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Development of a lexicon for the sensory description of edible insects commercially available in Australia

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ABSTRACT

Sensory lexicons provide an important tool for describing the sensory properties of emerging, unfamiliar foods such as edible insects. This study sought to establish and validate a sensory lexicon for the description and differentiation of edible insects commercially available in Australia and prepared using common preservation and cooking methods (freeze-drying, hot-air drying, roasting, sautéing and deep-frying). Five species were evaluated, including house crickets (*Acheta domesticus*), yellow mealworm larvae (*Tenebrio molitor*), king mealworm larvae (*Zophobas morio*), tyrant ants (*Iridomyrmex* spp.) and green tree ants (*Oecophylla smaragdina*). Following generic descriptive sensory analysis methods, a trained panel (n=8) developed a sensory lexicon of 29 aroma and flavour descriptors, and 16 texture descriptors. Vocabulary were then categorised and ordered to generate a sensory wheel. Due to a lack of cross-over in sensory attributes between species, sub-categories of species-specific vocabulary were also generated for each insect. The lexicon enabled sensory profiling of commercially available edible insect samples which revealed large variation in aroma, flavour, and texture attributes due to both species and preparation method. This work provides a platform for development of a globally relevant edible insect sensory lexicon. International collaboration will enable expansion of the lexicon for use with other insect species and preparation methods, insect-derived ingredients (such as insect powder, defatted insect powder and textured insect protein) and in different cultural settings. As the industry grows, the applicability of vocabulary for differentiating within species and between competitive products should also be assessed.

1. Introduction

Insects have been identified as an environmentally sustainable source of high-quality protein. Entomophagy (the human consumption of insects) therefore offers a promising solution for protein diversification in Western food cultures (van Huis et al., 2013). Edible-insect-related businesses have consequently emerged in regions such as Europe, North America, Australia, and New Zealand. However, poor consumer acceptance remains a major and critical barrier to industry growth (Dagevos, 2021).

While entomophagy played an important role in early human diets (Lesnik, 2018) and continues to be practiced in regions such as Latin America, Africa, and Asia (Raheem et al., 2019), Western consumers typically lack exposure to insects in the context of food. Rather, insects are often associated with negative connotations (i.e., as a pest, nuisance and/or source of contamination) (Deroy, Reade, & Spence, 2015; van Huis, 2013). This is reflected in Western consumer responses to entomophagy whereby feelings of disgust are dominant (Bae & Choi, 2021; Jensen & Lieberoth, 2019), and considered a primary predictor of consumer acceptance (La Barbera, Verneau, Amato, & Grunert, 2018). Improving consumer familiarity with insects as food could therefore help to redefine entomophagy in Western food cultures (Yang & Lee, 2019).

Describing the sensory properties (aroma, flavour, texture, and appearance) of food products (e.g., through various forms of marketing such as product labelling and advertisements) can help consumers

Abbreviations: AD, *Acheta domesticus*; TM, *Tenebrio molitor*; ZM, *Zophobas morio*; IR, *Iridomyrmex* spp; OS, *Oecophylla smaragdina*; ANOVA, analysis of variance; *a*, aroma attribute; *f*, flavour attribute; *m*, mouthfeel attribute; *t*, texture attribute.

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increase familiarity with new and unique product categories (Tuorila & Hartmann, 2020). This may play a role in improving consumer acceptance by better informing product expectations and culinary use among consumers and other end users (e.g., chefs and product developers) (Piqueras-Fiszman & Spence, 2015; Tan et al., 2015; Wassmann, Siegrist, & Hartmann, 2021). The accurate description of sensory properties is also important for various aspects of food production (e.g., product development and quality control), as well as sensory and consumer research (Suwonsichon, 2019). In turn, this enables the commercialisation of high-quality food products which better meet consumer tastes and preferences. Sensory language (the vocabulary used to describe sensory properties) can therefore offer a crucial tool for development of the edible insect industry.

Presently, informal sensory language is routinely used by consumers, industry, and researchers to describe edible insects. While recent work has shown that significant variation in the aroma, flavour and texture of edible insects is attributable to preparation method (Mishyna, Chen, & Benjamin, 2020; Perez-Santaescolastica, De Winne, Devaere, & Fraeye, 2022), this language is often developed at a species-level and lacks information regarding how the insect was prepared (Elhassan, Wendin, Olsson, & Langton, 2019; Nordic Food Lab, Evans, Flore, & Frøst, 2017; Ramos-Elorduy & Menzel, 1998). Further, despite playing a critical role in consumer acceptance (Mishyna, Chen, & Benjamin, 2020), texture is poorly described. The vocabulary selected for sensory and consumer research also varies between studies, limiting their comparison (Nervo, Ricci & Torri, 2024; Sick, Hartmann & Frøst, 2024). Further research is therefore needed to establish well-defined vocabulary that can be used to more accurately and uniformly describe and differentiate edible insects prepared using common preservation and cooking methods.

A sensory lexicon comprises standardised vocabulary for the sensory attributes of a given food product category. Like a dictionary, it provides a list of descriptors (vocabulary used to describe sensory attributes) paired with a definition and reference standard. The definition clarifies the meaning of the descriptor while the reference standard (a food or chemical product) provides a benchmark against which the attribute can be measured. Thus, facilitating clear and consistent description across research, industry and among consumers, as well as in different countries and cultures (Suwonsichon, 2019). Previous research has established standardised vocabulary for a small number of edible insect samples. Albrektsson (2017) developed standardised aroma, flavour, and texture vocabulary for edible insects commercially available in Sweden, but common cooking techniques (e.g., roasting, sautéing, and deep-frying) were not evaluated. Kiatbenjakul, Intarapichet & Cadwallader (2015) have also developed aroma vocabulary for the male giant water bug (*Lethocerus indicus*). This study employed generic descriptive sensory analysis methods (Lawless & Heymann, 2010) to establish and validate a sensory lexicon for the description and differentiation of edible insects commercially available in Australia – including house crickets (*Acheta domesticus;* AD), yellow mealworm larvae (*Tenebrio molitor;* TM), king mealworm larvae (*Zophobas morio;* ZM), tyrant ants (*Iridomyrmex* spp.; IR) and green tree ants (*Oecophylla smaragdina;* OS) – and prepared using common preservation and cooking methods. Through collaborative efforts, it is anticipated that the lexicon can provide a starting point for development of a globally relevant descriptive tool.

2. Materials and method

2.1. Experimental design

This study followed generic descriptive sensory analysis methods described by Lawless and Heymann (2010), which involve four key stages: 1) establishing a 'frame of reference' by sampling a range of products from a given category, 2) generating terms to describe sensory attributes of the products, 3) refining the list of terms by consensus, and 4) developing a definition and reference standard for the final list of terms (Drake & Civille, 2003). Once prepared, the sensory lexicon was used to establish sensory profiles for a selection of edible insect samples (described in Section 2.3). This final step was employed to validate the vocabulary before ordering the terms into a tiered system for presentation as a sensory wheel (Lawless & Civille, 2013).

