw fish (0.63%) is about twice or trice greater compared to that of fried fish (1.42%). Mineral contents of *I. obscura* and *M. subhyalinus* were equivalent compared to cooking effects on their variations. Mineral content of

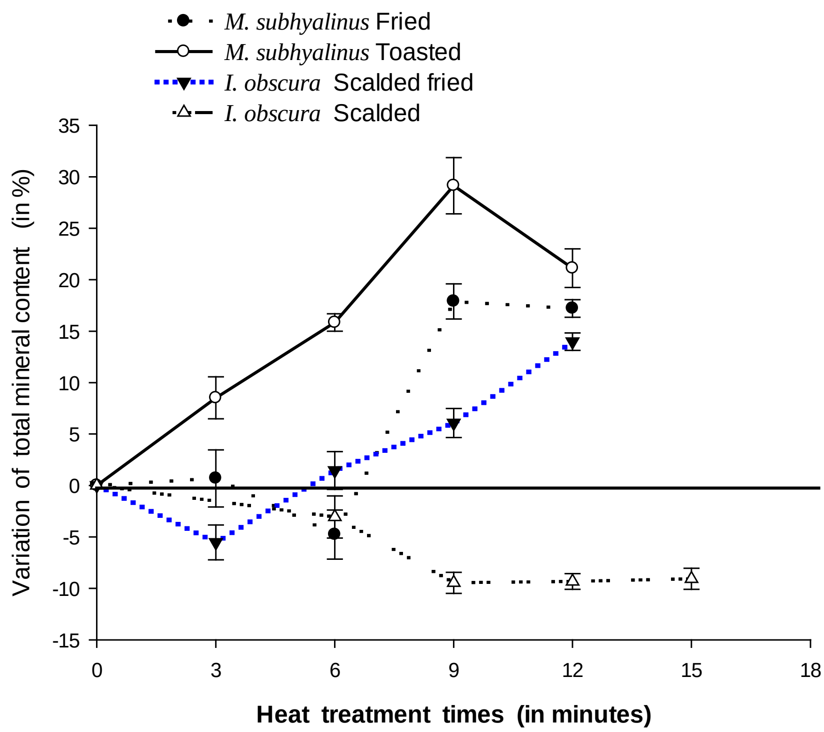

Figure 7. Variation of total mineral content for *M. subhyalinus* and *I. obscura* with respect to cooking method and time.

edible insects varies greatly with species and orders [3] and the applied heat treatments might have also affected the mineral composition from one insect species to another [27].

Variation of the Carbohydrate Content for *M. subhyalinus* and *I. obscura* during Cooking

Results of the carbohydrate content for both studied insects are presented in Figure 8. Overall, the carbohydrate content decreases considerably during the first 6 minutes of processing. Losses were higher during frying and grilling of *M. subhyalinus* (up to 90% loss). Xiaoming *et al.* [28] found that the carbohydrate content of insects varies between 3.7 to 16.3 g/100g of DM with a mean value of 8.2 g/100g of DM. Comparing the present results with those of [28], it shows that only the carbohydrate content of *I. obscura* falls within this intervalle (14.45 g/100g of DW). *M. subhyalinus* had low carbohydrate content of 3.04 g/100g of DW and the culinary treatments applied in this study contributed significantly ($p < 0.05$) to the reduction of the carbohydrate content with cooking time. Carbohydrates are involved in Maillard and caramelisation reactions [29]. This transforms carbohydrates into other products in particular the pyrazines responsible for the aroma and the melanoidins which give the brown color to these cooked insects. The decrease of **carbohydrate content** observed during scalding results from the losses of other constituents in particular by solubilization of free sugars and minerals which favour a concentration effect of other constituents. The cooking time considerably influenced the carbohydrate levels of *M. subhyalinus* and *I. obscura. It is important to* reduce the cooking time at 9 min.

