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Impact of defatting and drying methods on the overall liking and sensory profile of a cereal bar incorporating edible insect species

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ABSTRACT

It is necessary to develop products with desirable sensory properties in order to increase the acceptance of insect-based products by Western consumers. In this work, the impact of defatting on the sensory properties of cereal bars with yellow mealworm (*Tenebrio molitor*) larvae, in addition to the impact of different drying methods and different species (*T. molitor* and house cricket *Acheta domesticus*) were assessed. A model cereal bar incorporating oats, dried and dehydrated fruits was developed as well as four additional formulations with insect flour: defatted (Soxhlet method with ethanol) mealworm (TM_D), microwave (TM_MW) or oven dried (TM_O) mealworm and oven dried cricket (AD_O). A panel of 99 consumers rated overall liking and willingness to buy (9-point scale), and profiled the bars using a Check-All-That-Apply ballot. The bars with defatted or microwaved mealworm had similar liking and willingness to eat scores in comparison with the control bar. Conversely, bars with oven-dried insects had worse evaluations and were associated with negative attributes related to odor and flavor, which were hampered by defatting or microwave-drying. This study highlights how different processing methods can be applied in order to increase the sensory liking of insect-based products and also provides information on their sensory characterization.

1. Introduction

Entomophagy (intentional consumption of edible insects) is a traditional practice in several regions of the world (mainly Latin America, Africa and Asia) (Raheem et al., 2019). Due to the advantages presented by edible insects' consumption (environmental sustainable production and high nutritional value), they have also started to be recognized as a novel food source in Western countries (Lange and Nakamura, 2021). The popularity of insects as food has been growing, especially since the publication of the book *"Edible insects: future prospects for food and feed security food"* by the Food and Agriculture Organization (FAO) of the United Nations in 2013 (Huis et al., 2013). This increased popularity is not only present in the academic community but also in the food industry (e.g. commercialization of products incorporating processed insects) and the mainstream media. Additionally, the European Union has already approved the consumption of yellow mealworm larvae (EFSA Panel on Nutrition, 2021c), house cricket (EFSA Panel on Nutrition, N. F. a. F. A. 2021b) and migratory locust (EFSA Panel on Nutrition, N. F. a. F. A. 2021a), starting to put an end to years of legal uncertainty, which further demonstrates the increased implementation of edible insects in Western food markets.

However, despite these recent advances, acceptance of edible insects by Western consumers is still very low, particularly when considering a regular consumption of products incorporating edible insects. There has been a considerable amount of work performed on understating why consumers reject edible insects and which variables can positively influence acceptance. The majority of studies have focused on consumers' psychological traits and characteristics, identifying high disgust sensitivity/disgust towards insects and food neophobia as major predictors of entomophagy rejection (Cunha and Ribeiro, 2019; Mancini et al., 2019).

Strategies to increase acceptance have focused on diminishing disgust and neophobic reactions, and identifying target groups with a greater acceptance of entomophagy. The groups that have been identified consist of consumers with strong motivations related to their food choices (particularly the nutritional and/or environmental benefits) and consumers with great interest and curiosity in new food experiences (Palmieri et al., 2019; Placentino et al., 2021; Rovai et al., 2021; Tuccillo et al., 2020). Communicational strategies can also be important,

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and generally consist on popularizing entomophagy and the benefits associated with edible insects (Rumpold and van Huis, 2021). The correct communication of these benefits is essential because the general public still has a low knowledge of the benefits associated with edible insects (Florença et al., 2021).

Additionally, it is of utmost importance to bear in mind that the rejection of edible insects is driven by social and cultural norms that need to be changed in order to hamper disgust and neophobic reactions. Therefore, it is essential to associate insects with positive gastronomic experiences and increase the sensory appeal of developed products (Youssef and Spence, 2021). There are several ways to achieve this, including the organization of food banquets, publication of recipes by professional chefs, association with celebrities (Jensen and Lieberoth, 2019; Koch et al., 2021; Park et al., 2022) or incorporating processed insects into products that are considered appropriate by consumers (e.g. protein/energy bars, protein shakes, bakery/snack products) (Ardoin and Prinyawiwatkul, 2020).

However, the vast majority of studies on consumer perception of entomophagy has been performed on willingness to eat or try the products and the sensory experience associated with consuming insects or products incorporating them has been somewhat neglected. The taste of products is one of the most important factors when consumers make their food choices (Cunha et al., 2018), and most are not willing to choose a product solely on nutritional or environmental factors. In fact, poor taste has been identified as one of the major reasons for consumers to not repeat the purchase of insect-containing products (House, 2016). Additionally, several works have reported that the inclusion of insects led to a decrease in liking compared to control products and to a worse sensory and emotional profile, although there is a substantial lack of work evaluating the sensory profile of products incorporating insects (Cunha and Ribeiro, 2019). As such, it is necessary to better understand how the inclusion of insects influences the sensory profile of developed products and what processing technologies can be applied in order to improve their acceptance.

This work is a continuation of previous study (Ribeiro et al., 2019), which assessed the impact of defatting cricket species on the overall liking and sensory profile of cereal bars. In this study, the main goals were to assess how different processing technologies and insect species influenced the overall liking and sensory profile of a cereal bar. The insect species used were the yellow mealworm (*T. molitor*) larvae and house cricket (*A. domesticus*). The impact of different drying methods (electrical oven and microwave) and lipid extraction were assessed with *T. molitor*. For this study, it was decided to only defat oven-dried *T. molitor,* considering that in the previously cited study (Ribeiro et al., 2019) the authors had already studied the impact of defatting in the quality of freeze-dried crickets (both for *A. domesticus* and *G. sigillatus*). As such, it would be more pertinent to focus on different objectives (impact of different drying methods for different species and impact of defatting other species besides crickets). Lastly, the nutritional value of the developed bars was also evaluated.

