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Can flavour and texture defects of plant-based burger patties be mitigated by combining them with a bun and tomato sauce?

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ABSTRACT

Common challenges for plant-based meat replacers are undesired (inherent) off-flavours (flavour defects) such as beany flavour or bitter taste, which are often associated with the use of plant proteins in meat replacers. Furthermore, plant-based meat replacers are often perceived as dry and lack juiciness and tenderness (texture defects). However, many foods are not consumed in isolation and sensory properties, and their acceptance, can be altered by the addition of other food components or condiments.

The study aimed to compare the sensory properties and acceptance of commercially available plant-based burger patties eaten alone and in combination with other foods and/or condiments. Liking and sensory properties of a beef and two plant-based (soy and hemp) patties consumed alone, with a bun, with tomato sauce, and with a bun and tomato sauce were determined using a hedonic scale and Rate-All-That-Apply (RATA) methodology, respectively.

For both plant-based patties (hemp, soy) bitter taste, beany and nutty flavour intensity remained but decreased with addition of a bun and/or sauce, but positive liking drivers such as meaty and fat flavour were also reduced. This suggests that these off-flavours can only be partly mitigated by the addition of a bun and/or sauce, but clearly cannot be masked completely. Hemp patties were perceived to have a high amount of chunks, which was a driver of disliking. This texture defect decreased with the addition of a bun and a bun with sauce. Off-flavours and texture defects of the hemp- and soy-based patties were too intense to be fully masked and could only be mitigated to a limited extent by the addition of a bun and/or tomato sauce. Notably, these reductions in off-flavour and texture defects were not sufficient to impact liking. The results highlight the importance of understanding product performance in realistic consumption scenarios. Addition of further ingredients and condiments, as is typical in a burger context, may be advantageous, but further research is required to test such a hypothesis.

1. Introduction

Animal proteins (e.g. meat and dairy proteins) are increasingly challenged for environmental sustainability, health, safety, and animal rights/welfare concerns (Pluhar, 2010; Ruby, 2012; Tilman & Clark, 2014). A transition towards decreased meat and increased plant-based foods consumption has been suggested to be beneficial for biodiversity, land use, water use, climate, human health and animal welfare

(Aiking, 2011; Lamb et al., 2016; Leip et al., 2015). Despite the potential benefits of this transition, meat consumption remains high and acceptability of plant-based meat replacers is limited in most western societies (Latvala et al., 2012; Lea et al., 2006; Schösler et al., 2012, 2015).

Traditionally, plant-based foods such as pulses, tofu, and textured vegetable protein have been used to replace meat. Such products are generally accepted among vegan and vegetarian consumers, but are less appealing to flexitarians and omnivores due to their low sensory appeal

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(Fiorentini et al., 2020; Hoek et al., 2011). In more recent times, a broad range of innovative meat replacers became available that aim to closely mimic the sensory properties of conventional meat products in terms of functionality, nutrient composition, and sensory characteristics (Tso et al., 2020). For omnivores, the primary motivation to consume meat is the sensory pleasure derived from consumption (Mullee et al., 2017). Therefore, these new generation of meat replacers have the potential to aid omnivores in reducing their meat consumption. However, for many of these products the sensory experience is very different from meat, as recreating the unique texture, mouthfeel, and juiciness of traditional meat is an ongoing challenge (Fiorentini et al., 2020). As such, low sensory appeal of meat replacers has been identified as the primary barrier to their acceptance (Michel et al., 2021).

The importance of consumption context, including situational and/or meal context, for product acceptance has been previously highlighted (Elzerman et al., 2011; Jaeger & Porcherot, 2017; Meiselman, 2008; Piqueras-Fiszman & Jaeger, 2015). In particular, in the study conducted by Elzerman (2011), the evaluation of meat substitutes consumed both individually and as part of a dish was examined. Meat substitutes that had similar shapes, but differed in flavour and texture, differed in liking when evaluated individually. However, these differences in liking vanished when meat substitutes were incorporated into a rice dish. Similarly, meat substitutes with the same flavour and texture characteristics, but differing in shape (pieces and minced), differed in liking when assessed individually, but these differences in liking diminished when meat substitutes were included as part of a meal (rice, spaghetti, soup, and salad) (Elzerman et al., 2011). This is unsurprising since combining different foods increases stimulus complexity and decreases sensitivity to perceived sensory differences between foods (Carpenter et al., 2000; Kroll & Pilgrim, 1961; Lawless & Heymann, 2010; Stone et al., 2020). Foods that differ in composition, meaning they have variation in their formulation and ingredients, may be distinguishable when consumed individually. However, these perceptual differences might disappear when they are consumed alongside other foods, condiments, or as part of a meal. For example, consumers' ability to identify sensory attribute differences between regular and sodium-reduced products, such as salsa and soy sauce, was found to decrease when these products were consumed alongside foods like corn chips and cooked rice (Nguyen & Wismer, 2020). A similar effect was observed when different types of mayonnaises with varying fat content and viscosity were consumed alone or combined with bread and carrots. When consumed individually, consumers were able to distinguish between mayonnaises based on perception. However, when paired with bread or carrots, the impact on ability to differentiate between them varied. Specifically, the presence of bread caused the sensory profiles of the mayonnaises to overlap, making it more difficult to distinguish between them. In contrast, the presence of carrots did not affect discrimination of mayonnaise characteristics, underscoring how consumer perception of specific products can be influenced by the foods they are paired with, ultimately affecting sensory sensitivity (van Eck et al., 2019a). More recently, it was demonstrated that dynamic sensory perception of hazelnut chocolate spreads differing in fat and sugar content were strongly affected by addition of carriers, as perceptual differences between spreads decreased when consumed with breads and wafers (Gonzalez-Estanol et al., 2022). These studies demonstrate that sensory properties of foods and their acceptance can be altered by the addition of other food components or condiments and that perceptual differences between foods can disappear when they are consumed with other foods.