Typically, generic descriptive sensory analysis is conducted by an experienced sensory panel, but a new panel may also be recruited and trained following various published standards (e.g., ISO 8586:2023) (Lawless & Civille, 2013). As a sensory panel familiar with edible insects was not available, a new panel was recruited and trained in accordance with ISO Standards (ISO, 2012). Methods used for sensory panel recruitment, lexicon development and panel training as well as sensory profiling and lexicon validation are detailed in Sections 2.2 – 2.7. Ethical approval for the involvement of human subjects in this study was granted by the University of Adelaide's Human Research Ethics Committee, approval reference number H-2021-207, 16/12/2021.

2.2. Sensory panel

A nine-person sensory panel (eight women and one man, aged between 25 and 74 years), participated in this study. Panellists were selected on the basis of availability (e.g., the panellist was able to attend all sessions) and motivation (e.g., the panellist showed demonstrated interest in sensory research, sustainable food and/or edible insects), then screened for their ability to identify and describe aroma, flavour, and texture attributes using odour and basic taste identification assessments, as well as flavour detection and intensity tests, and a combined description test (ISO, 2012).

Following lexicon development and panel training (described in Section 2.6 and 2.7), one panellist was excluded due to poor reproducibility (e.g., their inability to consistently score samples relative to other panel members) (Rossi, 2001). An eight-person sensory panel therefore participated in later sensory profiling.

2.3. Sample selection

Samples selected for lexicon development and sensory profiling are described in Table 1. For the purpose of lexicon development, sample selection was conducted with the aim of providing comprehensive insights into potential aroma, flavour and texture attributes within the product category (Lawless & Heymann, 2010). A sub-set of samples was then selected for sensory profiling to validate the developed lexicon. Species were chosen on the basis of being available for consumer purchase in Australia at the time of this study. These include house crickets (*Acheta domesticus;* AD), yellow mealworm larvae (*Tenebrio molitor;* TM), king mealworm larvae (*Zophobas morio;* ZM), tyrant ants (*Iridomyrmex* spp.; IR) and green tree ants (*Oecophylla smaragdina;* OS). Samples were purchased from commercial Australian suppliers – Grubs Up (Pinjarra, Australia), Circle Harvest (Sydney, Australia), and Something Wild (Adelaide, Australia) – and prepared using methods of commercial and traditional relevance (Mishyna et al., 2020). At the time of this study, OS were sold and consumed in Australia in their raw form, while IR were sold and consumed as a hot-air dried product. AD, TM and ZM were commercially available as hot-air dried products only, but frozen samples were also sourced and subsequently freeze-dried, roasted, sautéed, and deep-fried to encompass preservation and cooking methods used in other regions (Mishyna et al., 2020). Evaluations were completed using whole insects only (excluding aroma evaluation, for which freeze-dried and hot-air dried samples were coarsely ground due to low aroma intensity and sample availability). Insect-derived ingredients (such as insect powder, defatted insect powder, textured insect protein and oils) were excluded from this study due to their lack of availability (only AD powder was available at the time of the study).

Table 1
Sample preparation and presentation for lexicon development and sensory profiling.

Sample	Scientific name	Preparation method: Freeze-dried	Hot-air dried[e]	Roasted[e]	Sautéed[e]	Deep-fried[e]	Presentation method: Aroma	Flavour and texture
House crickets[a]	*Acheta domesticus* (AD)	4 days, 0.5–1 mBar, condenser at −30 °C.	75 °C until moisture < 5 %.	20 min at 160 °C or 15 min at 180 °C.[d]	4 min at 175 °C in canola oil. 6.25 mL oil / 100 g.	75 s at 200 °C in canola oil. 300 mL oil / 100 g. Dried on paper towel before serving.	Freeze-dried and hot-air dried samples: 0.5 g, coarsely ground. Roasted, sautéed, and deep-fried samples: 2 whole insects.	2 whole insects, 1 insect per evaluation.
Yellow mealworm larvae[b]	*Tenebrio molitor* (TM)		Commercial product[b]	12 min at 160 °C or 10 min at 180 °C.[d]	2 min at 175 °C in canola oil. 6.25 mL oil / 100 g.	45 s at 200 °C in canola oil. 300 mL oil / 100 g. Dried on paper towel before serving.		
King mealworm larvae[a]	*Zophobas morio* (ZM)		75 °C until moisture < 5 %.	25 min at 160 °C or 20 min at 180 °C.[d]	4 min at 175 °C in canola oil. 6.25 mL oil / 100 g.	90 s at 200 °C in canola oil. 300 mL oil / 100 g. Dried on paper towel before serving.		
Tyrant ants[b]	*Iridomyrmex* spp. (IR)	*nil*	Commercial product[b]	*nil*	*nil*	*nil*	0.5 g whole insects.	0.5 g whole insects, 0.1 g per evaluation.
Green tree ants[c]	*Oecophylla smaragdina* (OS)	Other (served fresh).					15 whole ants. 4 ants per evaluation, freshly pressed with filter paper.	15 whole ants, 1 ant per evaluation.

[a]Samples purchased from Grubs Up (Pinjarra, Australia).
[b]Samples purchased from Circle Harvest (Sydney, Australia).
[c]Sample purchased from Something Wild (Adelaide, Australia).
[d]Samples roasted at two temperatures for lexicon development, 160 °C and 180 °C; and 160 °C only for sensory profiling.
[e]Samples blanched for 5 min at 100 °C before preparation.

2.4. Sample preparation

Sample preparation methods for lexicon development and sensory profiling are described in Table 1. Hot-air dried TM and IR were prepared by the supplier and stored in vacuum-sealed bags at 3 °C until evaluation. All other samples were supplied frozen and stored at – 20 °C until preparation for evaluation. Freeze-dried samples were prepared by a commercial freeze-drying facility, then stored in an airtight food storage bag at 3 °C. Hot-air dried AD and ZM were prepared the day before evaluation, and after cooling to room temperature (21 ± 1 °C) were stored in vacuum-sealed bags at 3 °C. Roasted, sautéed, and deep-fried samples were freshly prepared immediately prior to evaluation. OS were defrosted at room temperature (21 ± 1 °C) for 1-min prior to serving.

2.5. Sample presentation

Sample presentation formats are described in Table 1 and were developed separately for each species and preparation method. For individual evaluations during lexicon development, samples were contained in a small, white plastic bowl labelled with a three-digit code and presented on a white plastic tray, alongside a plastic spoon and glass of filtered water. To reflect consumer use, roasted samples were initially served immediately after preparation. As this method was associated with considerable temperature variability during evaluation (i.e., samples quickly cooled to room temperature), samples were re-evaluated at room temperature (21 ± 1 °C) during lexicon development and sensory profiling sessions.

For sensory profiling, samples were presented in lidded, plastic petri dishes labelled with three-digit codes. To aid temperature control of hot samples (e.g., sautéed and deep-fried) during the longer evaluation, petri dishes were lined with aluminium foil. All samples were presented on a white plastic tray, alongside a plastic spoon, a glass of filtered water and fresh green apple slices (for palate cleansing). A piece of filter paper was also provided for aroma evaluation of OS (allowing panellists to burst the ant abdomen prior to evaluation).