2. Material and methods

2.1. Insect species

Two edible insect species, yellow mealworm (*T. molitor*) and house cricket (*A. domesticus*), were used. Both species were supplied alive (fastened for 48H) from a commercial supplier (Portugal Bugs, Portugal). Species were washed with a 200 ppm solution of sodium hypochlorite and euthanized by freezing at −24 °C. Species were kept frozen in pouches with a snap closure until further use.

2.2. Processing methods

In a previous work (Santos et al., 2021), authors assessed the impact of different blanching conditions, ascorbic acid treatment and drying methods on the dry matter, water activity and color of *T. molitor*. Based on the obtained results, the appropriate conditions were chosen to process *T. molitor* for further incorporation into food products.

Briefly, frozen insects were blanched at 100 °C for 5 min (w:v, 1:10) and were conserved at 2 °C. Then, different drying methods and conditions were assessed (electrical oven - 80 °C/7H, 60 °C/24 h; microwave 800W – 5, 4, 3 min; food dehydrator - 52 °C/24H, 68 °C/7 h). The chosen drying methods were electrical oven (80 °C/7 h) and microwave (4 min), since electrical-oven drying gave the better dry matter and water activity results and microwave-drying for 4 min led to acceptable dry matter (> 95%) and water activity (< 0.6) results while having the best color results (highest L* and b* values). After drying, insects were ground with a Kenwood Stand-Mixer and stored in air-tight containers at room temperature and sheltered from light until further use.

As for *A. domesticus,* the blanching treatment was equal to the one applied to *T. molitor* and only one drying method was used (electrical oven, 80 °C/7H)

2.3. *Defatting of* T. molitor

In order to defat *T. molitor* the Soxhlet method was applied, similarly to the works performed by Ribeiro et al. (2019) with crickets and Laroche et al. (2019) with mealworm and crickets. Ground *T. molitor* samples (dried in electrical-oven, 80 °C/7 h) were initially defatted with five organic solvents (absolute ethanol, methanol, acetone, hexane and ethyl acetate) to evaluate the best fat extraction solvent. In sum, 15 g of each sample was extracted with 650 mL of one of the organic solvents in a Soxhlet extraction apparatus, for 6 h. The remaining solvent was evaporated with a vacuum rotary evaporator. Vacuum pressure for all evaporations was 600 mbar, and evaporation occurred until no more solvent was visible. Water temperature differed according to the solvent:

- Ethanol – 85 °C;
- Methanol – 71 °C;
- Acetone – 56 °C;
- Hexane – 73 °C;
- Ethyl acetate – 82 °C;

The amount of fat extracted was determined gravimetrically (all experiments performed in quadruplicate). The cartridges with the defatted samples were dried at 95 °C for 12 h and then the defatted flour was stored in air-tight containers at room temperature and sheltered from light until further use.

In order to confirm the obtained results, fat content of the defatted samples with each of the solvents was determined with the Soxhlet method and with petroleum ether as the solvent. Experiments were performed in triplicate, with 20 g of defatted sample and 750 ml of solvent. Remaining solvent was evaporated with a vacuum rotary evaporator and fat content was determined gravimetrically. Based on these results, the solvent with the highest extraction ability was selected to defat the ground *T. molitor* samples for further incorporation in bars.

2.4. Bars elaboration and nutritional composition

Five different formulations of oats dehydrated and dried fruits bars were formulated (Table 1). The different formulations consisted in a control bar – CTRL – (without incorporation of insect) and four formulations incorporating insects (at a 15% level): defatted mealworm (TM_D), whole ground microwave-dried (TM_MW) or electrical oven dried (TM-O) mealworm and whole ground cricket dried in an electrical oven (AD_O).

The dried dates and cranberries were chopped into small pieces, while the Brazilian nuts and dehydrated banana were ground in the Kenwood stand-mixer. All the ingredients were then weighted and mixed in the Kenwood stand-mixer, and the mixture was further kneaded by hand until it reached a consistent texture. Then, the product was placed into

Table 1
Ingredient composition (g/100 g) of the formulated bars.

Formulation	Dates	Cranberries	Oat powder	Dehydrated banana	Brazil nuts	Salt	Defatted *T. molitor*	Microwave-dried *T. molitor*	Oven-dried *T. molitor*	Oven-dried *A. domesticus*
CTRL	30	10	25	25	9.8	0.2	—	—	—	—
TM_D	30	10	20	20	4.8	0.2	15	—	—	—
TM_MW	30	10	20	20	4.8	0.2	—	15	—	—
TM_O	30	10	20	20	4.8	0.2	—	—	15	—
AD_O	30	10	20	20	4.8	0.2	—	—	—	15

a bar mold and pressed until a bar with *ca.* 60 g was obtained. This bar was then cut into *ca.* 20 g square pieces for sensory evaluation.

Bars were also subject to nutritional analysis in laboratory accredited with ISO/IEC 17025 (Centre for Innovation and Technological Support – CINATE, Porto, Portugal). Determinations were made for total fat (Soxhlet method), total sugars (Munson and Walker method), total dietary fiber (AOAC 991.43 and AOAC 985.29 methods), crude protein (Kjeldahl method with a nitrogen conversion factor of 6.25) and ash (incineration in a muffle at 550 ˚C).

