



RESEARCH ARTICLE

# Improving formulation of innovative edible insect-based crispbread containing *Tenebrio molitor* or *Acheta domesticus* through sensory profiling and liking

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Received 1 April 2024 | Accepted 6 January 2025 | Published online 27 February 2025 |  
Published in issue 9 May 2025

## Abstract

One of the critical factors in increasing consumer acceptance of edible insects is the development of appropriate products that lead to satisfactory sensory experiences. This way, the negative associations with entomophagy can be hampered, and developed products can be more successfully integrated into consumers' diets. This research aimed to integrate consumers into the food product development process, achieving crispbread formulations with increased acceptance and liking. Crispbread was developed with different formulations and sensory profiles, incorporating house cricket *Acheta domesticus* or yellow mealworm *Tenebrio molitor*. Two panels of 50 and 100 untrained consumers evaluated the crispbreads incorporating *A. domesticus* and *T. molitor*, respectively. The panels rated overall liking (9-point hedonic scale) and profiled the crispbreads using a Check-All-That-Apply ballot. Regardless of insect species and formulation, all the samples were accepted by consumers with hedonic scores above 5.5. Significant differences were observed between formulations for both insect species, with the chives-based crispbread having the highest liking scores and the incorporation of fennel seeds leading to the lowest liking scores. It was also possible to observe an effect of species, as crispbreads incorporating *A. domesticus* presented lower hedonic scores and higher association with negative attributes related to odour/flavour ('Earthy', 'Pet Food', 'Bitter') and texture ('Floury'). The results from this study highlight the importance of assessing consumers' opinions while developing insect-based food products, demonstrating that Portuguese consumers present higher liking scores of products incorporating *T. molitor* and chives.

## Keywords

consumer – entomophagy – liking – product development – sensory profile

## 1 Introduction

Consumer acceptance of edible insects is one of the major factors in the success of entomophagy in Western countries. Extensive work has been performed to understand which variables significantly impact entomophagy acceptance, and emotional factors have been identified as the most important drivers of rejections (Kröger *et al.*, 2021). In particular, disgust (either food disgust or disgust towards insects) has been consistently recognised as the factor with the most significant impact on rejection (Cunha and Ribeiro, 2019; Kröger *et al.*, 2021; Ribeiro *et al.*, 2022a). Although food disgust is described as a primary emotion against food products that triggers a sense of aversion and can function as a protective mechanism against harmful or unsafe practices (Hartmann and Siegrist, 2018; Rozin and Fallon, 1987), safety concerns are not the main culprit of disgust towards insects, as previous studies have highlighted that fear of contamination or diseases are not correlated with willingness to eat insects (Jensen and Lieberoth, 2019) and that risk perception associated with entomophagy is quite low (Lombardi *et al.*, 2019). Instead, disgust reactions towards edible insects are mainly caused by social, cultural and moral norms that lead to the association with disgusting cues (unclean conditions, contaminated food, dirt, pests, reminders of animal origin) (Hartmann and Siegrist, 2016, 2018; Qian and Yamada, 2020). Additionally, food neophobia (a personality trait describing a person's tendency to reject unfamiliar food or foods from other cultures (Pliner and Hobden, 1992) can also lead to entomophagy rejection, although to a lesser extent than emotional factors (Cunha and Ribeiro, 2019; Kröger *et al.*, 2021; Ribeiro *et al.*, 2022a).

Strategies to increase willingness to eat insect-based food products and ultimately incorporate such products in the consumer's diets should be implemented considering the role of emotional factors and food neophobia on entomophagy rejections. The most applied strategies are based on rational factors and focus on increasing familiarity with entomophagy and marketing edible insects based on their nutritional and sustainability advantages (van Huis and Rumpold, 2023). While these strategies can increase willingness to eat insect-based products, their effectiveness is more limited to specific segments, such as consumers who have an interest in food products' health and nutritional benefits (Placentino *et al.*, 2021; Ribeiro *et al.*, 2021; Verneau *et al.*, 2016; Woolf *et al.*, 2019).

As such, the development of food products that are considered appropriate by consumers and that guarantee positive sensory experiences is fundamental to assure not only increased acceptance but also to revert some of the negative social and cultural norms surrounding edible insects (Gumussoy and Rogers, 2023; La Barbera *et al.*, 2018). The sensory properties of edible insects are not only valorised in countries where they are part of the traditional gastronomy (Ayieko *et al.*, 2021) but also in several high-cuisine restaurants (Araújo and Veciana, 2015; Brandão, 2022; Rigg, 2017). However, a recent literature review of studies performing hedonic and sensory evaluations of insect-based food products, observed that incorporating edible insects led to worse hedonic evaluations and more negative sensory profiles (Ribeiro *et al.*, 2024).

The sensory properties of a food product are one of the key factors when consumers make their decisions (Cunha *et al.*, 2018), and most consumers are not willing to trade foods conveying positive experiences (sensory properties, price, availability, ability to fit in current diets) for others who only guarantee environmental, nutritional or health-related benefits (Baker *et al.*, 2022; House, 2016; Vermeir *et al.*, 2020). House (2016) has even reported that taste was one of the main reasons consumers did not repeat the purchase of insect-based food products. Furthermore, edible insects are not being positioned as a unique food practice, and insect-based products are one of many similar options, having to compete with and be subjected to a vast selection criterion (e.g. price, sensory properties, availability, convenience), which hinders their incorporation into the regular diet of consumers (House, 2019). This further emphasizes the importance of understanding the sensory properties of edible insects and developing products that meet consumers' sensory expectations.

Reflecting on the importance of developing insect-based food products that present positive and satisfactory sensory attributes, this study focused on the consumer evaluation of crispbreads incorporating different insect species (house cricket *Acheta domesticus* and yellow mealworm *Tenebrio molitor*), with formulations varying in the addition of various dried herbs or spices. The main goals were to understand which formulations and insect species can lead to better hedonic evaluations and what sensory profile crispbreads should present to be accepted by potential consumers.

## 2 Material and methods

### *Crispbread formulation*

This study used two edible insect species: house cricket (*A. domesticus*) and yellow mealworm (*T. molitor*). Nutrinsect (Montecassiano, Italy) supplied *A. domesticus* as powder (dried and ground insect), while SFP – Sustainable Food Products, Lda (Perafita, Portugal) supplied *T. molitor* powder.