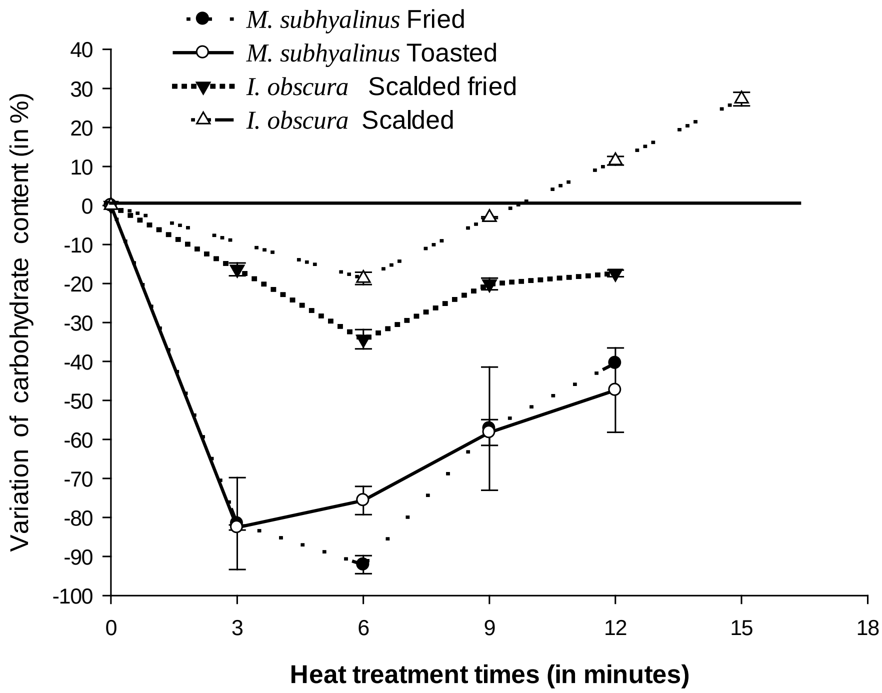

Figure 8. Evolution of carbohydrate content of *M. subhyalinus* and *I. obscura* with respect to the cooking mode and time.

Variation of Energetic Density of *M. subhyalinus* and *I. obscura* during Cooking

Energetic densities of insects vary with the cooking method and time (**Figure 9**). Significant differences ($p < 0.05$) were observed between the energetic density of scalded and fried *I. obscura* compared to the raw samples. The energetic density of scalded and fried insects increased after 12 min of cooking. This increase results from the loss of water during cooking and which contributed to concentrate the nutrients. Also, absorption of oil contributed to increase the quantity of lipids, and as such justifies the high energetic density. However, the energetic density of scalded *I. obscura* varied significatively and negatively ($p < 0.05$) after 15 min of cooking. A reduction of 2.17% was observed. This reduction results from water absorption during the treatment and the fats losses. This observation is in line with that of [2]. For *M. subhyalinus*, there was no significant difference between fried and raw samples after 12 min of cooking. Nevertheless, the reduction of energetic density was 2.66% after 12 min for the toasted sample. Despite the fact that the reduction is significant at 5% level, it has not influence on the energetic density.

Variation of Protein Digestibility for *M. subhyalinus* and *I. obscura* with Respect to Cooking Time

Based on results obtained in this study (**Figure 10**), the applied treatments lead to considerable loss of protein digestibility after a certain cooking time. The *in vitro* digestibility of proteins of raw samples is 85.20% and 86.65% respectively for *I. obscura* and *M. subhyalinus.*