Prior to sensory evaluation, food safety of the developed bars was also assessed with microbiological analyses (Table S1) in a laboratory accredited with ISO/IEC 17025 (Silliker Portugal, S. A., Vila Nova de Gaia, Portugal).

2.5. Sensory evaluation

2.5.1. Sensory panels

An untrained panel of 99 panelists (51.5% female, 54% with higher education, average age of 42.0 ± 15.1 years, average food neophobia score of 13.5 ± 5.5 and average disgust towards insects score of 15.7 ± 7.4) was used in this study. Panelists were willing consumers of alternative protein sources (including insects). Sense Test's (sensory evaluation and consumer tests company in Vila Nova de Gaia, Portugal) database was used for the recruitment of the consumers (residents of the Oporto metropolitan area, North of Portugal). The company ensures the protection and confidentiality of data through the authorization 2063/2009 of the National Data Protection Commission, and follows the EU General Data Protection Regulation (EU 2016/679), as well as a longstanding internal code of conduct, assuring informed consent. Additionally, prior to the evaluation, all consumers filled out an informed consent that they did not have allergies to either shellfish or house dust mites. Sensory evaluation was carried out in individual sensory booths at Sense Test's sensory evaluation lab, equipped in accordance with ISO 8589:2007 – *Sensory analysis – General guidance for the design of test rooms*.

2.5.2. Panel characterization

Prior to the evaluation of the samples, the food neophobia and disgust towards insects levels of the consumers were assessed. Each participant initially answered the 5 neophobic items of the food neophobia scale (Pliner and Hobden, 1992) and then the 5-item disgust towards insects (Rozin, 2014), both on a 7-point scale ranging from 1 – "disagree completely" to 7 – "agree completely". The order of presentation of the items was randomized between participants.

2.5.3. Overall liking

A monadic balanced order of presentation, according to the Latin square design, to counterbalance possible carry-over effects (Macfie et al., 1989) was used to present the samples to the participants. Each sample (*ca.* 20 g) was presented in a white plastic plate blind-labelled with three-digit random codes

Participants were provided with a porcelain spittoon, a glass of bottled natural still water and unsalted crackers and were asked to chew a piece of cracker and to rinse the mouth with water between each sample, to rinse the palate.

For each sample, participants initially evaluated overall liking using a 9-point hedonic scale of 9 points, ranging from 1 - "dislike extremely" to 9 - "like extremely" (Peryam and Pilgrim, 1957).

2.5.4. CATA (Check-All-That-Apply)

A CATA ballot was developed based on literature research (Cunha and Ribeiro, 2019; Ribeiro et al., 2019) and pilot work with 10 experienced researchers (simultaneous evaluation of all samples, with the identification of characterizing and differentiating attributes divided by sensory modality). The final ballot had a total of 34 sensory attributes (Table 2). The order of presentation of the attributes was randomized between participants and between samples (Ares et al., 2013) and divided by sensory modalities to reduce the cognitive effort of the participants (Ares and Jaeger, 2013).

2.5.5. FACT (Food-action-rating-scale)

Furthermore, the Food Action Rating Scale – FACT (willingness to eat the product if it was available on the market) (Schutz, 1965) was also evaluated on a 9 point scale, ranging from "1 - only if forced, I would eat this bar" to 9 – "I would eat this bar every time I had the chance".

2.6. Statistical analysis

The results of lipid extraction were analyzed with the software SPSS 27.0. A One-Way ANOVA followed by a Tukey test of multiple comparisons was applied. A significance level of 0.05 was used.

The results of the sensory evaluations were analyzed with the software XL-STAT (Addinsoft, USA). Overall liking and willingness to eat (FACT scale) were evaluated with the application of the Friedman test followed by the Wilcoxon signed rank test. For the CATA results, a contingency table with the frequency of utilization of each attribute in each sample was built. The Cochran Q test (Parente et al., 2011) at a 90% confidence level was applied to identify discriminating attributes between samples. All subsequent analyses were only performed with discriminating attributes. Correspondence analysis (CA) (Ares et al., 2011) was subsequently applied to the contingency table, in order to provide a sensory map of the samples, allowing the determination of similarities and differences between sensory profiles. A multidimensional alignment (MDA) was also applied to assess the degree of multidimensional association between products and attributes presented on the perceptual map (Meyners and Castura, 2014; Meyners et al., 2013). Lastly, a penalty analysis was also applied to determine the attributes that had a significant positive or negative effect on the liking of the bars (Ares et al., 2014).

3. Results

3.1. Defatting of T. molitor

Results of the lipid extraction procedures (Table 3) revealed that absolute ethanol was the solvent which allowed a greater extraction of mealworm lipids (30.4 ± 1.07 g/100 g DM). Nonetheless, significant differences were only found between ethanol and acetone (26.1 ± 0.90 g/100 g DM).

Table 2
List of sensory attributes utilized in CATA ballot, with *p*-values from the Cochran's Q test. Attributes that statistically differentiated the samples (*p*-value below 0.100) are represented in bold.