For this study, crispbread samples incorporating 20% (w/w) of either *A. domesticus* or *T. molitor* powder were developed. Seven formulations were developed for each type of crispbread (after pilot tests with a bakery chef), varying in added herbs and spices: plain (without herbs or spices), basil, chives, fennel seeds, oregano, rosemary, and sage. All samples presented the same basic formulation (% of dry ingredients, nutritional characteristics presented in Supplementary Tables S1-S5), which consisted of:

- 65% “basic flour” (70% soft wheat flour + 30% durum wheat flour)
- 20% insect powder (*A. domesticus* or *T. molitor*)
- 8% chickpea flour
- 5% oat flour
- 2% barley malt
- 1% salt
- 0.5% baker’s yeast
- water (50 g for every 100 g of dry ingredients)

Crispbreads were developed at *Università Politecnica delle Marche*. All ingredients were mixed in a professional spiral kneading machine (K12-2V Kosmika, Kosmitech, Morrovalle, Italy) for about 10 minutes. The kneading was left leavening at 25 °C for 60 minutes. Kneading pieces of about 125 g were smoothed to a height of about 1-2 mm using a rolling machine (SANSONE 42 XP, BLU 3 PRO, Falconara Marittima, Italy). Crispbread was shaped into small squares (approximately 4 cm × 4 cm), lightly sprinkled with salt, and then baked in an oven (FOSTR6230MT oven, Fimar, Rimini, Italy) at 240 °C for 5 minutes.

Crispbread squares were packaged in serving units using sealed food-grade plastic bags (sealer machine, Bonsenkitchen) composed of food-grade polyethylene (Bonsenkitchen, Flowery Branch, GA, USA) and shipped at room temperature to Sense Test (sensory evaluation and consumer tests company in Vila Nova de Gaia, Portugal) for further analysis.

### *Sensory panels*

For the evaluation of the crispbread incorporating *A. domesticus*, an untrained panel of 50 panellists (52.0%



FIGURE 1 Representation of sample presentation for each evaluation.

female/48.0% male, average age of  $52.8 \pm 10.2$  years, and age range between 27-65 years) was used, while for the evaluation of the crispbread incorporating *T. molitor*, an untrained panel of 94 panellists (57.4% female/42.6% male, average age of  $45.0 \pm 12.3$  years and age range between 22-68 years) was used. Panellists from both panels were willing consumers of alternative protein sources (including insects). Sense Test’s database was used to recruit consumers (residents of the Oporto metropolitan area, North of Portugal). The company ensures the protection and confidentiality of data through the authorisation 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, certified through ISO9001 standard procedures. Additionally, before the evaluation, all panellists filled out an informed consent form stating they did not have allergies to shellfish or house dust mites. Sensory evaluation was carried out in individual sensory booths at Sense Test’s sensory evaluation lab, equipped with ISO 8589:2007 – Sensory analysis – General guidance for the design of test rooms.

### *Sensory evaluation*

For each test (evaluation of crispbread incorporating *A. domesticus* or *T. molitor*), a monadic balanced order of presentation was used to present the samples to the participants, according to the Latin square design to counterbalance possible carry-over effects (Macfie *et al.*, 1989). For each sample, two crackers were presented in a white plastic plate blind-labelled with three-digit random codes (Figure 1).

Participants were provided with a porcelain spittoon, a glass of bottled natural still water, and unsalted crackers. They were asked to chew a piece of cracker, rinse

TABLE 1 List of sensory attributes utilised in the CATA ballot, with *P*-values from Cochran's Q test relative to the evaluation of crispbread incorporating *A. domesticus*. Attributes that statistically differentiated the samples (*P*-value below 0.050) are represented in bold

Appearance		Odor		Texture		Flavour	
Attribute	<i>P</i> -value	Attribute	<i>P</i> -value	Attribute	<i>P</i> -value	Attribute	<i>P</i> -value
Appealing	<b>0.037</b>	Cereals	0.241	<b>Crispy</b>	<b>&lt;0.001</b>	Animal	0.260
Bright colour	<b>0.001</b>	Earthy	0.855	Crunchy	0.063	<b>Anise</b>	<b>&lt;0.001</b>
Brown	<b>0.028</b>	Herbs	0.091	Dry	0.182	Bitter	0.074
Dark colour	<b>0.001</b>	Pet food	0.189	<b>Floury</b>	<b>0.049</b>	<b>Cereals</b>	<b>0.021</b>
Golden	0.130	Toasted	0.176	<b>Hard</b>	<b>0.029</b>	Dry fruits	0.243
Greyish	0.149			Massive	0.233	Earthy	0.223
				<b>Soft</b>	<b>&lt;0.001</b>	Herbs	0.554
						Pepper	0.583
						Rancid	0.503
						<b>Salty</b>	<b>0.007</b>
						Spices	0.089
						Spicy	0.213
						<b>Tasteless</b>	<b>0.014</b>
						Tasty	0.210
						Toasted	0.060

their mouths with water between each sample, and rinse their palates.

For each sample, participants initially evaluated overall liking using a 9-point hedonic scale, ranging from 1 – “dislike extremely” to 9 – “like extremely” (Peryam and Pilgrim, 1957). Afterwards, participants profiled the samples using a Check-All-That-Apply ballot developed based on literature research (Ribeiro *et al.*, 2024) and pilot work with nine Sense Test team members with experience in sensory profiling methods. The most referenced attributes in the pilot work were chosen for the final CATA ballot, composed of 33 sensory attributes (Tables 1 and 2) and validated through a test simulation. The order of presentation of the attributes was randomised between participants and between samples and divided by sensory modalities to reduce the cognitive effort of the participants (Cunha *et al.*, 2023).

### Statistical analysis

The results were analysed using the software XL-STAT (Addinsoft, New York, NY, USA). Overall liking results were presented with descriptive statistics (mean and standard deviation) and evaluated using the Friedman test, followed by the Wilcoxon signed rank test (95% confidence level). A contingency table with the frequency of utilisation of each attribute in each sample was built for the CATA results. The Cochran Q test (Parante *et al.*, 2011) was applied at a 95% confidence level 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 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 crispbreads (Ares *et al.*, 2014).