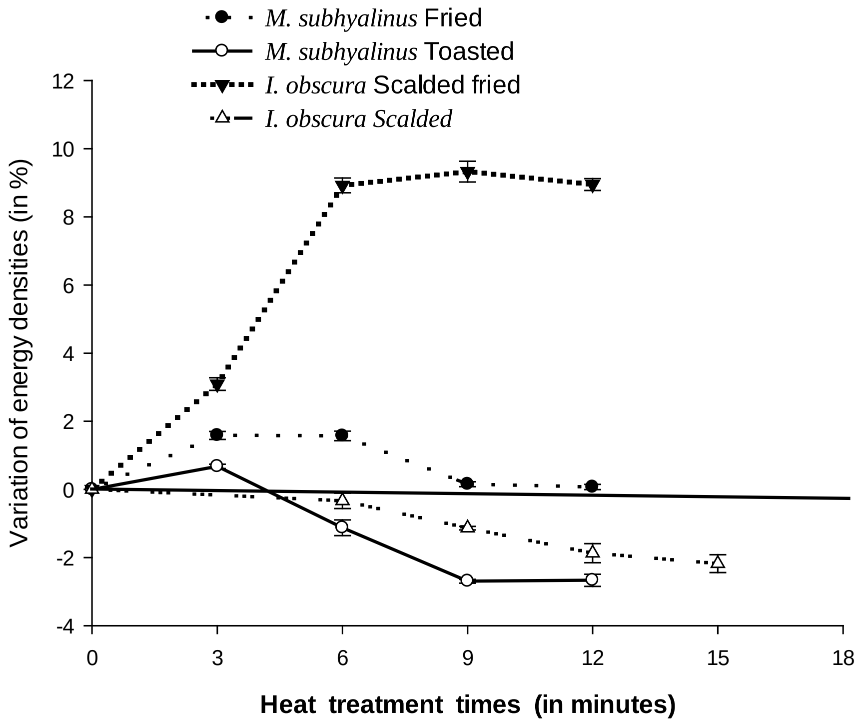

Figure 9. Evolution of energetic density for *M. subhyalinus* and *I. obscura* with respect to cooking time.

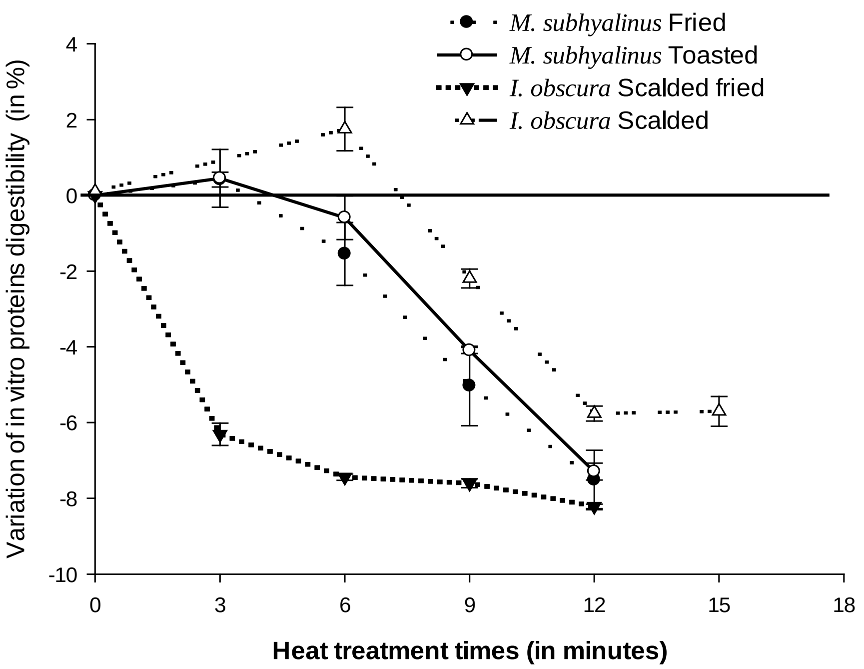

Figure 10. *In vitro* digestibility of proteins for *M. subhyalinus* and *I. obscura* with respect to cooking methods and time.

Compared to the raw samples, digestibility increased with cooking temperature 70˚C to 90˚C and this corresponds to a 3 min of cooking time for fried and toasted *M. subhyalinus* and 6 min of cooking time for scalded *I. obscura*. This effect can be explained by a progressive denaturation of proteins, which exposed cleavage sites to digestive enzymes, meanwhile at higher temperature, oxidation lead to the degradation of proteins. This could hide the cleavage sites as explained by [30], thus, the reduction of digestibility during treatments at high temperatures above the cooking temperature previously mentioned. Proteins undergo several technological treatments before being ingested. There exist typically three mechanical treatments which consist of product denaturation and its assembling; chemical treatment by which the action of solutes (salts, acids, spices, etc) modifies the structure and the composition of tissues; and thermal treatment for which the effects are variables with respect to temperatures and the target time. During these treatments, the macro and microstructures of the matter are modified by physicochemical changes involving proteins, lipids and micronutrients [31]. These structural modifications at the alimentary level are susceptible of either increasing or reducing the accessibility of the proteins to the site of enzyme digestion. The becoming of proteins is therefore susceptible of being modified by the nature of unit operation and notably the duration of heat treatments. In fact, digestibility of proteins is reduced by formation of disulfate bonds in the matrix of proteins or the formation of protein aggregates which limited the action of proteolytic enzymes. This observation may justify the reduction of digestibility of proteins of fried *M. subhyalinus*, toasted *M. subhyalinus*, scalded *I. obscura*, scalded and fried *I. obscura* after 6, 9, 9, 6 min of cooking time respectively. Also, peroxidation products of lipids increased with temperature above 100˚C. These products react with proteins notably to form Schiff bases [30]. These Schiff Bases constitute the first step in the aggregation at the molecular scale and new molecular interactions leading to hiding of cleavage sites. Authors [32] mentioned that digestibility is increase if the unfolding of polypeptide chain is favoured. In addition, structural modifications of proteins induced by the action of heating increase the inaccessibility of some digestive proteases. This observation can be elucidated by the increase of the digestibility of proteins at the end of 3, 3 and 6 min of cooking for fried *M. subhyalinus*, toasted *M. subhyalinus* and scalded *I. obscura* respectively. These events depend also for the intrinsic contributors to the conformation stability of proteins of different sources. Auto-oxidation reactions (that take place at high cooking temperatures like frying and toasting) improved the formation of covalent bonds that link polyphenols and proteins in a reversible mana, reducing as such the digestibility of proteins [33]. Based on results obtained, it is preferable to limit the cocking time at 6 min for scalding, 3 to 6 for toasting and frying, because these temperatures best preserve the digestibility of proteins. However, the issue will be the acceptability of these products by the consumers for these desired cooking durations.