2.6. Development of a sensory lexicon

Panellists initially received general training in the detection and description of aroma, flavour, and texture attributes across 3 × 3 hr sessions. They were then presented with each sample over 2 × 2 hr sessions, and asked to individually evaluate the aroma, flavour, and texture – describing any attributes that they identified, without the use of hedonic or quantitative terms. For their initial evaluation, panellists were required to follow a specific assessment technique for aroma, flavour, and texture evaluation (standardised to normal consumption). They were then invited to use alternative assessment techniques if desired but asked to record their method. This allowed for the optimisation of assessment techniques used for sensory profiling sessions, as described in Supplementary Materials, Section A. Descriptors were subsequently collated and presented to the panel alongside the samples and a range of potential reference standards for each descriptor (Lawless & Heymann, 2010). The consensus method was then followed to refine the list of descriptors and remove redundancy, as well as develop descriptor definitions and final reference standards.

2.7. Sensory profiling and lexicon validation

2.7.1. Panel training

Following lexicon development, the panel was trained in sensory profiling of edible insect samples. Training sessions were conducted over 4 × 3 hr sessions. In accordance with ISO Standards (ISO, 2012), panellists were trained in the use of a 10 cm unstructured line scale (anchored 'low' at 1 cm and 'high' at 9 cm) for aroma, flavour and texture evaluation – progressing from simple (e.g., single attribute,

Table 2
Aroma and flavour descriptors, definitions, and reference standards for house crickets (*Acheta domesticus*; AD), yellow mealworm larvae (*Tenebrio molitor*; TM), king mealworm larvae (*Zophobas morio*; ZM), tyrant ants (*Iridomyrmex* spp.; IR) and green tree ants (*Oecophylla smaragdina*; OS).

Descriptor	Definition	Reference standard[b c]	Insect species[d]
Cereal	Aroma and flavour of cereals, such as barley, oat and wheat.	30 g equal ratio of McKenzie's Raw Barley, Black and Gold Rolled Oats and coarsely ground Weet-bix; mixed and submerged in distilled water.	AD, TM, ZM
Toasted	Aroma and flavour of toasted bread crust.	2 tbsp Tip Top 'The One' White Sandwich Sliced Bread, toasted until golden brown on each side. Cooled, then coarsely ground.	AD, TM, ZM
Popcorn*	Aroma and flavour of freshly popped popcorn.	2 tbsp Riviana Popping Corn, popped in 2 tbsp vegetable oil per ¼ cup corn kernels. Popcorn popped within 24 h of use and coarsely ground.	AD, TM, ZM
Oily	Aroma and flavour of oil.	2 tbsp Black and Gold Vegetable Oil.	AD, TM, ZM
Hot chips (fries)	Aroma and flavour of frying oil, similar to hot chips. Oily, caramelised and starchy notes.	30 g McCain Superfries (straight cut), deep-fried until crispy in vegetable oil. Cooled to room temperature and chopped into 2 cm pieces.	AD, TM, ZM
Raw walnut	Aroma and flavour of raw walnut; not freshly deshelled, producing slight rancidity.	30 g Lucky natural golden walnuts, coarsely ground.	TM
Roasted nuts	Aroma and flavour of roasted, mixed nuts.	30 g mixed nuts (equal ratio Coles roasted, unsalted peanuts; Lucky toasted pistachios; Lucky oven roasted almonds and Lucky natural golden walnuts; coarsely ground).	AD, TM, ZM
Nutritional yeast	Aroma and flavour of nutritional yeast; cheesy and yeasty notes.	2 tbsp Premium Choice Nutritional Savoury Yeast Flakes.	TM, ZM
Roasted chicken	Aroma and flavour of roasted chicken skin; caramelised and meaty notes.	30 g skin of a Foodland Roasted Chicken (leg cut).	AD, TM, ZM
Bacon*	Aroma and flavour of fried bacon.	30 g Primo Pan-sized, Triple Smoked Rindless Bacon, fried until golden brown and crispy on each side; finely diced.	ZM
Beef stock	Aroma and flavour of rich, savoury stock; beefy and soy sauce notes.	1 crumbled Massel's Beef Style Stock Cube and 0.5 g Vegemite, mixed.	IR, AD
Earthy	Aroma and flavour of raw mushroom and wet soil; similar to a damp forest floor.	2 tbsp equal ratio coarsely chopped button mushrooms and wet soil.	AD, TM, ZM
Wet hay[a]	Aroma of wet hay.	2 tbsp coarsely ground Garden Essentials Sugarcane Mulch, moistened with water.	TM
Warm spices	Aroma and flavour of warm spices such as cinnamon, clove and pepper.	1 tbsp 10:2 ratio, MasterFoods Allspice (ground) and MasterFoods Peppercorns Black (cracked).	IR
Woody	Aroma and flavour of toasted wood; dry and earthy notes.	2 tbsp American Oak, small grade-screened (heavy toast).	IR
Burnt match	The aroma and flavour of a burnt match; burnt wood and slightly sulphurous.	4 freshly struck matches, burnt approx. halfway down match.	IR
Rubber[f]	The flavour of rubber; tarry notes.	30 g 4:1 ratio of Bic Glue Stick glue and Marbig Rubber Band Assorted (cut into 1 cm pieces).	ZM
Boiled egg yolk	Aroma and flavour of cooked egg yolk.	Egg yolk from egg boiled for 6 min.	AD, TM, ZM
Seaweed	An oceanic aroma and flavour; seaweed and salty notes.	30 g coarsely chopped dried kelp.	AD, ZM
Dried shrimp	The aroma and flavour of dried shrimp.	30 g coarsely chopped Richmond dried shrimp.	AD, ZM
Burnt toast	The aroma and flavour of burnt toast; cereal and chemical.	2 tbsp Tip Top 'The One' White Sandwich Sliced Bread, toasted until a black surface on each side is reached. Cooled, then coarsely ground.	IR
Vinegar	The sharp, acidic aroma and flavour of vinegar.	2 tbsp Cornwell White Vinegar.	OS, IR
Green apple	Aroma and flavour of freshly cut green apple with a hint of citrus.	30 g finely diced granny smith apple, 5 g lemon rind, 5 g lime rind, ½ tsp fresh lemon juice.	OS
Fruit candy	Aroma and flavour of fruit candy.	2 tbsp finely ground tropical Skittles, equal parts of each flavour.	OS
Mint[a]	Cooling, minty, menthol aroma.	2 tbsp 6:1 ratio Fisherman's Friend Original Mint (finely ground) and Hoyt's dried mint leaves.	OS
Cut grass[a]	The aroma of freshly cut grass; green, fresh.	30 g freshly cut grass, moistened with distilled water.	OS
Lingering flavour[f]	Presence of a lingering flavour 20 s after swallowing (or expectoration).	*nil*	OS, IR, AD, TM, ZM
Salty[f]	Salty taste.	50 mL sodium chloride (5 g/L water).	AD, TM, ZM
Savoury[f]	Savoury taste (umami).	50 mL monosodium glutamate (0.6 g/L water).	IR, AD, TM, ZM
Sour[f]	Sour taste.	50 mL citric acid (1 g/L water).	OS, IR
Bitter[f]	Bitter taste.	50 mL caffeine (0.5 g/L water).	IR, AD, TM, ZM