## 3 Results

### Overall liking

For both crispbread incorporating *A. domesticus* (Table 3) and *T. molitor* (Table 4), the different formulations significantly impacted overall liking scores. For samples incorporating *A. domesticus* (Table 3), the highest liking scores were observed for the ‘Chives’ ( $7.0 \pm 1.4$  and 82% positive responses) and ‘Rosemary’ ( $6.6 \pm 1.4$  and 80% positive responses) formulations. On the other hand, the sample with the lowest overall liking scores was the ‘Basil’ formulation ( $5.8 \pm 1.8$  and 62% positive responses). Similar to what occurred for *A. domesticus*, the highest liking scores for crispbread incorporating

TABLE 2 List of sensory attributes utilised in CATA ballot, with *P*-values from Cochran's Q test relative to the evaluation of crispbread incorporating *T. molitor*. Attributes that statistically differentiated the samples (*P*-value below 0.050) are represented in bold

Appearance		Odor		Texture		Flavour	
Attribute	<i>P</i> -value	Attribute	<i>P</i> -value	Attribute	<i>P</i> -value	Attribute	<i>P</i> -value
Appealing	0.270	<b>Cereals</b>	<b>0.010</b>	Crispy	0.062	Animal	0.566
Bright colour	< <b>0.001</b>	Earthy	0.136	Crunchy	0.085	<b>Anise</b>	< <b>0.001</b>
Brown	0.804	<b>Herbs</b>	< <b>0.001</b>	Dry	0.253	<b>Bitter</b>	<b>0.016</b>
Dark colour	<b>0.014</b>	<b>Pet food</b>	<b>0.023</b>	Floury	0.820	Cereals	0.057
Golden	0.130	Toasted	0.118	<b>Hard</b>	<b>0.028</b>	Dry fruits	0.112
Greyish	<b>0.016</b>			Massive	0.460	Earthy	0.068
				<b>Soft</b>	<b>0.024</b>	<b>Herbs</b>	< <b>0.001</b>
						<b>Pepper</b>	< <b>0.001</b>
						Rancid	0.532
						<b>Salty</b>	<b>0.038</b>
						<b>Spices</b>	< <b>0.001</b>
						Spicy	0.625
						Tasteless	0.423
						<b>Tasty</b>	<b>0.009</b>
						<b>Toasted</b>	<b>0.022</b>

TABLE 3 Mean ( $\pm$  SD) overall liking and relative frequency of positive (scores  $\geq 6$ ) evaluations of the different tested crispbread formulations incorporating *A. domesticus*

Sample	Overall liking	Positive responses (%)
Basil	5.8 ( $\pm 1.8$ ) <sup>d</sup>	62%
Chives	7.0 ( $\pm 1.4$ ) <sup>a</sup>	82%
Fennel seeds	6.3 ( $\pm 1.4$ ) <sup>c</sup>	76%
Oregano	6.1 ( $\pm 1.5$ ) <sup>c</sup>	72%
Plain	6.4 ( $\pm 1.7$ ) <sup>b</sup>	76%
Rosemary	6.6 ( $\pm 1.4$ ) <sup>ab</sup>	80%
Sage	6.4 ( $\pm 1.2$ ) <sup>b</sup>	84%

a, b, c, d Homogenous groups according to the Wilcoxon test (95% confidence).

TABLE 4 Mean ( $\pm$  SD) overall liking and relative frequency of positive (scores  $\geq 6$ ) evaluations of the different tested crispbread formulations incorporating *T. molitor*

Sample	Overall liking	Positive responses (%)
Basil	6.6 ( $\pm 1.8$ ) <sup>bc</sup>	86%
Chives	7.0 ( $\pm 1.7$ ) <sup>a</sup>	95%
Fennel seeds	6.3 ( $\pm 1.9$ ) <sup>c</sup>	80%
Oregano	6.9 ( $\pm 1.5$ ) <sup>a</sup>	95%
Plain	6.8 ( $\pm 1.7$ ) <sup>ab</sup>	91%
Rosemary	6.6 ( $\pm 1.7$ ) <sup>bc</sup>	86%
Sage	6.7 ( $\pm 1.8$ ) <sup>ab</sup>	89%

a, b, c Homogenous groups according to the Wilcoxon test (95% confidence).

*T. molitor* were observed for the 'Chives' formulation (7.0  $\pm$  1.7 and 95% positive responses). However, there were no significant differences for the 'Oregano' (6.9  $\pm$  1.5 and 95% positive responses), 'Plain' (6.8  $\pm$  1.7 and 91% positive responses) and 'Sage' (6.7  $\pm$  1.8 and 89% positive responses) formulations. The sample with the lowest liking scores was the 'Fennel seeds' formulation (6.3  $\pm$  1.9 and 80% positive responses), although with no significant differences for the 'Rosemary' (6.6  $\pm$  1.7 and 86% positive responses) and 'Basil' (6.6  $\pm$  1.8 and 86% positive responses) formulations.

Although different panels were used, liking scores for samples incorporating *A. domesticus* (mean ranging from 5.8  $\pm$  1.8 to 7.0  $\pm$  1.4 and positive scores rang-

ing between 62% and 84%) were generally lower than for samples incorporating *T. molitor* (lowest mean score was 6.3  $\pm$  1.9 and all samples had a rate of positive responses above 80%).

### Sensory profile

#### Crispbread incorporating *A. domesticus*

For the evaluation of crispbread incorporating *A. domesticus*, 12 of the 33 (36.4%) sensory attributes on the CATA ballot significantly differentiated the samples ( $p < 0.050$  on the Cochran's Q test; Table 5). Texture was the only sensory modality with less than 50% of discriminating attributes (2/7, 28.6%). Odour was the only sensory modality without discriminating attributes, while