Principal Component Analysis of Nutritional and Functional Properties of Cooking Duration

Principal component analysis (PCA) was done to group the cooking time that can have influence on the nutritional properties. The principal component analysis enabled the establishment of groups within constituents (dry matter, lipids, proteins, protein digestibility and total mineral). **Figure 11** presents the bidimensional repartition of *I. obscura* and *M. subhyalinus* cooked at different times and their constituents that influenced the nutritional properties on the principal components coordinates (F1, F2).

Figure 11 reveals that the principal component F1 explains respectively 60.73%, 71.13%, 73.05%, 88.23% of total information. It is noted that contribution of variables for the formation of the principal axis F1 like the protein content, the protein digestibility and their fats content are highly associated to F1 axes. The distribution of constituents along F1 shows a distinction among them with respect to cooking time. It can be drawn from the graphs that:

- Fried *M. subhyalinus* for 3 and 6 min grouped a maximum of proteins, lipids and protein digestibility;
- Toasted *M. subhyalinus* for 3 and 6 min presented a maximum of protein content, lipids and protein digestibility;
- Scalded *I. obscura* for 6 min concentrated a maximum of the protein content, lipids, and protein digestibility;

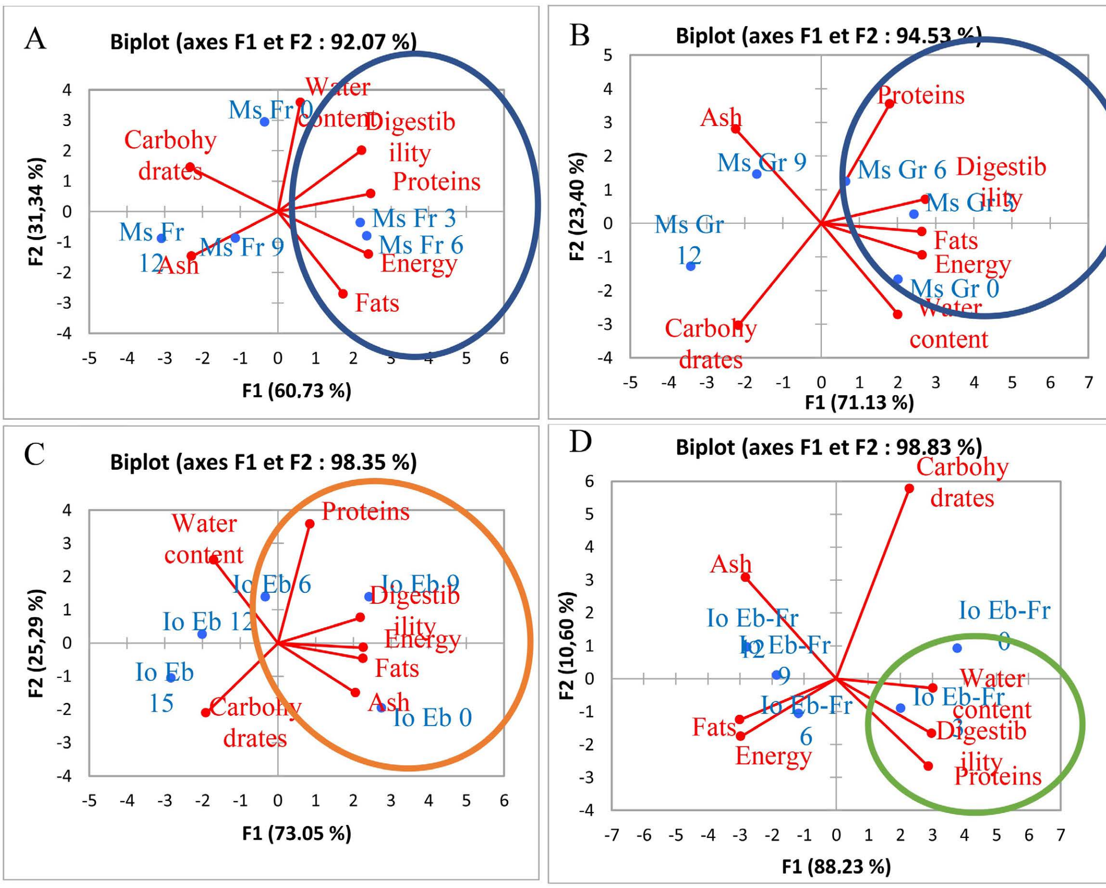

Figure 11. Two-dimensional distribution at different cooking times of the technological treatments (*M. subhyalinus* fried (A), *M. subhyalinus* roasted (B) and *I. obscura* scalded (C), *I. obscura* scalded fried (D)) and their components on the coordinates of the principal components (F1, F2). Legend: Io Eb: *I. obscura* scalded; Io Eb Fr: *I. obscura* scalded fried; Ms Fr: *M. subhyalinus* fried; Ms Gr: *M. subhyalinus* toasted; 0, 3, 6…: times.

- Scalded *I. obscura* for 6 min then fried for 3 min gave a maximum of the protein content, lipids, protein digestibility.

It clearly appears from **Figure 11** that constituents like lipids, proteins, digestibility and a total mineral content which are elements of nutritional interest are well represented at the cooking time of 3 to 6 min for fried *M. subhyalinus* and toasted at 6 min for scalded *I. obscura* and 3 min of frying for previously scalded *I. obscura* for 9 min. These times are considered as best cooking times.