Common challenges for plant-based meat replacers are undesired (inherent) off-flavours (flavour defects) such as beany flavour or bitter taste, which are often associated with the use of plant proteins in meat replacers (Chigwedere et al., 2022; Roland et al., 2017; Wang et al., 2022). Furthermore, plant-based meat replacers are often perceived as dry and lack juiciness and tenderness (texture defects) (Sha & Xiong, 2020). This raises the question whether flavour and texture defects of plant-based meat replacers such as plant-based burger patties can be

mitigated or even fully masked by combining them with other food components such as tomato ketchup (referred to as tomato sauce here) and a bun which provide different desired flavour and texture sensations. Investigating sensory perception of plant-based meat replacers in composite foods instead of in isolation also provides knowledge that is more representative of the natural consumption context of patties. This study aimed to compare the sensory properties and acceptance of commercially available plant-based burger patties eaten alone and in combination with other foods and/or condiments. Liking and sensory properties of a beef and two plant-based (soy and hemp) patties consumed alone, with a bun, with tomato sauce, and with a bun and tomato sauce were determined using a hedonic scale and Rate-All-That-Apply (RATA) methodology, respectively. It was hypothesised that combining plant-based burger patties with a bun and/or tomato sauce (i) masks off-flavours of plant-based burger patties, (ii) decreases texture defects such as lack of juiciness and (iii) increases liking.

2. Materials and methods

2.1. Sample preparation














Three commercially available burger patties were selected for this study: hemp-based patties (Bean Supreme, New Zealand), soy-based patties (Veggie Delights, New Zealand), and minced beef patties (Countdown, New Zealand). These patties were selected as they represented a wide variation in sensory characteristics across the New Zealand plant-based burger market and are made from different plant protein sources (hemp and soy). Composite foods were prepared by combining the patties with sauce (Tomato Sauce, Heinz Wattie's, New Zealand) and/or a bun (Nature's fresh, Goodman Fielder, New Zealand). The combinations of patty with sauce and patty with bun were chosen to systematically build up the complexity of the burger. This enabled the evaluation of the interactions between each ingredient and provided insights into their (potential) synergistic contribution in off-flavour reduction in simplified model burgers. The combination of patty with tomato sauce and bun represents a consumption context that is relevant for patties (Chamie, 2023; Unruh et al., 2016), while it is acknowledged that it represents a model burger rather than a full burger in which patties are often combined with more components such as buns, sauces, pickles, salad and cheese. All samples were bought in local supermarkets in New Zealand.

Patties were evaluated alone and in combination with a bun, with tomato sauce and with a bun and tomato sauce. The sensory properties and liking of all patties and their combinations were determined. Liking of buns and sauce was also determined. An overview of all used samples is shown in Table 1.

The patties ($n = 3$; hemp, soy and beef) were kept frozen in their original package until a day before the evaluation, then defrosted overnight in the refrigerator. Before the evaluation, they were taken out of the fridge, were lightly brushed with Rice Bran Oil (Countdown, New Zealand) on both sides and cooked on a commercial grill (Grill Station, Roband, Australia) where they were heated at 180 °C between a top and bottom cooking plate. The hemp and soy patties were cooked for 5 min, and the beef patties for 7 min. All patties were flipped half-way through the cooking time. Once cooked, patties were cut into thirds (beef 24.6 ± 2.0 g; hemp 29.8 ± 2.3 g; 24.9 ± 2.5 g) (Table 1) and wrapped individually in aluminium foil. Patties were cooked prior to each sensory session and held in a food warmer (E84 Food Warmer, Bakbar, New Zealand) heated to 50 ± 5 °C for a maximum of 30 min before serving. Buns were cut into thirds (31.1 ± 2.0 g), wrapped in aluminium foil, and kept at room temperature for a maximum 30 min before serving. The tomato sauce (5.4 ± 0.3 g) was poured into containers, covered with a lid and kept at room temperature until serving.

To determine tomato sauce quantity, a focus group of four participants was served a third of a patty in a preliminary study. They were asked to take a regular tomato sauce container (Tomato Sauce, Heinz

Table 1
Overview of foods with sample codes and photos illustrating the samples used for sensory and liking evaluations.

Group	Samples	Codes	
Individual foods	Bun	B	
	Tomato sauce	T	
	Soy patty	SP	
	Hemp patty	HP	
	Beef patty	BP	
	Soy patty + bun	SP+B	
	Soy patty + tomato sauce	SP+T	
	Soy patty + bun + tomato sauce	SP+B+T	
	Hemp patty + bun	HP+B	
	Composite foods	Hemp patty + tomato sauce	HP+T
Hemp patty + bun + tomato sauce		HP+B+T	
Beef patty + bun		BP+B	
Beef patty + tomato sauce		BP+T	
Beef patty + bun + tomato sauce		BP+B+T	

Wattie's, New Zealand) and spread it on top of the patty as they would normally do if they were going to eat a burger. The average weight of sauce was obtained (5.4 ± 0.3 g) and was fixed for the main study. Composite foods were wrapped in aluminium foil and placed in 'burger

boxes' to keep warm and add to context authenticity (Kraft Clam Shell Burger Box, NZ Safety Blackwoods, New Zealand). Burger boxes were held in a food warmer (E84 Food Warmer, Bakbar, New Zealand) heated to 50 ± 5 °C until served. To avoid tomato sauce soaking into the bun, the sauce was portioned into containers and spread on top of the patty with a spoon by the participants immediately before tasting. Participants could take multiple bites of all samples to perform the sensory evaluation. All samples were coded with random three-digit codes.