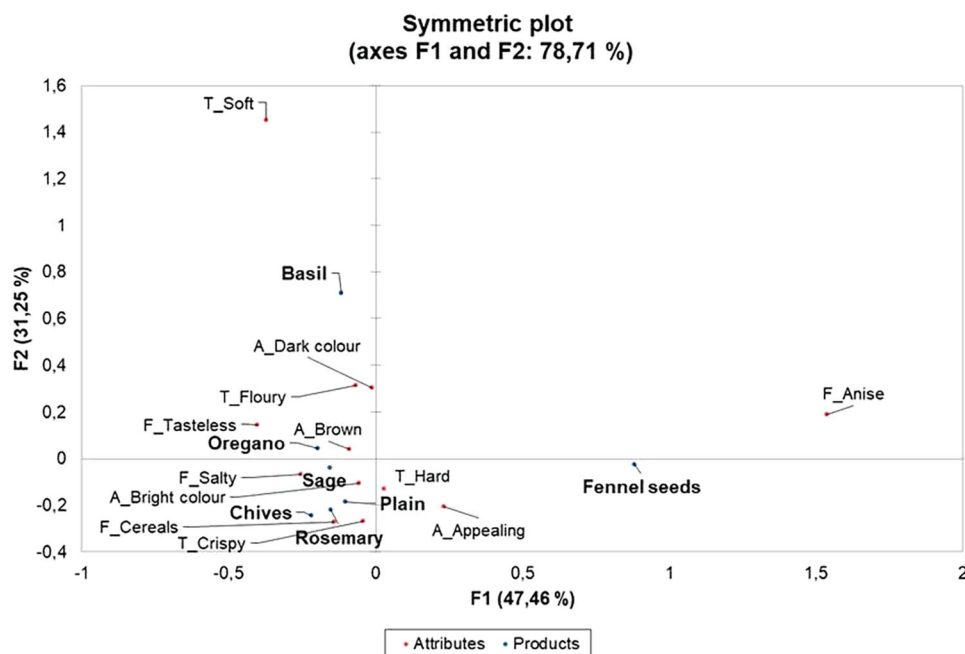


FIGURE 2 Correspondence Analysis (CA) of CATA frequencies containing only the attributes related to appearance (A), odour (O), texture (T), and flavour (F) that significantly differentiated the crispbread samples incorporating *A. domesticus* (according to the Cochran Q test at 95% significance level).

66.7% (4/6) of appearance attributes were discriminant. Additionally, 57.1% (4/7) of texture attributes were discriminant, while 26.7% (4/15) of flavour attributes were discriminant.

The most frequently chosen attributes across all samples per sensory dimension were:

- Appearance: 'Brown' colour (64.9%);
- Odour: 'Herbs' (41.4%) and 'Cereals' (34.9%);
- Texture: 'Crunchy' (38.9%), 'Hard' (35.4%), 'Dry' (34.0%) and 'Crispy' (33.1%);
- Flavour: 'Herbs' (43.4%) and 'Spices' (42.6%).

Of these attributes, only the 'Brown' colour, 'Hard' texture and 'Crispy' texture significantly differentiated the samples (Table 1). As such, all the crispbread samples incorporating *A. domesticus* can be equally characterised as presenting odour of 'Cereals' and 'Herbs', 'Crunchy' and 'Dry' texture and flavour of 'Herbs' and 'Spices'. Nevertheless, it is essential to note that the attributes odour of 'Herbs', 'Crunchy' texture and flavour of 'Spices' had *p*-values between 0.05 and 0.1, with the 'Plain' sample being less associated with the terms related to odour and taste.

The CA of CATA frequencies (Figure 2) and MDA analysis (Figure 3) allow us to visualize the similarities and differences between samples and quantify the relation between attributes and samples, respectively.

It is possible to observe that samples can be grouped into three groups. The 'Basil' sample (which presented the lowest overall liking scores) was significantly associ-

ated with the attributes 'Soft' texture and 'Dark colour' while negatively associated with 'Cereals' flavour and 'Hard' texture. The 'Oregano' sample (second lowest overall liking scores) presented some similarities with the 'Basil' sample, particularly with a strong association with 'Floury' texture. However, the oregano sample had some unique associations among all samples, with strong associations with 'Bright colour' and 'Tasteless'.

The 'Fennel seeds' sample (which had the third lowest overall liking scores) was associated with an 'Anise' flavour (which significantly differentiated from the sage, rosemary and chives samples) but also an 'Appealing' appearance (which might indicate that appearance did not significantly influence overall liking). On the other hand, the 'Fennel seeds' sample was negatively associated with the 'Salty' flavour (an attribute strongly associated with the samples with the highest liking scores).

The other samples ('Plain', 'Rosemary', 'Sage' and 'Chives') presented a similar sensory profile, although some differences could still be observed. These samples were associated with attributes such as 'Crispy' texture ('Plain' and 'Chives'), 'Salty' flavour ('Chives' and 'Sage') and 'Cereals' flavour ('Chives' and 'Rosemary'). As expected, the 'Plain' sample was not strongly associated with flavour attributes but was negatively associated with 'Floury' texture, differentiating it from the 'Basil' and 'Oregano' samples.