4. Conclusion

It was found from the present work that cooking induces the degradations of insect constituents. This study also revealed that the cooking time has influenced different parameters analysed. Ash and protein increased during frying and grilling, while carbohydrates decrease. The digestibility of *M. subhyalinus* and *I. obscura* proteins diminishes with the increase in the heat treatment cooking time compared to raw samples. The best treatment times for *M. subhyalinus* are 3 to 6 min for frying and 3 to 6 min for toasting and that of *I. obscura* are 6 min for the scalded treatment, and the combined processes of scalding (6 min) and frying (3 min). Based on our findings, *M. subhyalinus* and *I. obscura* should be incorporated into the daily diet to reduce mineral deficiencies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hoare, A.L. (2007) The Use of Non-Timber Forest Products in the Congo Basin: Constraints and Opportunities. Report to the Rain Forest Foundation, London, 56 p.

[2] Malaisse, F. (2005) Human Consumption of Lepidoptera, Termites, Orthoptera and Ants in Africa. In: Paoletti, M.G., Ed., *Ecological Implications of Minilivestock*: *Potential of Insects*, *Rodents*, *Frogs and Snails,* Science Publishers, Inc., Enfield (USA), 175-230.

[3] Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P. (2013) Edible Insects: Future Prospects for Food and Feed Security. FAO Forestry Paper No. 171, Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/docrep/018/i3253e/i3253e.pdf

[4] Djouffa, K.M.L., Saïdou, C., Ali, A., Mohammadou, B.A. and Tchiegang, C. (2021) Edible Insects in the Adamawa and Eastern Regions of Cameroon: Collection, Processing and Consumption. *Journal of Insects as Food and Feed*, **7**, 483-494. https://doi.org/10.3920/JIFF2020.0015

[5] Djouffa, K.M.L., Saïdou, C., Mohammadou, B.A. and Ali, A. (2021) Effect of Culinary Treatments on the Nutritional and Microbiological Properties of *Macrotermes subhyalinus* and *Imbrasia obscura*: Two Insects Consumed in the Adamawa and Est regions of Cameroon. *Journal of Environmental Science Toxicology and Food Technology*, **15**, 35-46.