[a]Aroma descriptor only.
[f]Flavour descriptor only.
[b]All reference standards are considered equivalent to nine (90 = high) on a scale of 0–100.
[c]All aroma and flavour reference standards were presented in 3.8 cm × 5 cm clear lidded containers for sensory profiling sessions.
[d]This descriptor was included in the species-specific lexicon for the listed insect species.
* Descriptor removed from final lexicon (as described in Section 3.2.4).

water-based sample) to complex evaluations (e.g. multiple attributes, food sample). Panellists then selected assessment techniques, a palate cleanser (fresh green apple slices) and descriptor list for each species by consensus, before completing product specific training with edible insect samples (reflecting final evaluation conditions and requirements). Due to the time-sensitive nature of textural properties during sensory profiling, reference products for texture were only provided during product training – allowing panellists to become familiar with each attribute and reach consensus for low and high intensity. Final panel selection was completed as per ISO Standards (ISO, 2012).

2.7.2. Sensory profiling

Sensory profiling sessions were completed in a 12-booth sensory laboratory at the University of Adelaide's Waite Campus, under controlled conditions (21 ± 1 °C, pure white LED lighting). Each booth was equipped with a computer and responses were recorded using RedJade® software (Redwood City, CA, USA). Samples were presented (in triplicate) using a monadic sequence and randomised block design.

Table 3
Texture descriptors, definitions, and reference standards for house crickets (*Acheta domesticus*; AD), yellow mealworm larvae (*Tenebrio molitor*; TM), king mealworm larvae (*Zophobas morio*; ZM), tyrant ants (*Iridomyrmex* spp.; IR) and green tree ants (*Oecophylla smaragdina*; OS).

Descriptor	Definition[a]	Reference standard		Insect species[b]
		Low intensity	High intensity	
Burst-in-mouth[t]	The sensation of a sudden popping upon bite-down, releasing interior contents.	1 × 1 cm cube of fresh orange.	1 × Chatime Bubble Tea Popping Pearl.	OS
Prickly[t]	Sharp protruding points.	*nil*	*nil*	IR, AD, TM, ZM
Brittle[t]	Shattering fracture (many pieces), following a relatively small amount of force.	1 × Captain's Table water cracker.	2 × 2 cm piece Cruskit Original cracker.	IR, AD, TM, ZM
Tough[t]	Malleable and resistant to fracture; bending/compressing in response to biting force.	2 × 2 cm piece Coles Bakery White Sourdough, crusts removed.	2 cm piece Coles dried Mango Slices.	OS, AD, TM, ZM
Dense[t]	A measure of air-pockets incorporated into food structure, where low refers to the presence of large air pockets, medium refers to the presence of small air pockets and high refers to no air pockets.	2 × 2 cm piece Cruskit Original cracker.	1 × 1 cm piece Coles roasted chicken (breast, no skin).	AD, TM, ZM
Crunchy[t]	A textured food which fractures during mastication and produces relatively loud 'crackly' sounds.	1 × 1 cm piece honeycomb.	2 × 2 cm piece Cruskit Original cracker.	IR, AD, TM, ZM
Chewy[t]	A food that does not break into pieces during mastication and requires drawn-out chewing to prepare for swallowing.	2 × 2 cm cube Coles Bakery White Sourdough, crusts removed.	1 × The Natural Confectionary Co. Snake.	OS, AD, TM, ZM
Crumbly[t]	A food that breaks into small, crumb-like pieces during mastication. The food does not require drawn-out chewing to prepare for swallowing.	2 cm piece Arnott's Scotch Finger biscuit.	1 × Always Fresh Mini Toasts.	AD, TM, ZM
Flaky[t]	A food that breaks into coarse, flake-like pieces during mastication. The food does not require drawn-out chewing to prepare for swallowing.	2 × 2 cm piece Cruskit Original cracker.	2 cm piece Cadbury Flake.	IR, AD, TM, ZM
Particulate[m]	The sensation of particulates in the mouth during mastication. Can be analysed separately as low/chalky, medium/grainy, high/gritty.	¼ tsp cornflour (low); ¼ tsp Macro Natural Semolina Flour (medium).	¼ tsp Macro Australian Polenta.	IR, AD, TM, ZM
Wads-up[m]	The aggregation of the food during mastication, forming a pasty 'wad' in the mouth.	1 × Captain's Table water cracker.	2 × 2 cm cube Coles Bakery White Sourdough, crusts removed.	AD, TM, ZM
Hard-to-clear[m]	The sensation of small pieces catching in- or sticking to the teeth or throat while or after swallowing.	*nil*	*nil*	OS, IR, AD, TM, ZM
Drying[m]	A drying sensation on the tongue and in the mouth after swallowing.	1 × Captain's Table water cracker.	2 cm piece Cruskit Original cracker.	IR, AD, TM, ZM
Astringent[m]	Puckering sensation, primarily on the surface of the tongue and walls of mouth. Can leave the mouth feeling rough, raw, or sandpapery.	50 mL tannic acid (0.05 g/L water).	50 mL tannic acid (1.5 g/L water).	OS, IR
Mouthcoating[m]	The sensation of having a coating across mouth surfaces.	Vegetable oil	Lard	AD, TM, ZM
Tooth packing[m]	The sensation of food building-up in- and sticking on the surface of teeth, particularly in molars.	1 × Captain's Table water cracker.	1 × The Natural Confectionary Co. Snake.	AD, TM, ZM

[t]Texture descriptor.
[m]Mouthfeel descriptor.
[a]Specific description for low and high intensity are provided in Supplementary Materials, Section A.
[b]This descriptor was included in the species-specific lexicon for the listed insect species.

For each sample, panellists were asked to evaluate the intensity of selected aroma, flavour, and texture attributes on an unstructured line scale, anchored from low to high (if the attribute was not perceptible, the scale was left blank). Evaluations followed a standardised sample assessment technique, described in Supplementary Materials, Section A. Panellists were also provided with a set of reference aroma and flavour standards, as well as a copy of the lexicon (shown in Supplementary Materials, Section A). Sampling was conducted across 6 sessions, with 2 sessions per day (8–9 samples per session) and a 15 min break between same-day sessions. A 1 min break was also provided between samples, during which panellists were required to palate cleanse using filtered water and fresh green apple slices. This protocol was designed in conjunction with panellists to manage fatigue and maximise their availability, and evaluated by examining the replicability of panellist scores during training.

2.7.3. Lexicon validation

Sensory profiles for each insect species were used to validate the vocabulary (e.g., confirming whether the terms enable description and differentiation of the product category) (Drake & Civille, 2003), as described in Section 2.7.4. The final list of descriptors was then categorised and ordered to generate a sensory wheel.