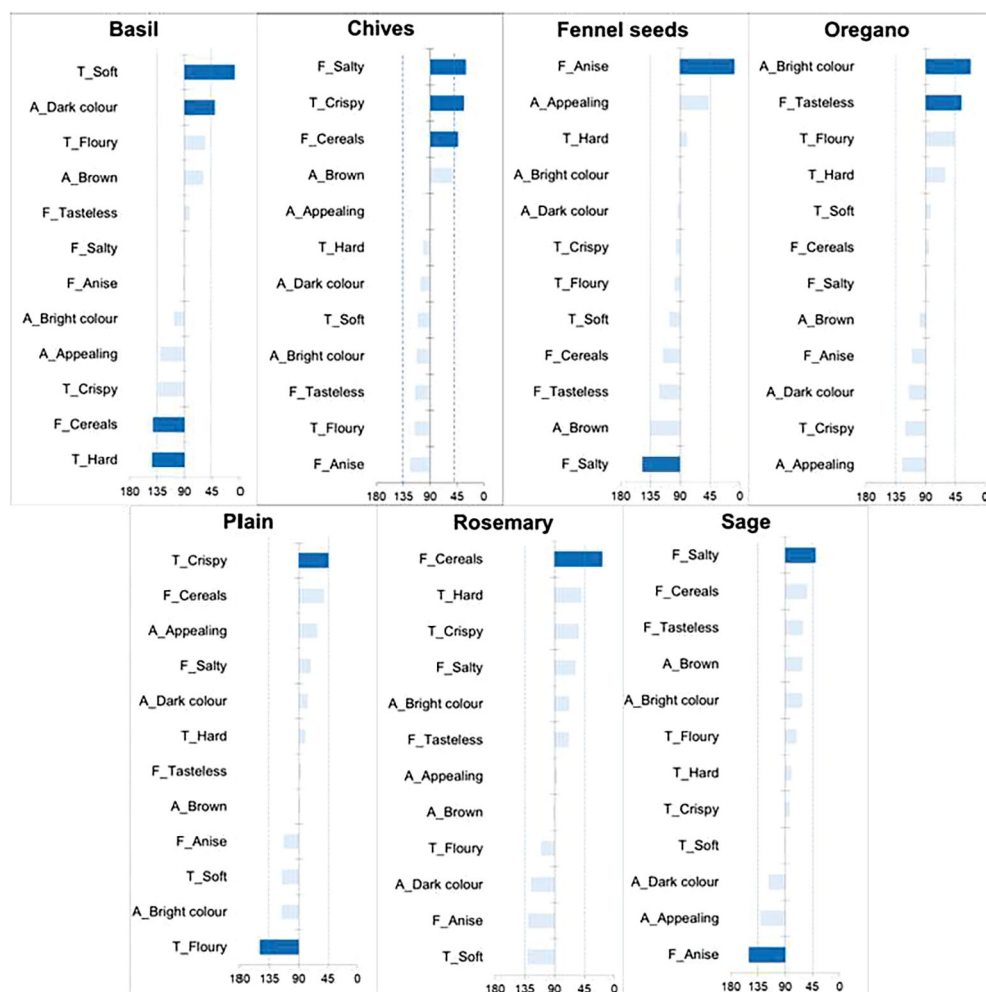


FIGURE 3 Results of MDA analysis, with cosines of the angles between the crispbread samples incorporating *A. domesticus* and all the attributes that significantly differentiated the samples (according to the Cochran Q test at a 95% significance level). Vertical dashed lines indicate the cut-off values of  $\cos(45^\circ)$  and  $\cos(135^\circ)$ , representing positive and negative correlations between samples and attributes, respectively.

### Crispbread incorporating *T. molitor*

For the evaluation of crispbread incorporating *T. molitor*, 16 of the 33 (48.5%) sensory attributes present on the CATA ballot significantly differentiated the samples ( $p < 0.050$  on the Cochran's Q test; Table 2). Texture was the only sensory modality with less than 50% discriminating attributes (2/7, 28.6%). Odour was the sensory modality with a higher rate of discriminating attributes (3/5, 60.0%), while appearance and flavour had similar discrimination rates (50.0%, 3/6 and 53.3%, 8/15, respectively).

The most frequently chosen attributes across all samples per sensory dimension were:

- Appearance: 'Brown' colour (47.0%);
- Odour: 'Cereals' (42.1%) and 'Herbs' (40.9%);
- Texture: 'Crunchy' (38.0%), 'Hard' (35.6%), 'Crispy' (34.3%) and 'Dry' (33.4%);

- Flavour: 'Herbs' (43.3%), 'Spices' (38.1%) and 'Cereals' (31.2%).

Of these attributes, only 'Cereals' odour, 'Herbs' odour, 'Hard' texture, 'Herbs' flavour and 'Spices' flavour differentiated the samples (Table 2). As such, all the crispbread samples incorporating *T. molitor* can be equally characterised as presenting a 'Brown' colour, 'Crunchy', 'Crispy' and 'Dry' texture and 'Cereals' flavour. Nevertheless, it is important to note that the attributes 'Crunchy' and 'Crispy' texture and 'Cereals' flavour had  $p$ -values between 0.05 and 0.1, with the 'Chives' and 'Sage' samples being more associated with the texture attributes and the 'Fennel seeds' sample is less associated with the 'Cereals' flavour.

The CA of CATA frequencies (Figure 4) and MDA analysis (Figure 5) allow us to visualise the similarities and differences between samples and quantify the relation between attributes and samples, respectively.

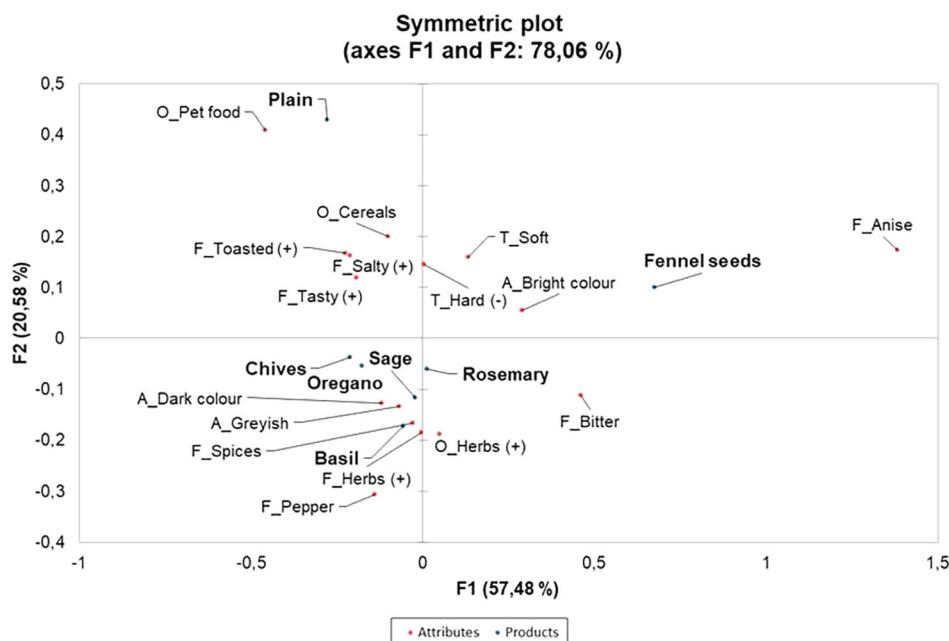


FIGURE 4 Correspondence Analysis (CA) of CATA frequencies containing only the attributes related to appearance (A), odour (O), texture (T), and flavour (F) that significantly differentiated the crispbread samples incorporating *T. molitor* (according to the Cochran Q test at 95% significance level). Attributes represented with symbols (+) or (-) were identified as significantly impacting the overall liking through Penalty Analysis.

The 'Fennel seeds' sample (which presented the lowest overall liking scores) was significantly associated with the attributes 'Anise' and 'Bitter' flavour, which differentiated from the samples 'Oregano' and 'Chives' (which had the highest liking scores). Furthermore, this sample was negatively associated with several flavour attributes that positively affected overall liking ('Tasty', 'Toasted' and 'Salty').

The 'Plain' sample also exhibited a significantly different sensory profile than the other samples. While this sample was significantly associated with several attributes with a positive effect on overall liking ('Salty', 'Toasted' and 'Tasty' flavour), it was also associated with 'Hard' texture (which has a negative effect on overall liking) and had a negative association with flavour and odour attributes ('Herbs') with a positive impact on overall liking. Furthermore, the 'Plain' sample also differentiated from the other samples due to significant associations with 'Cereal' flavour and 'Pet food' odour and negative association with 'Spices' flavour.