2.2. Participants

Ninety-one consumers were recruited for this study from the Food Experience and Sensory Testing (Feast) Lab (Palmerston North, New Zealand) consumer data base. All participants self-reported consumption of meat and burgers at least once a month. Other inclusion criteria were no allergies or intolerances to wheat/gluten, dairy, nuts, soybeans, eggs, not pregnant nor lactating, being able to fully communicate in English and no history of oral perception disorders or olfactory impairments (self-reported). Participants were asked to self-report their meat and burger consumption frequency using a multiple-choice questionnaire with 'daily', '2–3 times a week', 'once a week', 'once a fortnight' and 'once a month' as possible answers. The study was submitted according to the Massey University's Human Ethics procedure (reference number 4000026311) and was deemed to be low risk. Participants gave written informed consent prior to the study and received financial compensation for their time in form of a gift card after completing the study. Out of ninety-one participants volunteering, $n = 87$ participants (60% women, 39.1 ± 11.9 yrs) completed the study.

2.3. Attribute selection

Sensory attributes to describe sensory properties of beef and plant-based patties were identified from literature (Carvalho et al., 2015; De Angelis et al., 2020; Grasso et al., 2019, 2022). Three focus groups ($n = 22$) were held to determine if all sensory attributes from the compiled list were relevant to describe a wide variety of beef and plant-based patties. Attributes related to the evaluation of tomato sauce and breads were selected from literature and validated with a focus group of participants ($n = 4$) that did not take part in the main study. The final list of attributes and definitions used for RATA evaluation is shown in Table 2. This list included 18 attributes covering taste, flavour, mouthfeel, texture, and aftertaste modalities.

Table 2
List of sensory attributes with definitions used for the RATA evaluation of patties evaluated alone and in combination with a bun and/or sauce.

Attribute	Definition
Juiciness	Moisture/juice is released from the sample during chewing
Greasiness/oiliness	Sensation related to an oily or greasy coating in the mouth
Tenderness	The sample is easy to chew
Chunkiness	The sample has thick or lumpy pieces
Mouth dryness	The dry, puckering mouthfeel sensation
Saltiness	Basic taste associated with salt/ sodium chloride
Sweetness	Basic taste associated with sugar/ sucrose
Bitterness	Basic bitter taste associated with caffeine
Savoury/Umami	Taste of glutamate (MSG) e.g., soy sauce, broth-like
Smoky/grilled	Flavour of smoke e.g., ashy/ woody/ burnt
Meaty flavour	Flavour associated to cooked beef/meat
Wheaty flavour	flavour associated with many wheat-based cereals
Fat flavour	The flavour of cooked animal fat
Beany flavour	The flavour of beans e.g., soybean, includes musty/earthy
Nutty flavour	The flavour of nuts (unspecific)
Tomato flavour	The flavour of crushed tomatoes
Aromatic spices	The flavour of aromatic spices e.g., cloves, cumin, fennel, cinnamon, nutmeg, allspice, paprika, coriander seed
Aftertaste	Described as the product taste/flavour intensity that remains in the mouth

2.4. Procedure

The study was conducted in a recreated eating context of a bar restaurant (Supplementary Material Fig. 1) to simulate a common consumption context of burgers. To create the immersive eating context, 360° images of a bar restaurant (purchased from Shutterstock [https://www.shutterstock.com]) were projected on the walls of the testing room using Igloo immersive technology (Igloo Vision Ltd, Australia). In addition, audio of bar ambiance and background music was played (Sleep Sounds Express, 2015).

The study consisted of four sessions divided in two parts (Fig. 1). The first part entailed one session of 20 min during which participants evaluated all individual foods (patties alone; sauce alone; bun alone). All participants underwent the first part of the study. After that, they proceeded to the second part, which comprised the composite foods evaluation (patties with bun; patties with sauce; patties with bun and sauce) and involved three separate sessions of 30 min each, one for each type of patty (hemp, beef, soy). Between the two parts, there was a wash-up period of at least two days, which allowed for some time to elapse between the two parts of the study. However, it is acknowledged that this wash-up period of at least two days may not have entirely eliminated the possibility of a potential order effect. This block design was selected for logistical convenience, as samples were prepared immediately prior to the evaluation sessions. The four different sessions encompassed liking assessments and descriptive sensory profiling using RATA and took place across two weeks.

For the first part, the five individual foods (bun, sauce, hemp patty, soy patty and beef patty) were divided into two blocks, the sauce and bun were in one block and the three patties were grouped in another block. Block order was counterbalanced across participants and the sample order within each block was determined in accordance to William's Latin Square design. In between samples, participants were asked to take a sip of water and a cracker (Arnott's water cracker original, Australia) to cleanse their palate.

The samples were given to participants monadically, and followed a specific evaluation procedure. In the sauce and bun block, participants tasted the sample and rated their overall liking, liking of texture, and liking of flavour on a 9-points hedonic scale anchored with the words 'extremely dislike' to 'extremely like'. Participants then rinsed their palate with water and a cracker before proceeding to the next sample. The process was repeated for each sample.

Similarly, in the block with the patties, samples were also given

monadically, and participants followed a specific evaluation procedure for each sample. Using the same 9-point hedonic scale, participants tasted the patty in front of them and rated overall liking, liking of texture and liking of flavour. Following this, participants took a minimum of a one-min break during which they rinsed their palate with a sip of water and a bite of cracker. Participants were then asked to taste the same sample again and conduct the sensory RATA evaluation. Before moving on to the next sample, participants rinsed their palate again with water and a cracker. This entire process was repeated for each sample. No specific instructions were given about the amount of sample that participants could taste.

Part two (Fig. 1) consisted of three sessions, one for each type of patty (beef, soy, and hemp). In each session, participants evaluated the composite foods (patty with tomato sauce; patty with bun; patty with tomato sauce and bun). Similar to the first session, samples were given monadically, and participants followed the previously described evaluation procedure. During each session, participants tasted the sample in front of them and rated overall liking, liking of texture and liking of flavour on a 9-points hedonic scale anchored with the words 'extremely dislike' to 'extremely like'. Following the initial tasting, participants took a minimum of a one-min break to rinse their palate with a sip of water and a piece of cracker. Subsequently, participants were asked to taste the same sample again and conduct the sensory RATA evaluation. Finally, they rinsed their palate once more with water and a cracker. This entire process was repeated for each sample. The order of the type of patties was counterbalanced across participants and the order of composite foods was in accordance with William's Latin Square design. While no specific instructions were given regarding the quantity of sample that participants could taste, they were instructed to bite through all components of the composite foods.