Appearance		Odor		Texture		Flavor	
Attribute	p	Attribute	p	Attribute	p	Attribute	p
Greyish	**0.021**	Frying oil	0.282	**Grainy**	**<0.001**	Acid	0.960
Brownish	**<0.001**	**Banana**	**0.061**	**Soft**	**<0.001**	Unpleasant aftertaste	0.713
Golden	**<0.001**	Moldy	0.947	**Astringent**	**0.069**	**Very long aftertaste**	**0.026**
Appealing	**<0.001**	Old closet	0.176	**Pasty**	**<0.001**	**Sweet**	**0.031**
		Rancid	**0.068**	**Dry**	**<0.001**	**Banana**	**0.061**
		Unpleasant	**0.037**	Consistent	0.179	Earthy	0.628
		Feed	**0.024**			**Rancid**	**0.023**
		Hay	0.112			**Pleasant**	**0.036**
		Cereal	0.035			**Feed**	**<0.001**
		Peanut	0.250			Hay	0.455
		Nuts	0.587			Corn strips	0.499
						Peanut	**0.028**
						Nuts	0.709

Table 3
Fat content (g/100 g DM ± s.d.) of whole ground *T. molitor* determined with different solvents and defatted *T. molitor* determined with ether petroleum. a,b,c – Represents in each column homogeneous groups in accordance with the Tukey's test ($p < 0.050$). Results are means of four (whole ground) and three (defatted) replications.

Solvent	Whole	Defatted
Ethanol	30.4 ± 1.07[a]	1.4 ± 0.07[b]
Methanol	29.7 ± 3.77[ab]	16.8 ± 0.13[a]
Acetone	26.1 ± 0.90[b]	1.2 ± 0.24[b]
Hexane	27.5 ± 0.68[ab]	1.4 ± 0.04[b]
Ethyl acetate	29.1 ± 1.45[ab]	1.2 ± 0.16[b]

Table 4
Proximate composition (g/100 g) of developed bars. Energy values expressed as Kcal/100g and calculated as [(9* g Fat) + (4 * g Protein) + (4 * g Sugars).

Formulation	Fat	Sugars	Fiber	Protein	Ash	Energy
CTRL	16.3	27.6	6.8	9.2	1.59	293.9
TM-D	11.5	27.8	6.9	15.2	1.95	275.5
TM-MW	14.3	28.6	7.3	12.7	1.86	293.9
TM-O	14.8	29.6	7.7	13.8	1.99	306.8
AD-O	14.1	28.1	12.1	12.7	1.99	290.1

The analysis performed on the defatted extracts (Table 3) demonstrated that, except for methanol, all the extracts had very low levels of fat (ranging between 1.2 and 1.4 g/100 g DM). On the other hand, the extract defatted with methanol had very high levels of fat still present (16.8 ± 0.13 g/100 g DM) demonstrating its inefficiency.

Considering the results of the lipid extraction of whole ground *T. molitor* and the results of fat content of defatted extracts, ethanol was chosen as the solvent for defatting *T. molitor* for further inclusion in the developed bars.

3.2. Nutritional content of the bars

The inclusion of edible insects (*T. molitor* or *A. domesticus*) led to noticeable differences in the nutritional composition of the bars (Table 4). These differences were more evident for fat, protein and fiber content since for sugars (27.6–29.6 g/100 g) and ash (1.59–1.99 g/100 g) the bars had very similar values.

Generally, the inclusion of whole ground insects (either *T. molitor* or *A. domesticus*) led to a decrease in fat and increase in protein. These effects were more evident with the inclusion of defatted *T. molitor* since these bars had the lowest fat content (11.5 g/100 g) and highest protein content (15.2 g/100 g). While all the developed bars could be labeled as being sources of protein (at least 12% of the energy value is provided by protein), only the bars with defatted *T. molitor* could be labelled as being high in protein (at least 20% of the energy value provided by protein).

As for fiber, all bars could be labeled as being high in fiber (at least 6 g/100 g) but a noticeable increase was only verified with the inclusion of *A. domesticus* (12.1 g/100 g).

Table 5
Mean (± SD) overall liking and willingness to eat (FACT) evaluations of the different tested bar formulations. a, b, c - homogenous groups according to the Wilcoxon test (95% confidence), applied independently to both variables.

Formulation	Overall Liking	FACT
CTRL	6.73 (± 1.47)[a]	5.91 (± 1.66)[a]
TM-D	6.48 (± 1.45)[ab]	5.74 (± 1.78)[a]
TM-MW	6.50 (± 1.62)[ab]	5.54 (± 1.83)[ab]
TM-O	6.02 (± 1.79)[c]	5.00 (± 2.11)[b]
AD-O	6.26 (± 1.62)[bc]	5.36 (± 1.88)[ab]

3.3. Sensory evaluation of bars

3.3.1. Overall liking and willingness to eat

The incorporation of edible insects had different impacts on overall willing and willingness to eat (FACT scale), depending on applied fractionation techniques, drying method and species (Table 5). For both scales, the control sample had the highest scores (Overall Liking - 6.73 ± 1.47; FACT - 5.91 ± 1.66). The incorporation of defatted *T. molitor* (Overall Liking - 6.48 ± 1.45; FACT - 5.74 ± 1.78) or microwave-dried *T. molitor* (Overall Liking - 6.50 ± 1.62; FACT - 5.54 ± 1.83) did not lead to significant differences in either scale, being the bars with the second-best evaluations. On the other hand, oven drying led to the worse results with the bars incorporating oven-dried *T. molitor* (Overall Liking - 6.02 ± 1.79; FACT - 5.00 ± 2.11) having significant differences to the control bar and bars incorporating defatted *T. molitor* in both scales. The incorporation of *A. domesticus* (Overall Liking - 6.26 ± 1.62; FACT - 5.36 ± 1.88) led to better results than the incorporation of identically dried *T. molitor*.