[6] Chen, Y.J., Zhou, G.H. and Zou, X.K. (2007) Effect of Cooking and Microwave Heat-

ing on the Fatty Acid Composition of Beef Intramuscular Lipid. *Proceedings of the 53rd International Congress of Meat Science and Technology*, Beijing, 5-10 August 2007, 471- 472.

[7] Ortigues-Marty, I., Thomas, E. and Preveraud, D.P. (2004) Influence of Maturation and Cooking Treatments on the Nutritional Value of Bovine Meats: Water Losses and Vitamin B12. *Meat Science*, **73**, 451-458. https://doi.org/10.1016/j.meatsci.2006.01.003

[8] Yang, J., Sulaeman, A. and Setiawan, B. (1993) Sensory and Nutritive Qualities of Pork Strips Prepared by Three Household Cooking Techniques. *Journal of Food Quality*, **17**, 33-40. https://doi.org/10.1111/j.1745-4557.1994.tb00129.x

[9] Belitz, H.D., Grosch, W. and Schieberle, P. (2004) Aroma Compounds. In: Belitz, H.-D., Grosch, W. and Schieberle, P., Eds., *Food Chemistry*, Springer, Berlin, 342-408. https://doi.org/10.1007/978-3-662-07279-0_6

[10] Jeantet, R., Croguennec, T., Schuck, P. and Brulé, G. (2006) Science des aliments. Vol. 1, Tec & Doc Lavoisier, Paris, 383 p.

[11] Association Française de Normalisation (AFNOR) (1982) Recueil des normes françaises des produits dérivés des fruits et légumes, Jus de fruits. 1st Edition, AFNOR, Paris, 328 p.

[12] Association of Official Analytical Chemists (AOAC) (1990) Official Methods of Analysis of the Association of Official Analytical Chemists. 15th Edtion, Washington DC.

[13] Bourely, J. (1982) Observation sur le dosage de l'huile des graines de cotonnier. *Coton et Fibres Tropicales*, **27**, 183-196.

[14] Association Française de Normalisation (AFNOR) (1984) Recueil de normes françaises. Produits agricoles alimentaires: Directives générales pour le dosage de l'azote avec minéralisation selon la méthode de Kjedahl. AFNOR.

[15] Devani, M.B., Shishoo, J.C., Shal, S.A. and Suhagia, B.N. (1989) Spectrophotometrical Method for Determination of Nitrogen in Kjeldahl Digest. *Journal of AOAC International*, **72**, 953-956. https://doi.org/10.1093/jaoac/72.6.953

[16] Stadlmayrm, B., Charrondierem, R.U., Enujiugham, N.V., Bayilim, G.R., Fagbohounm, G.E., Sambm, B., Addym, P., Barikmom, I., Ouattaram, F., Oshaugm, A., Akinyelem, I., Amponsahm, A.G., Bomfeh, K., Ene-Obongmm, H., Ifeyironwmam, F.S., Thiammm I. and Burlingamem B. (2012) West African Food Composition Table. FAO, Rome, 57-75.

[17] Hsu, H.W., Vavak, D.L., Satterlee, L.D. and Miller, G.A. (1977) A Multienzyme Technique for Estimating Protein Digestibility. *Journal of Food Science*, **42**, 1269-1273. https://doi.org/10.1111/j.1365-2621.1977.tb14476.x

[18] Chapeland-Leclerc, F., Papon, N., Noel, T. and Villard, J. (2005) Moisissures et risques toxicologiques (mycotoxicoses). *Revue Française des Laboratoires*, **373**, 61-66. https://doi.org/10.1016/S0338-9898(05)80236-7

[19] Zhang, Y., Wang, X., Wang, W. and Zhang, J. (2014) Effect of Boiling and Frying on Nutritional Value and *in Vitro* Digestibility of Rabbit Meat. *African Journal of Food Science*, **8**, 92-103. https://doi.org/10.5897/AJFS2013.1114

[20] Yu, T.H., Wu, C.M. and Ho, C.T. (1993) Volatile Compounds of Deep-Oil Fried, Microwave-Heated and Oven-Baked Garlic Slices. *Journal of Agriculture and Food Chemistry*, **41**, 800-805. https://doi.org/10.1021/jf00029a023

[21] Skog, K., Steineck, G., Augustsson, K.J. and Gerstad, M. (1995) Effect of Cooking Temperature on the Formation of Heterocyclic Amines in Fried Meat Products and