For all sessions, participants were asked to refrain from eating, and drinking anything except for water for at least one hour before the start of the session. At the beginning of each session, participants were provided with attributes list and their definitions, and a short explanation of the RATA assessment procedure was given.

2.5. Rate-All-That-Apply (RATA)

In line with previous RATA studies, participants were asked to select whether an attribute (Table 2) applied to describe the sample being tasted, and only if so, to rate its perceived intensity (Ares et al., 2014; Giacalone & Hedelund, 2016) using a 9-box scale ranging from 'low' to

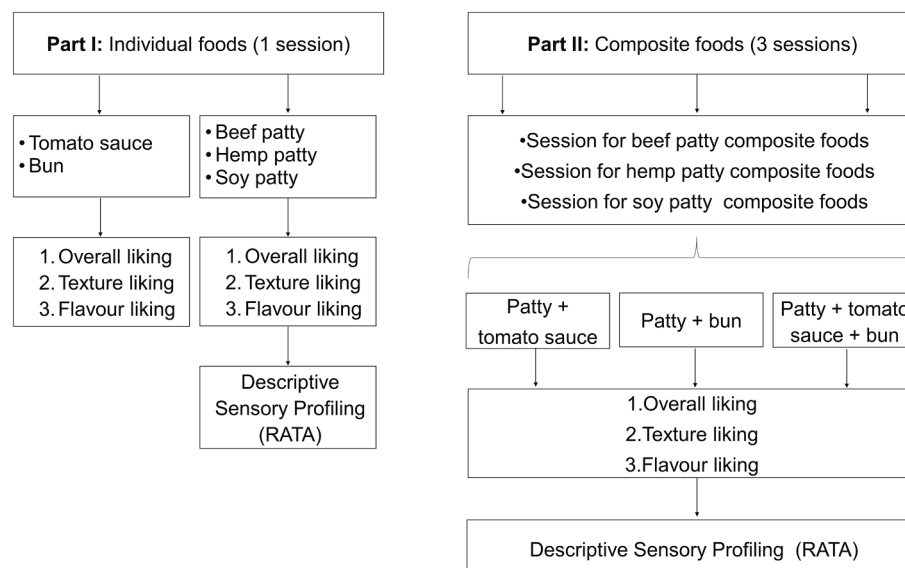


Fig. 1. Flow diagram representing organization of sessions evaluating individual foods and composite foods.

'high'. The order of attributes was grouped by modality and randomised across participants but maintained for each participant between samples. All data was collected using computerised data acquisition software (Compusense Cloud, Guelph, Ontario, Canada).

2.6. Data Analysis

2.6.1. Liking scores

Throughout the manuscript, the term "food combinations" refers to (1) the patties alone, (2) the combination of patties with a bun, (3) the combination of tomato sauce spread on top of patties and (4) the combination of patties with tomato sauce spread on top with a bun (Table 1). Mean scores and standard deviations for overall, flavour and texture liking scores of all food combinations and type of patty were established. To determine significant differences and effects between samples' liking scores, three Linear Mixed Models (LMM) with each liking score (overall, texture, and flavour) as the response variable were determined. Type of patty (beef, hemp, soy), food combination (patty alone; patty with bun; patty with sauce; patty with sauce and bun), and the food combination*patty type interaction were set as fixed factors and participants as a random factor. When the food combination*patty type interaction was not significant, the interaction was removed from the model and a LMM was carried out without it. Significance level was set at $\alpha < 0.05$. Tukey Post-hoc pairwise comparison tests were conducted when significant effects were identified. Pearson correlation coefficients were calculated to assess inter-relationships between liking scores and sensory variables. Analyses were done using lme4, emmeans, and lmerTest packages of R software version 3.1.1 (R Core Team, 2020).

To evaluate how addition of bun and/or sauce impacted patty liking, relative changes in liking scores were determined (%) by calculating the difference in liking between patties evaluated alone ($L_{\text{Patty alone}}$) and patties combined with a bun ($L_{\text{Patty with bun}}$) and/or sauce ($L_{\text{Patty with sauce}}$; $L_{\text{Patty with bun and sauce}}$) and dividing the liking difference by the liking of the patties evaluated alone ($L_{\text{Patty alone}}$) (1).

$$\text{Relative liking change (\%)} = \frac{L_{\text{Patty alone}} - L_{\text{Patty with bun and/or sauce}}}{L_{\text{Patty alone}}} \times 100 \quad (1)$$

2.6.2. RATA scores

RATA data was interpreted as a 10-point scales considering "not applicable" as intensity = 0. Intensity scores were treated as continuous data. Results for each attribute per sample are reported as mean with standard deviation.

To determine significant differences between samples, a LMM was performed with food combination (patty alone; patty with bun; patty with sauce; patty with bun and sauce), patty type (hemp; soy; beef) and the food combination*patty type interaction as fixed factors and participant as a random factor for each sensory attribute. In case of significant differences, post-hoc tests were performed with Tukey's Honest Significant Difference test (HSD) at 95% confidence level. When the food combination*patty type interaction was not significant, the interaction was removed from the model and a LMM was carried out without it.