3.3.2. Sensory profile

The developed CATA ballot (Table 2) had a total of 34 sensory attributes, divided by appearance, odor, texture and flavor. Of these 34 attributes, 20 (58.8%) significantly discriminated ($p < 0.100$ on the Cochran's Q test) the samples. Odor was the sensory modality with lowest proportion of discriminating attributes (36.4%; 4/11) while 100%

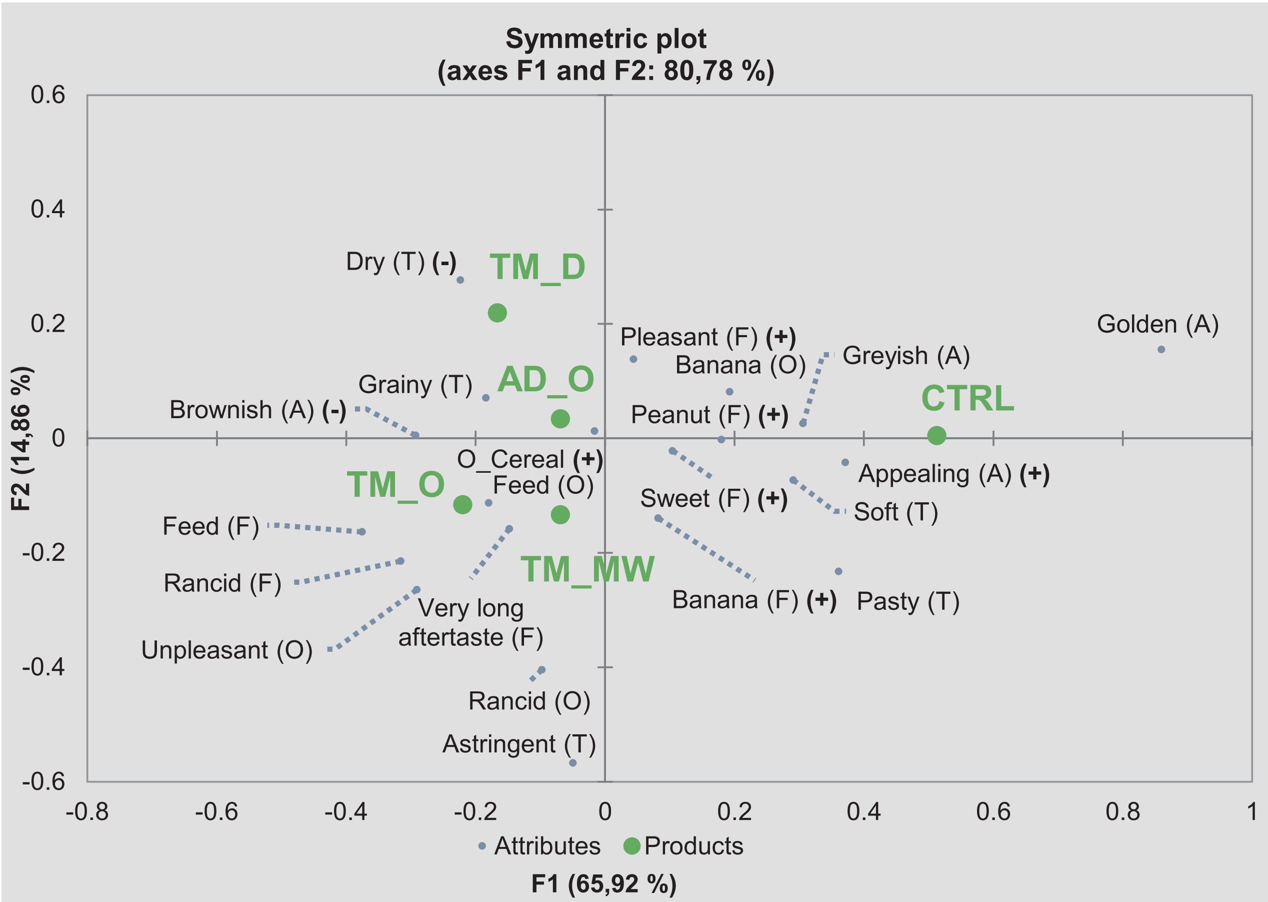

Fig. 1. Correspondence Analysis (CA) of CATA frequencies containing only the attributes related to appearance (A), odor (O), texture (T), and flavor (F) that significantly differentiated the samples (according to the Cochran Q test at 90% significance level). Attributes represented with symbols (+) or (-), were identified as having a significant impact on the overall liking through Penalty Analysis.

(4/4) of appearance attributes were discriminant. Additionally, 83.3% (5/6) of texture attributes were discriminant while 53.8% (7/13) of flavor attributes were discriminant.

The CA of CATA frequencies (Fig. 1) and MDA analysis (Fig. 2) allow us to have a visual representation of the similarities and differences between samples and to have a quantification of the relation between attributes and samples, respectively. Furthermore, the drivers of liking and disliking (attributes identified through Penalty Analysis to have a significant impact on the overall liking) are also represented in both the CA and MDA analysis.

It is possible to see that there are pronounced differences in the sensory profile of the control bar and the bars incorporating edible insects, although the bars TM_MW and AD_O were not strongly differentiated from the other samples (Figs. 1 and 2). Concerning the appearance of the samples, the incorporation of edible insects had a negative effect on the profile of the bars. The control sample was strongly associated with the attributes ‘golden’ and ‘appealing’ (driver of liking), while the bars with the incorporation of insects (in particular the TM_O bar) were negatively associated with these attributes being instead characterized as having a ‘brownish’ appearance (driver of disliking).

Regarding the texture attributes, there were also perceptible differences between samples. The control bar was characterized as being ‘soft’ and ‘pasty’, while the TM_D bar was characterized as being ‘dry’ (driver of disliking) and ‘grainy’. The TM_O bar was also characterized as ‘grainy’ (although to a lesser degree than the TM_D bar) while the TM_MW bar was characterized as ‘astringent’.