2.7.4. Statistical analysis

Statistical analysis was completed using XLSTAT software Version 2023.1.5 (Addinsoft, Paris, France). To assess the importance of each descriptor for describing and differentiating sensory attributes, a three-way mixed model analysis of variance (ANOVA) was fitted for AD, TM and ZM samples, with the *assessor* as a random effect, and *replicate* and *product* as fixed effects. A post-hoc Tukey's honestly significant difference (HSD) test was then applied to identify significant differences between samples prepared using different preservation and cooking methods. As AD, TM and ZM samples were evaluated using species-specific sub-lexicons, a separate ANOVA was fitted for each species to prevent zero-inflation. Multiple factor analysis (MFA) was then conducted on differentiating sensory attributes ($P \leq 0.05$) across AD, TM and ZM to visualise the relationship between preparation method and sensory profiles, and explore trends between different species. In the absence of comparative products (only one sample was available for each species), mean attribute intensity scores were calculated to evaluate sensory language for IR and OS.

3. Results and discussion

3.1. Preliminary sensory lexicon development

A preliminary list of 47 terms was generated during lexicon development, comprising 31 aroma and flavour descriptors, and 16 texture descriptors (including texture and mouthfeel attributes). All terms as well as their definition and reference standard are detailed in Tables 2 and 3. Like the '*Lexicon for Australian Native Plant Foods and Ingredients*' described by Smyth et al. (2012), the broad product category resulted in a lack of cross-over between attributes – in this case, between species. For example, AD, TM and ZM shared no aroma and flavour descriptors with OS. This distinction between insect species was also observed by Mishyna et al. (2020). To reduce redundancy and panel fatigue, subcategories of species-specific lexicons were therefore generated for each insect. Notably, *dried shrimp* and *seaweed* were excluded from the TM lexicon despite previous description in roasted and deep-fried TM (Seo, Kim, & Cho, 2020). As these attributes are associated with the presence of pyrazines (2,6-dimethyl-pyrazine, 2,3,5-trimethyl-pyrazine), heptan-2-one and 1-butyl-pyrrolidine, this could be explained by panel selection of alternative savoury-type descriptors including *roasted nuts*, *toasted*, *nutritional yeast* and *boiled egg yolk*.

Another key challenge for this product category relates to sample availability. Typically, a panel would be exposed to a large sample set (frame of reference) of approximately 25–100 products (Drake & Civille, 2003). However, given Australia's relatively small edible insect industry, a limited number of products were commercially available. The frame of reference used for lexicon development was therefore restricted to one product sample per insect species, prepared using relevant preservation and cooking methods. While this reflects the Australian market at the time of this study, samples from other suppliers may exhibit diverse sensory properties (e.g., due to changes in rearing, processing and/or preparation methods) (Mishyna et al., 2020). As the industry expands, future work should therefore include a more detailed investigation of sensory variation within insect species and between competitive products. This should incorporate samples from the international market as well as edible insect species of cultural and commercial significance (not currently available for sale in Australia) – providing a globally relevant language that incorporates traditional and commercial preparations. As sautéed and deep-fried samples were prepared using only canola oil, the applicability of this lexicon for evaluating insects cooked in other frying oils could also be further explored.

3.2. Sensory profiling and lexicon validation

The preliminary sensory lexicon was evaluated for use in the description and differentiation of IR, OS, AD, TM and ZM, by species and preparation method. As species-specific aroma, flavour and texture attributes were used for the evaluation of each insect, sensory profiles are reported separately for IR, OS, AD, TM and ZM.

3.2.1. Panel performance and sample variability

Panel performance and sample variability (e.g., variation between replicates) were examined by species, using results from the sensory profiling of AD, TM and ZM. Results are summarised in Supplementary Materials, Section B. IR and OS were not considered due to the absence of comparative samples (only one sample was available for each species).

Examination of the *product* × *assessor* effect across AD, TM and ZM indicates that panellists were evaluating attributes differently ($P \leq 0.05$), which is common for descriptive sensory analysis methods (Lawless & Heymann, 2010). The comparison of significant *product* effect and *product* × *assessor* effect *F*-values ($P \leq 0.05$) indicates that a small group of differentiating attributes (*roasted nuts*, *earthy*, *oily, drying and mouthcoating*) were most affected, with all showing a larger *F*-value for the *product* × *assessor* effect than the *product* effect. Panel disagreement relating to these and other attributes (such as *dried shrimp*) was also observed during lexicon development. However, following sample re-evaluation and additional panel training, all attributes were retained in the preliminary sensory lexicon because the panel perceived that they were important to product use and acceptability. Continued differences in evaluation may therefore reflect long-term, deep-rooted influences such as product familiarity (Jeong & Lee, 2021). While sensory panel performance was considered satisfactory for the purpose of validating lexicon applicability, future work should explore Rate-All-That-Apply (RATA) and hedonic testing with untrained consumers to determine whether a) affected attributes are perceived at a population level, and b) these attributes influence consumer acceptability and preference.

While some variability was expected between samples (e.g., due to biological variation) (Meyer-Rochow, Gahukar, Ghosh, & Jung, 2021), there was no significant ($P \leq 0.05$) *replicate* × *assessor* effect for most attributes. However, a higher number of attributes with a significant *replicate* × *assessor* effect was observed for AD. Sample variability may have therefore had a greater effect on product discrimination for this species. Alternatively, panellist fatigue may be higher when tasting AD samples due to more complex textural properties (e.g., large legs and wings), reducing repeatability.

3.2.2. Describing and differentiating by species

IR and OS can be described by distinct sensory profiles shown in Fig. 1. IR was characterised by *burnt match*, *woody* and savoury *beef stock* attributes, a moderately *bitter* taste, *lingering flavour* and a *brittle, prickly* texture, that was *grainy* upon mastication. After swallowing, the sample was moderately *hard-to-clear*, *drying* and *astringent*. OS was characterised by *green apple*, *cut grass* and *vinegar* aromas. Upon bite down, the sample was mildly *tough* and *burst-in-mouth*, releasing a strong *sour* taste and *green apple* and *vinegar* flavours. This characteristic sourness alongside fruity aroma and flavour could be explained by the high concentration of volatile organic acids (predominantly formic acid) in OS (Alagappan et al., 2021). 1-Hexanol has also been reported in smaller quantities in the anterior of the ant, possibly accounting for the presence of *cut grass* aroma (Alagappan et al., 2021). Upon mastication and swallowing, the sample was moderately *chewy* and *hard-to-clear* with an *astringent* mouthfeel. Across both IR and OS samples, secondary (lower intensity) attributes were also demonstrated (e.g., attributes with mean intensity scores of < 40). As these qualities may play a role in differentiating commercial products as well as consumer preference (e.g., dominance of *savoury* versus *warm spices* flavours, and artificial/*fruit candy* versus fresh/*green apple* aroma and flavour), their inclusion in the lexicon is warranted at this stage of market and research development. A review of selected species-specific descriptors is recommended when additional commercial products become available. Where possible, this should include other preparations such as fresh, freeze-drying and hot-air drying.