To evaluate how addition of bun and/or sauce impacted the sensory properties of the patties, relative changes in intensity ratings were determined (%) for each attribute by calculating the difference in intensity between the patties evaluated alone ($I_{\text{Patty alone}}$) and the patties combined with a bun ($I_{\text{Patty with bun}}$) and/or sauce ($I_{\text{Patty with sauce}}$; $I_{\text{Patty with bun and sauce}}$), and dividing this intensity difference by the intensity of the patties evaluated alone ($I_{\text{Patty alone}}$) (2).

$$\text{Relative intensity change (\%)} = \frac{I_{\text{Patty alone}} - I_{\text{Patty with bun and/or sauce}}}{I_{\text{Patty alone}}} \times 100 \quad (2)$$

Principal component analysis (PCA) with confidence ellipses of 0.90 was carried out on average intensity ratings to analyse the relationships between sensory attributes and samples. Only attributes that were

significantly different ($p < 0.05$) are shown in the PCA (SensoMineR package).

3. Results

3.1. Sensory properties and liking of meat and plant-based patties

Flavour, texture and overall liking of patties and their combination with a bun and/or sauce are summarised in Table 3. No significant food combination*patty type interaction was found for any liking score and thus the interaction effect was removed from the LMM. Beef samples scored highest for texture liking, flavour and overall liking followed by the soy patties. Hemp patties were liked the least, the texture liking of hemp patties was particularly lower compared to soy and beef patties. There was a significant effect of the food combination and patty type on the three liking scores.

The mean intensity sensory scores for all samples are summarised in Table 4. Considering patty type (beef, hemp, soy) as a main effect from the LMM, beef patties scored significantly higher in tenderness intensity ($F(2, 948.7) = 169.8, p < 0.001$) and meaty flavour intensity ($F(2, 951.3) = 1069, p < 0.001$). Hemp patties were perceived as the most bitter ($F(2, 944.8) = 59.2, p < 0.001$) and having the highest beany ($F(2, 951.5) = 631.9, p < 0.001$) and nutty ($F(2, 951.5) = 502.4, p < 0.001$) flavour intensity compared with the other patties. Smoky ($F(2, 949.6) = 222.2, p < 0.001$), aromatic spices ($F(2, 950.4) = 144.1, p < 0.001$) and saltiness intensity ($F(2, 951.2) = 76.2, p < 0.001$) were significantly higher for soy patties than the other patties.

The Pearson's correlation coefficients are presented in Table 5 to assess relationships between sensory attributes and texture, flavour, and overall liking. Regarding the taste and flavour attributes, bitter ($r = -0.74, p < 0.05$), wheaty flavour ($r = -0.76, p < 0.05$), beany ($r = -0.95, p < 0.05$), and nutty ($r = -0.93, p < 0.05$) flavour were significantly negatively correlated with overall liking. In contrast, fat flavour ($r = 0.92, p < 0.05$), greasiness ($r = 0.92, p < 0.05$), smoky ($r = 0.81, p < 0.05$), and meaty flavour ($r = 0.97, p < 0.05$) were significantly positively correlated with overall liking. Regarding the texture attributes, mouth dryness ($r = -0.90, p < 0.05$) and chunkiness ($r = -0.84, p < 0.05$) were significantly negatively correlated with overall liking, in contrast to juiciness which was significantly positively correlated with overall liking ($r = 0.97, p < 0.05$).

Fig. 2 shows the Principal Component Analysis (PCA) of the mean intensity scores of all attributes, visualising the differences indicated by the LMMs. The individual factor map (Fig. 2A) shows the representation of all samples with confidence ellipses of 0.90. The correlation circles (Fig. 2B) visualise the mean intensity scores of the sensory attributes with all liking scores presented as supplementary variables. The first two components explain 61.5% and 22.1% of the total variance. The first dimension distinguished between the different types of patties.

In general, hemp samples (depicted in shades of green) were characterised by higher bitter, beany, nutty and mouth drying intensities compared to the soy and beef samples. The beef samples (depicted in shades of brown) were characterised by meaty, fat flavour, tender and juicy sensations. Lastly, the soy-based samples (depicted in shades of yellow) were described by after taste, salty, savoury and flavour of aromatic spices sensations (Fig. 2A).

The correlation circle (Fig. 2B) displays the liking scores projected as supplementary variables (blue dashed lines) into the sensory profiles of the samples. The positive side of the first dimension is correlated with meaty and fatty flavour and with tender and juicy texture indicating that they are the flavour and texture attributes driving overall liking, flavour and texture liking. In contrast, the negative side of the first dimension is correlated with beany, nutty and wheaty flavours and with chunky and mouth drying texture indicating that these are undesired sensory characteristics, off-flavours and texture defects driving disliking of the samples. These findings are, as expected, in agreement with the results of the Pearson correlation coefficients relating sensory attributes to

Table 3
 Summary of liking scores (mean \pm SD) of individual patties and composite foods with patties. BP denotes Beef Patty, SP Soy Patty, HP Hemp Patty, B Bun and T denotes Tomato sauce. F and p values derived from linear mixed models for each liking score for food combination and patty type as fixed effects and participants as random effect. P values presented as *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$), and N.S (not significant). Lowercase letters indicate significant differences between means across samples obtained from Tukey's Student t-tests for pairwise comparisons. The food combination*patty type interaction was not significant and is therefore not included in the model.

	Food combination												Patty type			
	Beef				Soy				Hemp				Food combination		F	P
	BP	BP + B	BP + B + T	BP + T	SP	SP + B	SP + B + T	SP + T	HP	HP + B	HP + B + T	HP + T	F	P	F	P
Overall liking	7.3 \pm 0.9e	6.7 \pm 1.2d	7.3 \pm 1.1e	7.3 \pm 1.1e	6.6 \pm 1.5d	6.1 \pm 1.6c	6.7 \pm 1.3d	6.6 \pm 1.5d	5.0 \pm 2.0b	4.7 \pm 1.7a	5.3 \pm 1.7b	5.2 \pm 1.7b	12.4	***	267.8	***
Texture liking	6.9 \pm 1.3efg	6.6 \pm 1.4ef	7.2 \pm 1.1g	7.1 \pm 1.2fg	6.1 \pm 1.6cd	6.0 \pm 1.6c	6.5 \pm 1.4de	6.4 \pm 1.6cde	4.4 \pm 2.0ab	4.3 \pm 1.6a	4.9 \pm 1.8b	4.6 \pm 1.7ab	7.3	***	302.5	***
Flavour liking	7.3 \pm 1.1e	6.6 \pm 1.3d	7.3 \pm 1.2e	7.3 \pm 1.1e	6.5 \pm 1.7d	6.0 \pm 1.6c	6.5 \pm 1.4d	6.5 \pm 1.6d	5.2 \pm 2b	4.8 \pm 1.6a	5.5 \pm 1.7b	5.3 \pm 1.6b	11.0	***	192.8	***

texture, flavour, and overall liking (Table 5).