With the odor and flavor attributes, it is perhaps easier to understand the differences in overall liking and willingness to eat. The most disliked bar (TM_O) was strongly associated with several negative attributes related to both odor (‘feed’, ‘unpleasant’) and flavor (‘feed’, ‘rancid’) while the second most disliked bar (AD_O) was also associated, to a lesser degree, with negative odor attributes (‘feed’, ‘rancid’). The TM_MW bar was characterized as having a ‘very long aftertaste’ and ‘odor of cereal’ (driver of liking), while the TM_D bar was not strongly associated with any odor or flavor attribute (although it was slightly characterized as having a ‘pleasant flavor’, which is a driver of liking). On the other hand, the control bar was associated with ‘sweet flavor’, ‘peanut flavor’ (drivers of liking) and ‘banana odor’. On the contrary there was a negative association between positive odor/flavor attributes and the bars incorporating edible insects: ‘banana flavor’ (TM_D), ‘sweet flavor (TM_D, TM_O), ‘banana odor’ (TM_MW, TM_O), ‘pleasant flavor’, ‘peanut flavor’ (TM_O, AD_O), ‘odor of cereal’ (AD_O).

4. Discussion

4.1. *Lipid extraction of* T. molitor

Ethanol was the solvent chosen for lipid extraction in *T. molitor*, given that it was the solvent that besides their food grade character led to a greater lipid extraction (Table 3). In previous studies, ethanol was also the best solvent to extract lipids from *A. domesticus* (Laroche et al., 2019; Ribeiro et al., 2019) and it provided similar results to other solvents and methods in *T. molitor* (Laroche et al., 2019; Zhao et al., 2016). The utilization of ethanol can be advantageous since it is considered a bio-based solvent that presents low toxicity and minimal health risks and environmental impact (Cascant et al., 2017). The polarity of ethanol

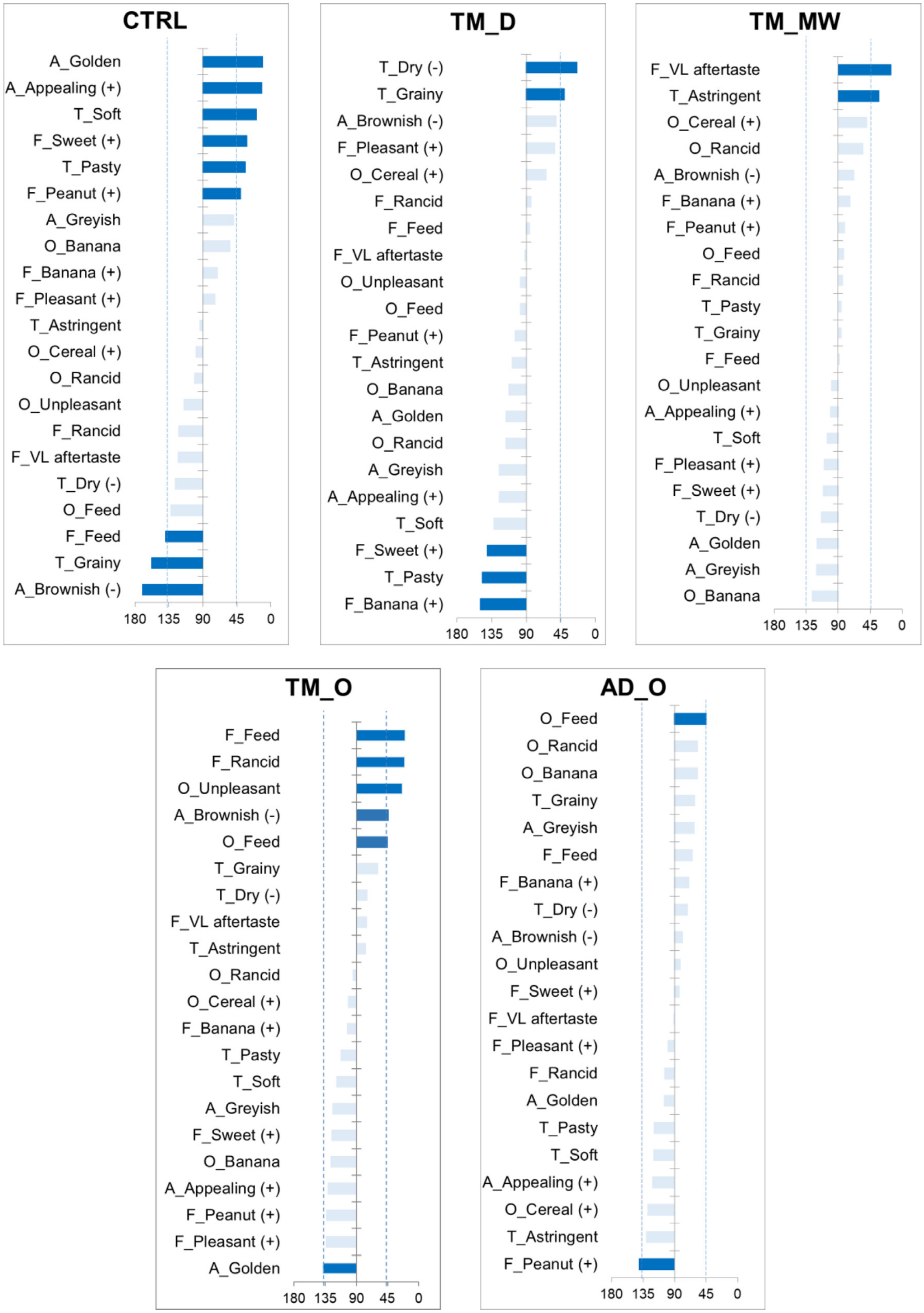

Fig. 2. Results of MDA analysis, with cosines of the angles between the samples and all the attributes that significantly differentiated the samples (according to the Cochran Q test at 90% significance level). Vertical dashed lines indicate the cut-off values of cos(45°) and cos(135°) – which represent positive and negative correlations between samples and attributes, respectively. Attributes represented with symbols (+) or (-), were identified as having a significant impact on the overall liking through Penalty Analysis.