The samples with the highest overall liking scores ('Chives' and 'Oregano') presented very similar sensory profiles and were associated with flavour attributes that had a positive effect on liking ('Tasty' and 'Toasted' flavour) while also being negatively associated with 'Bright colour'. The 'Sage' sample presented similarities with the 'Chives' and 'Oregano' samples, although the

former was more associated with the 'Herbs' and 'Spices' attributes.

Although the 'Rosemary' and 'Basil' samples presented significantly lower liking scores than the 'Chives' and 'Oregano' samples, they still presented very similar sensory profiles. Nevertheless, some differences could justify the overall liking scores results. Namely, the 'Basil' sample was significantly associated with 'Greyish' and 'Dark colour' and 'Pepper' flavours, unique associations among all the evaluated samples. As for the 'Rosemary' sample, it presented particularities for appearance since it was the only sample with significant negative associations with 'Dark colour'.

#### 4 Discussion and conclusion

The work presented in this study focused on the consumer evaluation of crispbreads incorporating different insect species (*A. domesticus* and *T. molitor*) and, with the addition of various dried herbs and spices, assessing which product characteristics can ensure higher consumer acceptance.

##### Overall liking

Firstly, observing the overall liking results (Tables 3 and 4), it is clear that the incorporation of *A. domesticus* led to worse results than the incorporation of *T.*

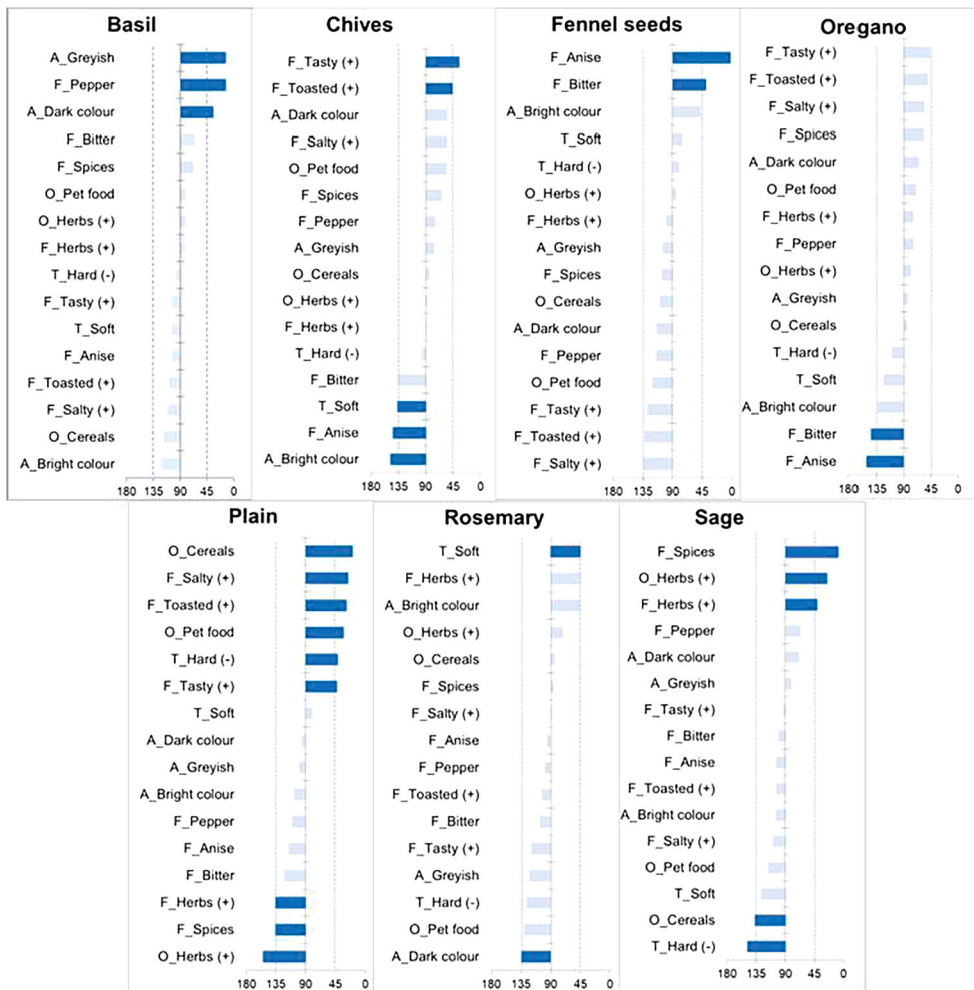


FIGURE 5 Results of MDA analysis, with cosines of the angles between the crispbread samples incorporating *T. molitor* and all the attributes that significantly differentiated the samples (according to the Cochran Q test at a 95% significance level). Vertical dashed lines indicate the cut-off values of  $\cos(45^\circ)$  and  $\cos(135^\circ)$ , representing positive and negative correlations between samples and attributes, respectively. Attributes represented with symbols (+) or (-) were identified as significantly impacting the overall liking through Penalty Analysis.

*molitor*, although results should be interpreted with caution since the same sensory panel did not perform evaluations. There are several differences between mealworm-based crispbread and cricket-based crispbread in their sensory profile that can justify the lower hedonic scores of cricket-based products (as outlined in detail in the following sections). In summary, the crispbreads incorporating *A. domesticus* were more associated with negative attributes related to appearance ('Brown' and 'Darker' colour), texture ('Floury'), and odour/flavour ('Pet food' odour, 'Earthy' odour, 'Bitter' flavour, and 'Earthy' flavour). Differences in hedonic evaluations between different species have been previously reported for both whole insects (Megido *et al.*, 2014; Zielińska *et al.*, 2018) and bakery-type products such as dry fruit balls (Chow *et al.*, 2021) bars (Bartkowicz and Babicz-Zielinska, 2020; Ribeiro *et al.*, 2019; Ribeiro *et al.*, 2022b), bread (Kowalski *et al.*, 2022), bis-

cuits (Akande *et al.*, 2020), cookies (Sriprabloom *et al.*, 2022), or muffins (Çabuk, 2021). Similar to the results presented here, both Chow *et al.* (2021) and Bartkowicz and Babicz-Zielinska (2020) reported that products incorporating *T. molitor* had higher liking scores than products incorporating *A. domesticus*. However, Ribeiro *et al.* (2022b) and Kowalski *et al.* (2022) reported opposing results. The sensory variations between different edible insect species should be further assessed. In particular, trained sensory panels should be used, and species from various manufacturers and submitted to other processing methods (e.g. drying) should be evaluated to better comprehend the differences.