3.2. Effect of bun and/or tomato sauce addition on flavour perception of plant-based patties

For the off-flavours beany, nutty and wheaty flavour, the LMM showed that the food combination (beany ($F(3, 953.3) = 6.12$, $p < 0.001$), nutty ($F(3, 952.9) = 9.97$, $p < 0.001$), wheaty ($F(3, 952.7) = 24.45$, $p < 0.001$)) and patty type (beany ($F(2, 951.5) = 631.9$, $p < 0.001$), nutty ($F(2, 951.5) = 502.43$, $p < 0.001$), wheaty ($F(2, 950.9) = 109.8$, $p < 0.001$)) effects were significant (Table 4). Within patty type, no significant differences were observed ($p > 0.05$). However, off-flavours of hemp and soy patties tended to be reduced when patties were combined with a bun, tomato sauce or both (Fig. 3). The largest relative reduction of beany intensity (-18.4%) was achieved when soy patties were combined with a bun and tomato sauce, whereas combining the soy patties with a bun (-13.2%) or tomato sauce (-13.2%) led to smaller relative reductions in beany intensity. In the case of hemp patties, beany intensity was reduced by -12.7% when patties were combined with a bun and tomato sauce, by -11.1% when combined with sauce and by -7.9% when combined with a bun. For both, hemp and soy patties, nutty intensity was reduced the most when combined with a bun and sauce. For soy patties, nutty intensity decreased by -21.2% and for hemp by -16.7%. When soy patties were combined with a bun, nutty intensity decreased by -18.2% and when combined with sauce by -6.1%. For hemp patties, nutty intensity decreased by -16.7% with the addition of a bun and by -13.3% with the addition of sauce and a bun. Wheaty flavour increased by 10.5% for soy and by 2.4% for hemp patties when buns were added. Wheaty flavour intensity decreased by -23.7% for soy and by -19.0% for hemp when sauce was added. Regarding the positive drivers of liking, the food combination* type of patty interaction was significant for fatty flavour ($F(6, 945.16) = 3.9$, $p < 0.001$) while for meaty flavour, food combination ($F(3, 953.09) = 9.95$, $p < 0.001$) and patty type ($F(2, 951.28) = 1069$, $p < 0.001$) were both significant (Table 3). Regardless of having no significant effects within each type of patty, meaty flavour intensity was reduced by -14.0% for soy and by -21.1% for hemp when patties were combined with a bun, while fatty flavour intensity was reduced by -40.9% for soy and by -27.8% for hemp when a bun was added to the patties (Fig. 3). Lastly, the LMM showed that the food combination*patty type interaction was significant for tomato flavour ($F(6,945.43) = 2.9$, $p < 0.01$) as the addition of sauce increased the tomato flavour intensity of all three patties but to a different extent. With addition of tomato sauce, tomato flavour intensity increased by 181% and by 184% in soy and hemp patties, respectively. When a bun and sauce were added, tomato flavour increased by 138% and by 152% in soy and hemp patties, respectively.

3.3. Effect of bun and/or tomato sauce addition on texture perception of plant-based patties

Fig. 2 and Table 5 highlighted that chunkiness and mouth dryness are negative drivers of liking. The LMM showed a significant effect of food combination (chunkiness ($F(3, 953.06) = 7.38$, $p < 0.001$), mouth dryness ($F(3, 953.06) = 7.38$, $p < 0.001$)) and patty type (chunkiness ($F(2, 951.19) = 107.96$, $p < 0.001$), mouth dryness ($F(2, 948.91) = 140.19$, $p < 0.001$)) but no significant differences within type of patty (Table 4). Regardless, when hemp and soy patties were combined with a bun and/or sauce, the intensities of chunkiness and mouth dryness tended to decrease (Fig. 3). Chunkiness intensity was reduced by -10.4% for soy and by -7.7% for hemp patties when a bun was added. Mouth dryness intensity increased by 44.4% for soy and by 16.7% for hemp patties when a bun was added. Positive drivers of liking such as juiciness, greasiness and tenderness (Fig. 2 and Table 5) were also influenced by bun and/or sauce addition. The interaction of food combination*type was significant for juiciness ($F(6, 944.75) = 2.9$, $p < 0.01$). Juiciness intensity decreased by -29.4% for soy and by -7.7% for

Table 4

Intensity scores (mean \pm SD) obtained from RATA evaluations (n = 87 participants) of food combinations. BP denotes Beef Patty, SP Soy Patty, HP Hemp Patty, B Bun and T denotes Tomato sauce. F and p values derived from linear mixed models for each attribute with food combination, patty type and food combination^apatty type interaction as fixed effects and participants as random effect. P values are presented as *** (p < 0.001), ** (p < 0.01), * (p < 0.05), and N.S (not significant). Lowercase letters indicate significant differences between means across samples obtained from Tukey's Student t-tests for pairwise comparisons.