can explain its effectiveness, but in this work it was also observed that methanol (which has higher polarity than ethanol) was the solvent with the lowest efficiency with its defatted fraction still containing 16.8 ± 0.13 g/100g DM of fat (Table 3). *T. molitor* has a more balanced proportion of polar and non-polar lipids that *A. domesticus* (Laroche et al., 2019), which led to the defatted fraction with methanol still containing a high proportion of nonpolar lipids, which were then extracted with petroleum ether.

4.2. Nutritional content of the bars

Besides modifications in insect processing, communicational strategies can also improve consumer perception of the tasted products. Both Gurdian et al. (2021a), Gurdian et al. (2021b) and Schouteten et al. (2016) demonstrated that providing positive information about entomophagy (e.g. nutritional or environmental benefits) can improve consumers' liking of a product. This effect has also been shown for willingness to try insects (Dupont and Fiebelkorn, 2020; Verneau et al., 2016), and further highlights the importance of developing products that can be targeted to groups who are more predisposed to eat edible insects (consumers aware of environmental/nutritional factors of their food choices and/or neophilic consumers). In this work, the bars with the incorporation of edible insects had a much higher protein content than the control bar and the bar with defatted *T. molitor* could even have the legal claim of high protein since more than 20% of the energy value of the bar is provided by protein (Table 4). The incorporation of edible insects into functional products seems to be one of the better options to introduce insects to Western food markets, since consumers already consider these types of products to be very appropriate to contain insects (Ardoin and Prinyawiwatkul, 2020) and even functional products with very high incorporation of insects (protein shakes with 30% of *A. domesticus* flour) have similar liking levels and sensory profile than a control product (Barton et al., 2020).

4.3. Overall liking/willingness to eat and the impact of species and drying methods

Results from overall liking and willingness to eat (Table 5), show that species and processing technologies had a significant effect. All the bars that incorporated insects had lower liking and acceptance than a control bar, although differences for the bars that incorporated defatted *T. molitor* or microwave-dried *T. molitor* were not statistically significant and the bars incorporating oven-dried *T. molitor* had the worst results. The negative effect of the incorporation of edible insects on liking is in accordance to the majority of studies already published in the literature (Cunha and Ribeiro, 2019), including the incorporation of crickets or mealworms in bars or other bakery-type products or snacks (Osimani et al., 2018; Ribeiro et al., 2019; Roncolini et al., 2019; Zhong, 2017).

One of the problems pertaining the communicational strategies of edible insects, is that the wide variety of sensory properties between different species is not accurately reported (House, 2019). Insects are perceived differently depending on species and cooking/processing methods. This is not only reported on recipe books and reports on traditional consumption of edible insects (Ramos-Elorduy, 1998) but also with the application of structured sensory profiling methods (Brynning et al., 2020). These differences also translate to different levels of acceptance by consumers (Bartkowicz and Babicz-Zielińska, 2020; Zielińska et al., 2018), as seen in this study, and can even be observed between closely related cricket (Ribeiro et al., 2019) and mealworm (García-Segovia et al., 2020) species. Although it is well established that different insect species have diverse sensory properties, it is not linear if some species taste better than others, especially when considering other factors such as feed or processing/cooking methods.

In this regard, there are several studies in the literature that show how different cooking/processing methods can impact the liking and sensory profile of insects (Baek et al., 2015; Caparros Megido et al., 2014; Seo et al., 2020; Ssepuuya et al., 2016). However, most differences have been found between techniques based on dry heat (e.g. hot air dry, roasting, oven broil) or based on moisture heat cooking (e.g. steaming, boiling), and to our knowledge there are no studies that have assessed consumer perception between edible insects dried in an oven or dried with a microwave. The drying method that is applied to edible insects has been extensively studied in terms of its effects on dry matter, water activity and even techno-functional properties (Melgar-Lalanne et al., 2019), but in this study we also showed that the effect on sensory properties have also to be assessed in order to choose the optimal drying conditions.

4.4. Sensory profile

4.4.1. Appearance

In terms of appearance, the incorporation of edible insects led to a negative effect (in particular with the incorporation of oven-dried *T. molitor*) since insect-containing bars were associated with a 'brownish' color, which contrasted with the 'golden' color of the control bar (Figs. 1 and 2). Previous works have also reported that the inclusion of cricket (Biró et al., 2020; Dion-Poulin et al., 2021; Ribeiro et al., 2019) or mealworm (Bartkowicz and Babicz-Zielińska, 2020; Choi et al., 2017; Schouteten et al., 2016) flour led to a darkening of the samples, and consequently more negative appearance evaluation. These negative effects on the appearance of the samples are particularly concerning because it can lead to an instant rejection from more neophobic consumers (Dovey et al., 2008). Furthermore, the darkening caused by insects' incorporation can be particularly damaging in bakery-type products (e.g. breads, bars, cookies), which are a type of products deemed as appropriate for insects' incorporation by consumers (Ardoin and Prinyawiwatkul, 2020).