The sensory profiles for AD, TM and ZM are described in Supplementary Materials (Section C) and summarised in Fig. 2. While preparation method significantly altered aroma, flavour, and texture attributes, all three species were characterised by savoury qualities, *lingering flavour*, and complex textural profiles, reflecting their morphology (e.g., exoskeleton, legs, wings, and antennae). Despite these similarities, the species could be separated by the source of savouriness and secondary attributes.

TM and ZM samples exhibited nutty savoury characteristics, described by *roasted nuts* and *nutritional yeast* aroma and flavour, while AD showed more meat-like qualities with dominant savoury attributes including *roasted chicken*, *roasted nuts,* and *beef stock*. All samples shared moderate *cereal* attributes, and mild *saltiness.* ZM could be separated by a distinct *rubber* flavour as well as secondary *seaweed* and *dried shrimp*

attributes. These qualities could be explained by a higher concentration of phenol and trimethylamine (Perez-Santaescolastica et al., 2022; Perez-Santaescolastica, De Winne, Devaere, & Fraeye, 2023). Phenol is known to contribute tarry notes while trimethylamine is a seaweed odour compound (Khatun et al., 2021; Tzompa-Sosa, Yi, Van Valenberg, & Lakemond, 2019). *Seaweed* and *dried shrimp* attributes were also present in AD. This may be due to the presence of 1-octen-3-ol, which contributes earthy, seaweed, fatty, mould, and mushroom notes, and has been reported previously in AD following freeze-drying and blanching (Perez-Santaescolastica et al., 2022, 2023). TM could also be distinguished from ZM and AD by the presence of *wet hay* and *raw walnut* qualities which were significantly more intense in hot-air dried samples ($P \leq 0.05$ and $P \leq 0.0001$ respectively).

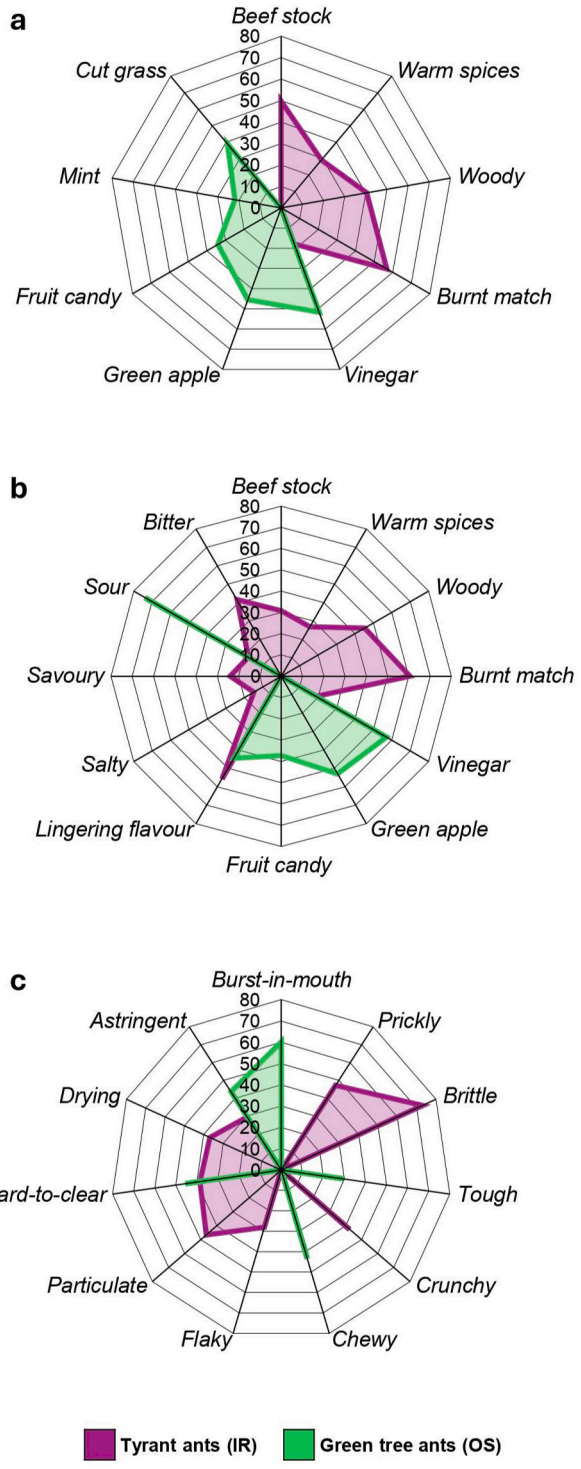

Fig. 1. Radar charts of mean attribute intensity scores for tyrant ants (*Iridomyrmex* spp.; IR) and green tree ants (*Oecophylla smaragdina*; OS). (a) Aroma attributes, (b) Flavour attributes, (c) Texture attributes.

3.2.3. Describing and differentiating by preparation method

Significant differences by Tukey-Kramer honestly significant difference are shown in Fig. 2 for AD, TM and ZM samples respectively. Nineteen attributes were found to be significantly different between TM samples (7 aroma, 6 flavour and 6 texture), 22 between ZM samples (8 aroma, 7 flavour and 7 texture) and 14 between AD samples (4 aroma, 4 flavour and 6 texture). To explore the respective effects of species and preparation method, Multiple Factor Analysis (MFA) was employed using differentiating attributes ($P \leq 0.05$) across AD, TM and ZM. The coordinates of the projected points and MFA biplot are shown in Fig. 3.

The first two factors (F1 and F2) explain 78.80 % of variance between AD, TM and ZM samples, with F1 (x-axis) explaining over half of variation in the data (54.71 %) and F2 (y-axis) explaining the remaining 24.09 %. The coordinates of the projected points show sautéed and deep-fried samples clustered to the right of the plot, while hot-air dried, freeze-dried, and roasted samples are spread across the left. Further, AD, TM and ZM demonstrate lesser spread when prepared by sautéing and deep-frying versus hot-air drying, freeze-drying and roasting. This indicates that sautéing and deep-frying may exert a stronger influence on the sensory profile of AD, TM and ZM samples versus other preparation methods. These samples were described by *hot chips*, *oily* and *roasted chicken* aroma and flavour attributes, as well as *chewy* and *dense* texture attributes, clustered on the right side of the biplot.

Hot-air dried, freeze-dried, and roasted samples were mostly described by attributes on the left side of the biplot. By interpreting these results alongside Fig. 2, it is evident that hot-air dried AD, TM and ZM samples were characterised by *brittle*, *crunchy*, *crumbly,* and *drying* texture attributes. However, their differentiating aroma and flavour attributes varied by species. *Raw walnut* and *wet hay* were strongly associated with hot-air dried TM while *seaweed*, *toasted,* and *earthy* were associated with hot-air dried ZM. Hot-air dried AD was characterised by a significant increase in *earthy* aroma and *toasted* flavour. Squared cosine values for freeze-dried samples indicate better explanation across F2 (0.806), with differentiating attributes mostly grouped in the lower quadrants of the biplot. Collectively, these samples were characterised by a *brittle* texture. Freeze-dried TM and ZM were also associated with nutty savoury attributes (*nutritional yeast* and *roasted nuts*) while freeze-dried AD samples were characterised by broad savoury and *cereal* notes of moderate intensity. Squared cosine values for roasted samples (0.778) indicate better explanation across F3 (not shown), reflecting shared attributes with other preparation methods.