	Beef				Soy				Hemp				Food combination		Patty type		Food combination ^a Patty type	
	BP	BP + B	BP + B + T	BP + T	SP	SP + B	SP + B + T	SP + T	HP	HP + B	HP + B + T	HP + T	F	p	F	p	F	p
	Juiciness	5.4 \pm 2.4d	4.1 \pm 2.3c	5.1 \pm 2d	5.6 \pm 2.2d	3.4 \pm 2.4c	2.4 \pm 1.8b	3.4 \pm 2c	3.8 \pm 2.2c	1.3 \pm 1.3a	1.2 \pm 1a	1.8 \pm 1.4ab	1.8 \pm 1.5ab	29.5	***	457.0	***	2.9
Greasiness/oiliness	5.2 \pm 2.1f	3.9 \pm 2.2d	4 \pm 2.1de	4.6 \pm 2.2ef	4.7 \pm 2.1f	2.5 \pm 1.7bc	2.8 \pm 1.8c	3.6 \pm 2d	1.9 \pm 1.4ab	1.4 \pm 0.9a	1.6 \pm 1.1fa	1.9 \pm 1.4ab	46.0	***	293.9	***	6.4	***
Tenderness	6.1 \pm 2.2e	6.0 \pm 1.9cde	6.3 \pm 1.6de	6.0 \pm 1.7cde	5.9 \pm 2.2bcd	5.2 \pm 2.1b	5.4 \pm 2.2bc	5.2 \pm 2.2b	3.9 \pm 2.6a	3.8 \pm 2.3a	4 \pm 2.4a	3.8 \pm 2.4a	2.9	*	169.9	***		
Chunkiness	5.0 \pm 2.3cd	4.2 \pm 2.2ab	4.3 \pm 2.3ab	4.6 \pm 2.3abcd	4.8 \pm 2.1bd	4.3 \pm 2.1ac	4.4 \pm 2.2ac	5 \pm 2.2abcd	6.5 \pm 2f	6.1 \pm 1.9e	6 \pm 2.1e	6.5 \pm 1.8ef	7.3	***	107.9	***		
Mouth dryness	2.5 \pm 2.1a	3.3 \pm 2.4b	2.6 \pm 2.1a	1.8 \pm 1.7a	3.6 \pm 2.3bc	5.2 \pm 2.5d	3.8 \pm 2.3bc	3.7 \pm 2.4b	4.8 \pm 2.5d	5.6 \pm 2.6e	4.8 \pm 2.4d	4.7 \pm 2.3cd	24.4	***	140.2	***		
Saltiness	4.1 \pm 2e	3.1 \pm 1.8bc	3.1 \pm 1.9bc	3.5 \pm 2 cd	4.8 \pm 2.1f	3.9 \pm 2.3de	3.9 \pm 2de	4.2 \pm 2.1e	3.4 \pm 2.1 cd	2.5 \pm 1.7a	2.7 \pm 1.7a	2.9 \pm 1.9ab	22.3	***	76.2	**		
Sweetness	1.8 \pm 1.9a	1.9 \pm 1.7ab	3.2 \pm 2.2c	3.1 \pm 2.4c	2.1 \pm 1.9cb	2.0 \pm 1.9cb	3.3 \pm 2.2c	3.3 \pm 2.2c	2.6 \pm 2.1bc	1.9 \pm 1.6ab	2.9 \pm 2c	2.9 \pm 2.2c	41.2	***	0.9	N.S	2.4	*
Bitterness	0.9 \pm 1.2bbc	0.8 \pm 1.2ab	0.6 \pm 0.9a	0.9 \pm 1.2ab	1.9 \pm 2.1ef	1.7 \pm 1.8def	1.3 \pm 1.6cd	1.7 \pm 1.8def	2.1 \pm 2.4f	1.7 \pm 2def	1.6 \pm 1.9de	1.7 \pm 1.9def	5.6	**	59.2	***		
Savoury/Umami	5.1 \pm 2.6de	4.4 \pm 2.6bc	4.6 \pm 2.6c	4.9 \pm 2.5c	5.6 \pm 2.5e	4.7 \pm 2.4c	4.6 \pm 2.4cd	4.9 \pm 2.5cd	4.5 \pm 2.4c	3.4 \pm 2.3a	3.7 \pm 2.4a	3.7 \pm 2.4ab	16.1	***	44.4	***		
Smoky/grilled	4.9 \pm 2.4fg	4.1 \pm 2.4d	4.4 \pm 2.5de	5 \pm 2.2ef	6 \pm 2.4 h	4.9 \pm 2.2ef	4.8 \pm 2.4fg	5.5 \pm 2.3gh	3.1 \pm 2.2c	2.3 \pm 1.8a	2.4 \pm 1.8ab	2.7 \pm 1.9bc	15.2	***	222.2	***		
Meaty flavour	7.7 \pm 1.4f	6.7 \pm 1.7e	7.1 \pm 1.7ef	7.6 \pm 1.4f	5.0 \pm 2.5d	4.3 \pm 2.2c	4.7 \pm 2.4cd	4.7 \pm 2.4d	1.9 \pm 1.7b	1.5 \pm 1.7a	1.7 \pm 1.9ab	1.9 \pm 1.8b	9.9	***	1069	***		
Wheaty flavour	1.7 \pm 1.7b	3 \pm 2.4cd	2.5 \pm 2.3bc	1.2 \pm 1.3a	3.8 \pm 2.4ef	4.2 \pm 2.6gh	3.9 \pm 2.4efgh	2.9 \pm 2.5cd	4.2 \pm 2.5fg	4.3 \pm 2.5 h	4.1 \pm 2.4fgh	3.4 \pm 2.4de	24.4	***	109.7	***		
Fat flavour	5.8 \pm 2.2d	4.6 \pm 2.2c	4.7 \pm 2c	5.1 \pm 1.9cd	4.4 \pm 2.3c	2.6 \pm 1.9b	2.8 \pm 1.8b	3.1 \pm 2b	1.8 \pm 1.5a	1.3 \pm 1a	1.6 \pm 1.3a	1.7 \pm 1.3a	32.3	***	473.3	***	3.9	***
Beany flavour	1.3 \pm 1.5b	1.2 \pm 1.6ab	0.9 \pm 1.3a	0.7 \pm 1.1a	3.8 \pm 2.5d	3.3 \pm 2.6 cd	3.1 \pm 2.5c	3.3 \pm 2.7c	6.3 \pm 2.5f	5.8 \pm 2.5ef	5.5 \pm 2.4e	5.6 \pm 2.4e	6.12	***	631.9	***		
Nutty flavour	1.6 \pm 1.9b	1.1 \pm 1.6a	1.1 \pm 1.4a	1.2 \pm 1.5ab	3.3 \pm 2.5d	2.7 \pm 2.4c	2.6 \pm 2.4c	3.1 \pm 2.7cd	6.0 \pm 2.6f	5.0 \pm 2.5e	5.0 \pm 2.5e	5.2 \pm 2.5ef	9.9	***	502.4	***		
Tomato flavour	1.1 \pm 1.4ab	0.7 \pm 1.3a	5.2 \pm 2.2def	5.8 \pm 2.4ef	2.1 \pm 2.1c	0.9 \pm 1.3a	5 \pm 2.1de	5.9 \pm 2.1f	1.9 \pm 1.9bc	0.7 \pm 1.1a	4.8 \pm 2.1d	5.4 \pm 2.2def	545.5	***	2.9	N.S	2.9	**
Aromatic Spices	3.3 \pm 2.3c	2.5 \pm 2a	2.7 \pm 2fa	3.1 \pm 2.2ab	6.0 \pm 2.3f	5.0 \pm 2.4de	4.6 \pm 2.4de	5.2 \pm 2.3e	4.5 \pm 2.4d	3.4 \pm 2.5bc	3.8 \pm 2.5bc	3.8 \pm 2.2c	16.6	***	144.1	***		
Aftertaste	4.5 \pm 2.5ef	3.7 \pm 2.3ac	4.1 \pm 2.4abcd	4.4 \pm 2.5bde	5.8 \pm 2.3 h	4.9 \pm 2.1ef	5 \pm 2.2fg	5.6 \pm 2.2gh	4.8 \pm 2.5ef	3.7 \pm 2.2ab	3.9 \pm 2.2abcd	4.1 \pm 2.2cde	15.8	***	53.5	***		