Regarding the effect of different formulations on liking results, there were several similarities between the crispbread incorporating either *A. domesticus* or *T. molitor*. The 'Chives' samples had the highest liking scores for both crispbreads, while the 'Basil' and 'Fennel seeds'

samples had lower liking scores. Additionally, for both crispbreads, the 'Sage' and 'Rosemary' samples had similar liking scores to the 'Plain' samples. The only major difference between crispbreads was observed for the 'Oregano' sample, which had the lowest liking score for the *A. domesticus* products and the second-highest liking score for the *T. molitor* products.

Nevertheless, it should be noted that in the systematic review performed by Ribeiro *et al.* (2024), it was observed that negative hedonic evaluations of bakery-type products occurred at low incorporation levels (<10%) and Ardoin *et al.* (2021) calculated that at around 20% inclusion of *A. domesticus* in whole-wheat crackers would lead to liking scores below 5 (on a 9-point hedonic scale). As such, the crispbread samples formulated in this study can be considered a success since it was possible to incorporate edible insects at a very high level (20%) and simultaneously observe high acceptance levels (12 of the 14 evaluated samples had more than 75% positive hedonic evaluations).

### Sensory profile

#### Appearance

In previous studies, it has been extensively demonstrated that the incorporation of edible insects in food products leads to a browning/darkening effect, which is negatively perceived by consumers, particularly when incorporated into bakery products such as bread, cookies, or crackers (Ribeiro *et al.*, 2024). In this study, both crispbreads incorporating *A. domesticus* and *T. molitor* were characterised as presenting a 'Brown colour', but the citation proportion was much more significant for *A. domesticus* (64.9%) than for *T. molitor* (47.0%). Additionally, relative to the crispbreads incorporating *T. molitor*, the crispbreads incorporating *A. domesticus* had a higher citation proportion for 'Dark colour' (17.4% vs 13.8%) and lower citation proportion for 'Bright colour' (8.0% vs 15.5%), 'Golden' (11.4% vs 22.8%) and 'Appealing' (14.9% vs 28.3%). So, these results seem to indicate that the darkening/browning effect is more pronounced with the incorporation of *A. domesticus* and that this effect has a negative impact on how appealing the samples are.

However, when analysing the results from the CA (Figures 2 and 4) and MDA (Figures 3 and 5), the relation between darker colour and a negative hedonic effect is more complex. It was observed that samples with high liking scores (*T. molitor* – 'Chives' and 'Oregano') were negatively associated with a 'Bright colour', while samples with low significant associations with 'Bright colour' were negatively associated with

'Appealing' (*A. domesticus* – 'Oregano'). Although it has been previously reported that colour liking is negatively affected by insect incorporation, even leading to much lower rejection threshold levels than other sensory dimensions (Ardoin *et al.*, 2020), Ardoin *et al.* (2021) have observed that overall liking of insect-based products is more correlated with flavour/texture liking than with colour liking.

There were some similarities in the effects of formulation between crispbreads incorporating either *A. domesticus* or *T. molitor*. Namely, the 'Rosemary' samples were associated with a lighter colour (significant negative associations with 'Dark colour'), while the 'Basil' samples were significantly associated with a 'Darker colour'.

#### Texture

The texture of the crispbread samples was not significantly affected by formulation or even insect species. The only attributes that equally characterised the crispbreads incorporating *A. domesticus* and *T. molitor* (attributes with the highest citation proportion that did not differentiate between samples) were related to texture ('Crunchy' and 'Dry'). As it occurs for other sensory dimensions, incorporating edible insects has been reported to affect texture properties negatively (Ribeiro *et al.*, 2024). In particular, one common pertains to an increased association with grainy/floury texture in both bakery-type (Biró *et al.*, 2020; Brynning *et al.*, 2020; Ribeiro *et al.*, 2019; Ribeiro *et al.*, 2022b) and meat products (Cruz-López *et al.*, 2022; Schouteten *et al.*, 2016; Tan *et al.*, 2017). In this study, the association with the floury texture was relatively low for both crispbreads, although the citation proportion was higher for *A. domesticus* (13.1%) than for *T. molitor* (9.7%). A grainier texture for *A. domesticus* powder than for *T. molitor* powder has been reported by Brynning *et al.* (2020) and can be caused not only by the exoskeleton of the adult cricket but also by the presence of legs and wings, which are rich sources of chitin (Navarro *et al.*, 2025)

Surprisingly, the different formulations significantly impacted consumers' perception of texture attributes, although they only differed on dry herbs/spices. For the crispbreads incorporating *A. domesticus*, the 'Basil' sample was perceived as softer, while the 'Rosemary' sample was perceived as harder. Furthermore, the 'Oregano' sample was perceived as presenting a 'Floury' texture, while the opposite occurred for the 'Plain' sample, which might indicate that adding the condiments contributed to the perception of a 'Floury' texture. When analysing the results of the crispbreads incorporating

*T. molitor*, it can be observed that the association with a 'Hard' texture had a negative impact on the overall liking of the samples. Sriprabhom *et al.* (2022) have previously identified that adding *T. molitor* to cookies increased the hardness of the samples and negatively correlated to consumers' evaluation of cookies. Similar results were also observed when *A. domesticus* was incorporated into cookies (Biró *et al.*, 2020) and biscuits (Ardoin *et al.*, 2021). There were also some effects of formulation, with the 'Plain' and 'Chives' samples being more associated with a more complex texture. In contrast, the 'Sage' and 'Rosemary' samples were perceived as softer (in direct contrast with the crispbreads incorporating *A. domesticus*). The size of the herbs/spices can affect the product's texture since finely ground herbs/spices can more easily absorb moisture or blend seamlessly with the dough, increasing hardness, while large-leaf herbs (e.g. basil) can create air pockets in the dough and increase softness (Prokopov *et al.*, 2018; Wójcik *et al.*, 2021).

#### Odour & Flavour

The adverse effects of insect incorporation on the odour and flavour of developed food products have been reported in a wide range of products, being one of the main reasons for the rejection of insect-based food products (Ribeiro *et al.*, 2024). The effects range from lower associations with characteristics odour/flavour attributes of the developed food product category (Bartkiewicz and Babicz-Zielinska, 2020; Ribeiro *et al.*, 2019; Schouteten *et al.*, 2016; Smarzynski *et al.*, 2019) to increased associations with off-odours and off-flavours, which are characteristic notes of old foods and lipid oxidation (e.g. rotten, feed, earthy) (Bartkiene *et al.*, 2022; Biró *et al.*, 2020; Brynning *et al.*, 2020; Ribeiro *et al.*, 2019; Ribeiro *et al.*, 2022b; Schouteten *et al.*, 2016; Smarzynski *et al.*, 2019; Tan *et al.*, 2017; Tzompa-Sosa *et al.*, 2021, 2022; Wendin *et al.*, 2021).