Based on the combined analyses of AD, TM and ZM, it is evident that preparation method caused large variation in insect aroma, flavour, and texture. This can be mainly attributed to dry heat transfer cooking methods which are associated with reactions such as Maillard browning and water evaporation (Perez-Santaescolastica et al., 2022; van Boekel, 2006). Maillard browning can impart savoury, meaty, roasted, toasted, and bitter notes while water evaporation can affect texture, making foods crunchy and brittle. Additionally, methods using oil can alter aroma and flavour, leading to dominant oily, fatty, and savoury attributes (Chang, Wu, Zhang, Jin, & Wang, 2020). These combined factors could account for the distinct profiles and clustering of sautéed and deep-fried samples. In contrast to dry heat transfer cooking methods, freeze-drying has been found to increase sensitivity to lipid oxidation, producing higher hexanal and 2-methyl propanal levels in insect samples (Khatun et al., 2021). This may explain the dominant *nutty* and *cereal* notes among freeze-dried samples as hexanal is associated with green and fatty aromas while 2-methyl propanal is characterised by fatty, malted and nutty aromas.

Finally, the sensory changes observed in samples that were hot-air

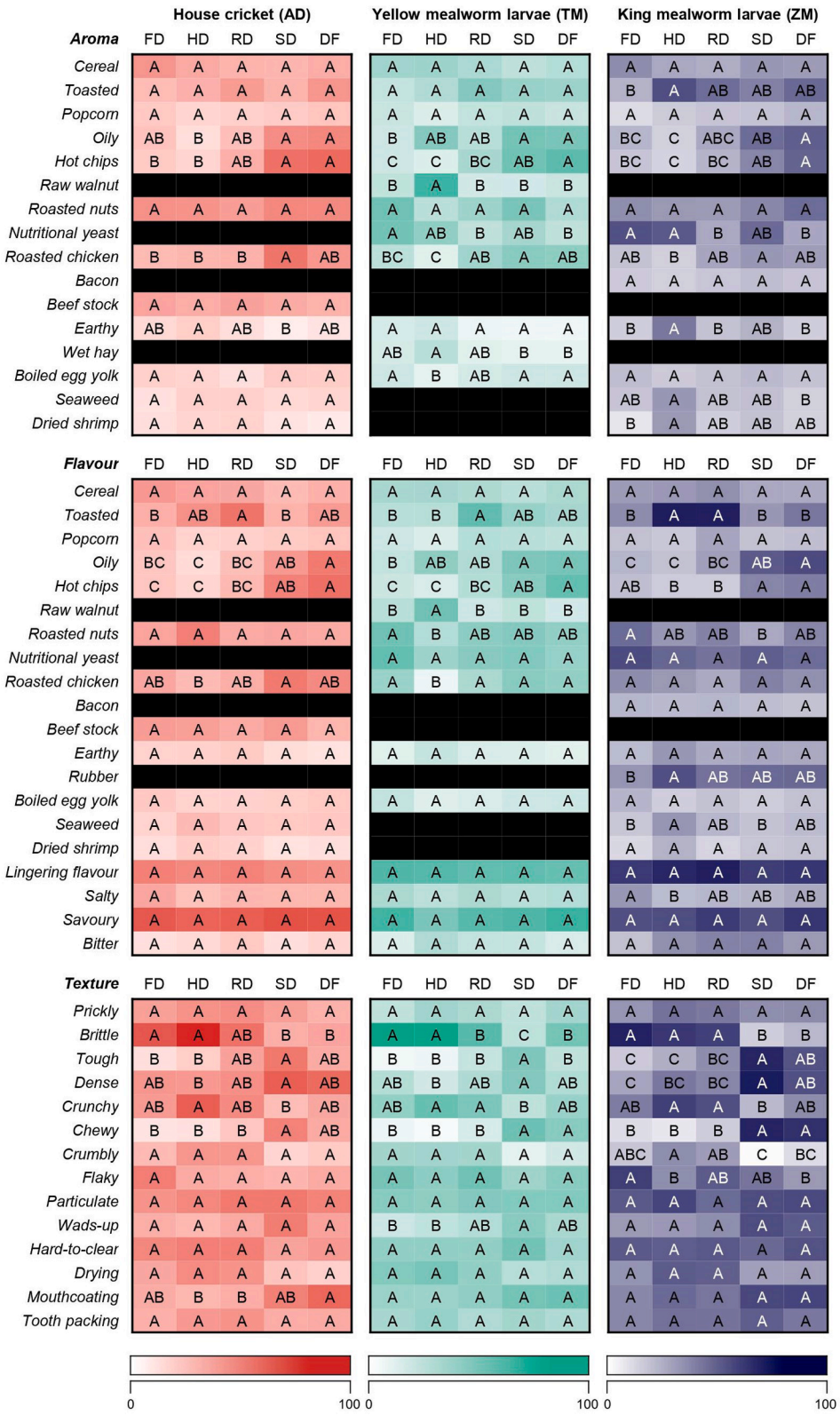

Fig. 2. Heatmap representing mean attribute intensity scores (rated from 0 to 100) for house cricket (*Acheta domesticus*; AD), yellow mealworm larvae (*Tenebrio molitor*; TM) and king mealworm larvae (*Zophobas morio*; ZM) samples. FD = Freeze-dried, HD = Hot-air dried, RD = Roasted, SD = Sautéed, DF = Deep-fried. Different letters (A, B, C) denote a statistically significant difference between samples of the same species for the given attribute (by Tukey-Kramer honestly significant difference). Black squares denote attributes that were not evaluated by panellists.