Pan Residues. *Carcinogenesis*, **16**, 861-867. https://doi.org/10.1093/carcin/16.4.861

[22] Haak, L., Sioen, I., Raes, K., Van Camp, J. and De Smet, S. (2007) Effect of Pan-Frying in Different Culinary Fats on the Fatty Acid Profile of Pork. *Food Chemistry*, **102**, 857-864. https://doi.org/10.1016/j.foodchem.2006.06.054

[23] Duchène, C. and Gandemer, G. (2017) Viandes crues, viandes cuites: Quels effets de la cuisson sur la composition en nutriments des viandes? *Cahier de nutrition et de diététique*, **52**, 134-149. https://doi.org/10.1016/j.cnd.2017.01.001

[24] Knothe, G. and 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. https://doi.org/10.1007/s11746-009-1423-2

[25] Bassey, F.L., Oguntude, F.C., Iwegbu, C.M.A., Osabor, V.N. and Edem, C.A. (2014) Effects of Processing on the Proximate and Metal Contents in Three Fish Species from Nigerian Coastal Waters. *Journal of Food Science and Nutrition*, **2**, 272-281. https://doi.org/10.1002/fsn3.102

[26] Hoffman, L.C., Prinsloo, J.F., Casey, N.H. and Theron, J. (1994) Effects of Five Cooking Methods on the Proximate, Fatty Acid and Mineral Composition of Fillets of the African Sharptooth Catfish, *Clarias gariepinus*. *Tydskrif vir Voedselwetenskap en Voeding*, **6**, 146-152.

[27] Nyangena, D.N., Mutungi, C., Imathiu, S., Kinyuru, J., Affognon, H., Ekesi, S., Nakimbugwe, D. and Fiaboe. K.K.M. (2020) Effects of Traditional Processing Techniques on the Nutritional and Microbiological Quality of Four Edible Insect Species Used for Food and Feed in East Africa. *Foods*, **9**, Article 574. https://doi.org/10.3390/foods9050574

[28] Xiaoming, C., Ying, F., Hong, Z. and Zhiyong, C. (2010) Review of the Nuritive Value of Edible Insects. *Proceedings of a Workshop on Asia-Pacific Resources and Their Potential for Development*, Chiang Mai, 19-21 February 2010, 34-40.

[29] Maillard, L.C. (1912) Action des acides aminés sur les sucres: Formation des mélanoïdines par voie méthodique. *Comptes Rendus de l'Académie des Sciences*, **154**, 66-68.

[30] Bax, M.L., Aubry, L., Ferreira, C., Daudin, J.D., Gatellier, P., Rémond, D. and Santé-Lhoutellier, V. (2012) Cooking Temperature Is a Key Determinant of *in Vitro* Meat Protein Digestion Rate: Investigation of Underlying Mechanisms. *Journal of Agricultural and Food Chemistry*, **60**, 2569-2576. https://doi.org/10.1021/jf205280y

[31] Oberli, M., Marsset-Baglieri, A., Airinei, G., Santé-Lhoutellier, V., Khodorova, N., Rémond, D., Foucault-Simonin, A., Piedcoq, J., Tomé, D., Fromentin, G., Benamouzig, R. and Gaudichon, C. (2015) High True Ileal Digestibility but Not Postprandial Utilization of Nitrogen from Bovine Meat Protein in Humans Is Moderately Decreased by High-Temperature, Long-Duration Cooking. *Journal of Nutrition*, **145**, 2212-2219. https://doi.org/10.3945/jn.115.216838

[32] Opstvedt, J., Nygård, E., Samuelsen, T.A., Venturini, G., Luzzana, U. and Mundheim, H. (2003) Effect on Protein Digestibility of Different Processing Conditions in the Production of Fish Meal and Fish Feed. *Journal of the Science Food and Agriculture*, **83**, 775-782. https://doi.org/10.1002/jsfa.1396

[33] Veldkamp, T., Van Duinkerken, G., Van Huis, A., Lakemond, C., Ottevanger, E., Bosch, G. and Van Boekel, T. (2012) Insects as a Sustainable Feed Ingredient in Pig and Poultry Diets: A Feasibility Study. Wageningen UR Livestock Research (Report/Wageningen UR Livestock Research 638), Lelystad, 48 p. http://library.wur.nl/WebQuery/wurpubs/428703