Several negative attributes were evaluated in this study (odour of 'Pet food', 'Earthy' odour, 'Bitter', 'Animal/Stable', 'Rancid' and 'Earthy' flavour), and for most of them the citation proportion was much higher for crispbreads incorporating *A. domesticus* than for crispbreads incorporating *T. molitor*: 'Pet food' odour (10.6% vs 4.0%), 'Earthy' odour (22.9% vs 17.0%), 'Bitter' flavour (12.9% vs 5.2%), and 'Earthy' flavour (15.1% vs 11.9%). Additionally, the crispbreads incorporating *T. molitor* had a higher citation proportion for positive attributes such as 'Cereals' odour (42.1% vs 34.9%), 'Cereals' flavour (31.2% vs 24.9%) and 'Tasty' flavour (24.9% vs 12.0%). These differences can be a possible justification for the lower overall liking scores of crispbreads

incorporating *A. domesticus*. Brynning *et al.* (2020) also reported that *A. domesticus* powder had a higher intensity for negative odour/flavour attributes (zoo odour, old flavour, or fish feed flavour) than *T. molitor* powder. However, Ribeiro *et al.* (2022b) reported an increased association of negative odour/flavour attributes for bars incorporating *T. molitor* than for bars incorporating *A. domesticus*, while Bartkiewicz and Babicz-Zielinska (2020) only observed that bars incorporating *A. domesticus* had a lower sweetness and nutty flavour intensity than bars incorporating *T. molitor*. The lack of studies comparing the sensory profile of insect species hinders our ability to make informed decisions when deciding which insect species to use when developing food products, and it should be one of the focuses of future research.

Nevertheless, less than 15% of consumers perceived all the negative odour/flavour attributes except for 'Earthy' flavour and odour. The low association with these negative attributes can explain the high acceptance of most evaluated samples, especially considering the high level of insect incorporation (20%).

It was also possible to observe that the effects of formulations were considerably different between crispbreads incorporating *A. domesticus* or *T. molitor*, except the 'Fennel seeds' samples (which had low liking scores) that presented a distinct sensory profile from the other samples, being associated with 'Anise' and 'Bitter' flavour while also presenting a low association with positive flavour attributes such as 'Salty', 'Tasty' or 'Toasted'. There is not much literature regarding consumer evaluation of bakery-type snacks fortified with fennel seeds, but Anayatullah *et al.* (2023) reported liking increases for crackers fortified with fennel seeds powder. Furthermore, bakery-type products with anise flavour are not uncommon for Portuguese consumers. So, it must be considered that the rejection of this formulation can be due to association with the 'Bitter' flavour, which could have occurred due to the processing applied to the fennel seeds or the variety of used fennel seeds. Another possible explanation is that the association with 'Anise' flavour offers a contrast with the more savoury and herbal profiles present on the other evaluated samples. For the crispbreads incorporating *A. domesticus*, there weren't many additional differences in the odour/flavour profile. The samples were equally characterised as presenting a 'Cereals' and 'Herbs' odour, and most samples were also associated with 'Herbs', 'Spices' and 'Cereals' flavour (except for the 'Fennel seeds' and 'Basil' samples).

On the other hand, the effect of the formulation was more significant for crispbreads incorporating *T. molitor*. All the samples were equally characterised as presenting 'Cereals' flavour, and even the 'Plain' sample was associated with several positive attributes such as 'Tasty', 'Toasted', 'Salty' and odour of 'Cereals'. However, this sample was negatively associated with 'Herbs' and 'Spices' attributes, which were characteristic of the 'Sage' sample and positively impacted liking scores. Furthermore, the 'Plain' sample was significantly associated with a negative odour attribute ('Pet food'), and including dried herbs/spices in the formulation hampered the association with this attribute. Additionally, the samples with the highest liking scores ('Chives' and 'Oregano') were not strongly associated with attributes related to 'Herbs' or 'Spices' and instead were only significantly associated with 'Tasty' and 'Toasted' and were negatively associated with 'Anise' and 'Bitter' flavour.

## 5 Limitations and future research

This study offers additional insights into the sensory profile of insect-based products formulated with different species and spices. This topic is essential to ensure that these products meet consumers' expectations and offer positive sensory experiences, which is indispensable to modifying social and cultural norms surrounding insect-based products. Nevertheless, this study presents some limitations that hindered the extent of information that can be obtained. These limitations are mostly linked to the experimental design, namely the composition of the sensory panel and the lack of control samples. Regarding the sensory panels, limitations on the quantity of crispbread that was developed and the timing of its development (which did not allow for conducting both sensory evaluations in the same timeframe) led to sensory panels with different sizes and compositions. This limited the extent of comparisons between the results with crispbreads incorporating either *A. domesticus* or *T. molitor*. It would be more beneficial to conduct both sensory evaluations with the same sensory panel, although there was some overlap between them since the recruitment strategy and consumer database were identical. Furthermore, since this study aimed to evaluate the impact of adding different dried herbs and spices, control samples (e.g. without insect incorporation) were not used. As such, the effect of insect incorporation on the sensory profile and hedonic evaluations is more difficult to understand.

The results from this study also support several research ideas for future projects. In using insects as food ingredients, more studies must be performed comparing different species and processing methods. This research is still quite novel, and still, there are no clear trends on the effects of species and processing methods on the sensory profile due to the scarcity of studies. Furthermore, the negative impact of using fennel seeds when developing bakery-type products needs to be studied in more detail, since it was not clear why Portuguese consumers penalized the samples with the addition of fennel seeds.

## Supplementary material

Supplementary material is available online at: <https://doi.org/10.6084/m9.figshare.28151384>

## Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 861976. Author B. Barbosa acknowledges Doctoral Grant No. 2023.03467. BDANA, funded by the Portuguese Foundation for Science and Technology (FCT). Authors Rocha, Ribeiro, Barbosa and Cunha also acknowledge financial support from National Funds from FCT within the scope of UIDB/05748/2020 – <https://doi.org/10.54499/UIDB/05748/2020> – and UIDP/05748/2020 – <https://doi.org/10.54499/UIDP/05748/2020> (GreenUPorto).

## Conflict of interest

The authors have no conflict of interest to declare.

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