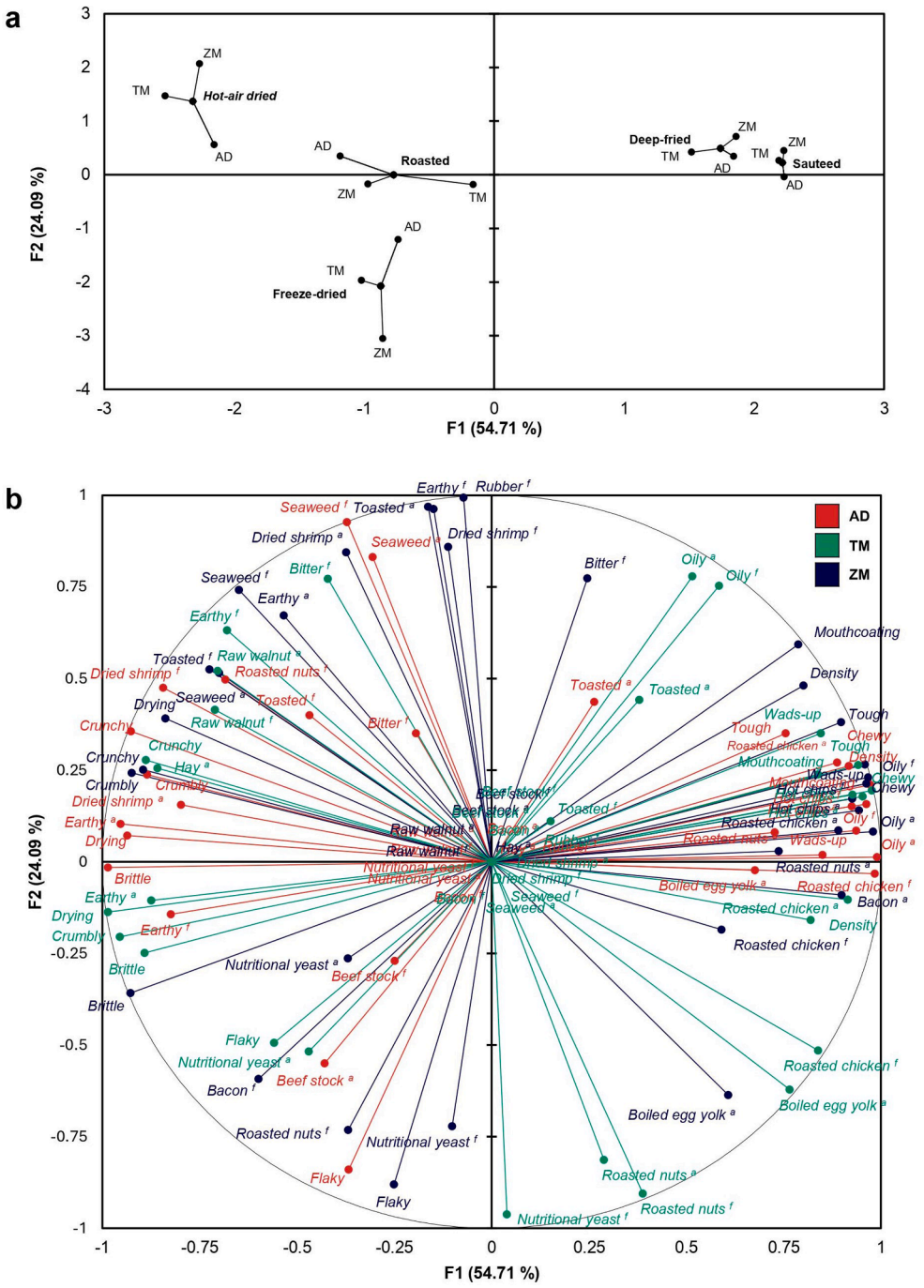

Fig. 3. Multiple factor analysis of differentiating attributes ($P \leq 0.05$) for house cricket (*Acheta domesticus*; AD), yellow mealworm larvae (*Tenebrio molitor*; TM) and king mealworm larvae (*Zophobas morio*; ZM) samples (axes F1 and F2: 78.80 %). (a) coordinates of the projected points, (b) biplot. *a* = aroma attribute, *f* = flavour.

dried are particularly noteworthy as all three species demonstrated significant increases in undesirable attributes such as *earthy*, *seaweed*, *dried-shrimp* and *rubber*. The distinct *raw walnut* characteristic in TM was also perceived as a negative attribute by some panellists. Given this is the main commercial preparation method in Australia, further research is warranted to determine to what extent these differences might affect consumer liking and preference – providing important insights for early product development.

3.2.4. *Development of a final sensory lexicon and wheel*

The results of sensory profiling confirmed applicability of the preliminary sensory lexicon for the description and differentiation of edible insects commercially available in Australia by species and preparation method. However, across all species *popcorn* and *bacon* were not characterised as differentiating attributes ($P \leq 0.05$), nor were they amongst more dominant aromas or flavours. These descriptors were therefore considered unnecessary and removed from the final sensory lexicon. While some authors have identified *popcorn* and *bacon* in TM (Wendin, Mårtensson, Djerf, & Langton, 2020; Żołnierczyk & Szumny, 2021), this could be related to factors such as biological differences between samples or cross-cultural effects on sensory perception. Further validation of the final sensory lexicon with a larger sample range and in other regions is therefore warranted.

The final sensory lexicon, comprising 29 aroma and flavour descriptors and 16 texture descriptors, is described in Tables 2 and 3. A sensory wheel was developed by categorising and ordering descriptors

to generate a three-tiered wheel, depicted in Fig. 4. The inner tier contains sensory properties, including aroma and flavour, as well as texture (comprising texture and mouthfeel attributes). The second tier contains sub-categories, within which each descriptor was grouped, and the third tier contains all descriptors. To improve visual communication, colour-coding and images were incorporated for each sub-category.

The vocabulary presented in the sensory lexicon and wheel reflect a combination of previously described and new attributes, therefore expanding-on and standardising current description tools (Albrektsson, 2017; Mishyna et al., 2020; Nervo, Ricci & Torri, 2024; Sick, Hartmann & Frøst, 2024).

4. Conclusions

This study established a sensory lexicon for the description and differentiation of edible insects that are commercially available in Australia. Following use of the lexicon for descriptive sensory profiling, unnecessary terms (*popcorn* and *bacon*) were identified and removed. Final vocabulary were then categorised and ordered to generate a sensory wheel, providing a visual communication tool for research and industry use. Due to the broad nature of the product category, sub-categories of species-specific terms were also generated for each insect.

The lexicon enabled sensory profiling of AD, TM, ZM, IR and OS, demonstrating significant variation by both species and preparation method. This emphasises the broad and versatile nature of edible insects as a food product category. For example, species and preparation methods can be selected to produce unique and diverse flavour and texture profiles for a wide range of culinary and food product applications. Further, they can be altered to better meet consumer preference and needs.

Overall, this work provides a platform for development of a globally relevant edible insect sensory lexicon. International collaboration will be required to evaluate and expand existing vocabulary for use with other insect species and in different cultural settings. This should prioritise edible insect species of both traditional and commercial significance, appropriate translation into different languages and the selection of locally available reference standards. As the edible insect industry grows, ongoing work will also be needed to validate the lexicon for differentiation within species and between competitive products. This should include samples prepared using different rearing, processing, preservation, and cooking methods, as well as new insect-derived ingredients and foods (such as insect powder, defatted insect powder and textured insect protein). With this work complete, the sensory lexicon and wheel will provide an indispensable tool for clear and consistent description of edible insects across research, industry and among consumers.

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CRediT authorship contribution statement

Ishka Bless: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Susan Elaine Putnam Bastian:** Writing - review & editing,

Fig. 4. Sensory lexicon for edible insects commercially available in Australia.

Supervision, Resources, Conceptualization. **Joanne Gould:** Writing – review & editing, Supervision, Resources, Conceptualization. **Qian Yang:** Writing – review & editing, Supervision, Resources, Conceptualization. **Kerry Leigh Wilkinson:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2024.114574.

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