4.4.2. Texture

The texture of the bars incorporating insects was associated with negative attributes, in particular the bar with defatted *T. molitor* ('dry' and 'grainy'), which again contrasted to the attributes that were associated with the control bar ('soft' and 'pasty') (Figs. 1 and 2). Similar effects have been reported on the literature, with flours from edible insects and insect-containing products being described as grainy, dry or gritty (Biró et al., 2020; Dion-Poulin et al., 2021; Schouteten et al., 2016; Tan et al., 2017). However, this effect can be attenuated by previous processing methods. In our work, microwave-dried insects were less associated with 'grainy' or 'dry' texture than oven-dried insects and Bassett (2018) demonstrated that the way insects are ground have a significant effect on the texture properties of the obtained flours.

4.4.3. Odor and flavor

The odor and flavor of the bars were severely impacted by the addition of edible insects, with the bars incorporating oven-dried insects being associated with negative attributes such 'feed' odor/flavor, 'unpleasant' odor and 'rancid' flavor (Figs. 1 and 2). Both Schouteten et al. (2016) and Tan et al. (2017) reported that the inclusion of mealworm in meat products led to the association with off-flavors and strong aftertaste while Biró et al. (2020) and Ribeiro et al. (2019) observed that the incorporation of crickets led to the association with negative attributes such as earthy or rancid and an increase in odor and flavor intensity. Furthermore, Brynning et al. (2020) used trained judges to evaluate insect flours and a note of old foods (e.g. zoo smell, fish feed) was observed.

Similarly to our previous work (Ribeiro et al., 2019), defatting also hindered the association with these negative odor and flavor attributes, which suggests that the lipid fraction might be responsible for the poor evaluations of insect-containing products. Studies assessing the incorporation of insect fat in food products have reported decreases in liking and association with negative flavor and odor attributes (bad aftertaste, off-flavor, longer aftertaste, rancid aroma) (Cheseto et al., 2020; Delicato et al., 2020; Tzompa-Sosa et al., 2021, 2022). Oxidation of the lipid fraction (edible insects are generally rich in polyunsaturated fatty acids) might be responsible for these undesirable odor/flavor attributes (Ribeiro et al., 2019). The applied drying methods can also have a great influence on the oxidation of the lipids, and both Mancini et al. (2021) and Lenaerts et al. (2018) have reported that microwave-drying leads to lower oxidation than other drying techniques (such as oven-drying or freeze-drying). This might explain why the incorporation of microwave-dried *T. molitor* led to better results than the incorporation of oven-dried *T. molitor* in this study. However, it also has to be considered that edible insects have odor-active compounds and volatile organic compounds that are associated with negative sensory attributes such as pungent, fish-like, earthy, potato/mushroom-like, cheese or sweaty (Grossmann et al., 2021; Tzompa-Sosa et al., 2019).

5. Conclusion

Edible insects and food products incorporating them must be sensory evaluated, since the developed products have to be liked by consumers in order to be successfully implemented in Western food markets. In this work, sensory-liking and sensory profile of bars incorporating different insect species, including *T. molitor* subjected to different processing methods, were evaluated, giving valuable information for future food product development. This type of information is crucial for the development of insect-containing products, because it allows the determination of the sensory attributes that are associated with edible insects and how exactly the inclusion of insects increases or decreases liking.

In this study, it was possible to observe differences between drying methods, with microwave-drying having higher liking and better sensory profile than oven-drying. The latter led to an association with negative odor and flavor attributes which could be partially caused by lipid oxidation. However, different drying method (microwave) or lipid extraction improved the sensory profile of the developed products and are two viable options for enhancing the quality of insect-containing products.

In regard to lipid extraction, ethanol was the chosen solvent since it led to at least similar extraction efficiency as other non-polar solvents and it is a safer and cleaner solvent. Besides the positive effect on sensory profile caused by using the defatted fraction, it also had a significant effect on the nutritional properties with the bar incorporating the defatted fraction being ‘high in protein’ (more than 20% of the energy value is provided by protein). This is particularly helpful in the case of edible insects, since it can increase acceptance among nutritional-aware consumers.

Ethical Statement – Studies in humans

The work described in the manuscript entitled ***Impact of defatting and drying methods on the overall liking and sensory profile of a cereal bar incorporating edible insect species*** has been carried out in accordance with the Declaration of Helsinki for experiments involving humans:

Panellists were willing consumers of alternative protein sources (including insects). Sense Test’s (sensory evaluation and consumer tests company in Vila Nova de Gaia, Portugal) database was used for the recruitment of the consumers (residents of the Oporto metropolitan area, North of Portugal). The company ensures the protection and confidentiality of data through the authorization 2063/2009 of the National Data Protection Commission, and follows the EU General Data Protection Regulation (EU 2016/679), as well as a longstanding internal code of conduct, assuring informed consent. Additionally, prior to the evaluation, all consumers filled out informed consent and confirmed that they did not have allergies to either shellfish or house dust mites. Sensory evaluation was carried out in individual sensory booths at Sense Test’s sensory evaluation lab, equipped in accordance with ISO 8589:2007 – Sensory analysis – General guidance for the design of test rooms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

José Carlos Ribeiro: Conceptualization, Formal analysis, Investigation, Writing – original draft. **Carla Santos:** Investigation, Writing – original draft. **Rui Costa Lima:** Resources, Writing – review & editing, Supervision. **Manuela E. Pintado:** Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Luís Miguel Cunha:** Conceptualization, Formal analysis, Resources, Funding acquisition, Supervision, Writing – review & editing.

Data Availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2022.100190.

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