Table 5
Pearson correlation coefficients for liking scores and sensory attributes. *Correlation is significant at $p < 0.05$.

	Juiciness	Greasiness/ oiliness	Tenderness	Chunkiness	Mouth dryness	Saltiness	Sweetness	Bitterness	Savoury umami	Smoky/ grilled	Meaty flavour	Wheaty flavour	Fat flavour	Beany flavour	Nutty flavour	Tomato flavour	Aromatic spices	Aftertaste
Overall liking	0.97*	0.91*	0.97*	-0.84*	-0.90*	0.55	0.15	-0.74*	0.75*	0.81*	0.97*	-0.76*	0.92*	-0.95*	-0.93*	0.21	-0.16	0.27
Texture liking	0.95*	0.86*	0.96*	-0.89*	-0.86*	0.49	0.16	-0.77*	0.69*	0.79*	0.96*	-0.73*	0.88*	-0.96*	-0.96*	0.20	-0.19	0.23
Flavour liking	0.98*	0.91*	0.95*	-0.80*	-0.93*	0.50	0.16	-0.77*	0.73*	0.76*	0.97*	-0.81*	0.93*	-0.94*	-0.92*	0.23	-0.21	0.22

hemp patties when a bun was added. Juiciness intensity increased by 11.8% for soy and by 38.5% for hemp patties when sauce was added. Juiciness intensity increased by 38.5% for hemp but did not change for soy patties when a bun and sauce were added. The interaction between food combination* patty type was also significant for greasiness ($F(6, 944.87) = 6.4, p < 0.001$). Relative changes within samples showed that addition of a bun decreased perception of greasiness by -46.8% for soy but only -26.3% for hemp. When tomato sauce was added, greasiness perception was reduced by -23.4% for soy but it did not change for hemp. When both components were added, greasiness perception was reduced by -40.4% for soy and by -15.8% for hemp. Lastly, tenderness perception was significantly affected by food combination ($F(3, 950.26) = 2.9, p < 0.01$) and patty type ($F(2, 948.75) = 169.9, p < 0.001$). Relative changes within samples showed that when a bun was added, tender intensity decreased by -11.9%.

4. Discussion

This study aimed to compare the sensory properties and acceptance of commercially available plant-based burger patties eaten alone and in combination with other foods and/or condiments. It was hypothesised that (i) combining plant-based burger patties with a bun and/or sauce masks off-flavours of the plant-based burger patties. For both plant-based patties (hemp, soy) negative drivers of liking such as bitter taste, beany and nutty flavour intensity decreased with the addition of a bun and/or sauce, but positive drivers of liking such as meaty and fat flavour were also reduced, only partly confirming the hypothesis. While these off-flavours were reduced in soy and hemp patties by the addition of a bun and/or sauce, the perception of these off-flavours did not disappear. This suggests that the off-flavours can only be partly mitigated by the addition of a bun and/or sauce, but clearly cannot be suppressed completely. This demonstrates that inherent off-flavours in the soy and hemp patties were strongly pronounced and the addition of tomato sauce with a strong desirable flavour was insufficient to mask the off-flavour. Previous studies reported that the sensory perception of individual food components was affected by addition of other components (Gonzalez-Estano, Clicer, et al., 2022; Meinert et al., 2011; Paulsen et al., 2012; van Eck et al., 2021; van Eck et al., 2019a). The overall flavour intensity of the tomato sauce is likely to be higher than the overall flavour intensity of the bun, so it could be argued that the stronger tomato sauce flavour mitigates the off-flavours more than the blander flavoured bun. Remarkably, the reduction in off-flavour intensities was larger upon addition of a bun than upon addition of sauce. It could be that the dry character of the bun and the difference in weight (31.1 ± 2.0 g) and volume of the bun compared to tomato sauce (5.4 ± 0.3 g) limited aroma release in the oral cavity and thus inhibited perception. Further studies are needed to better understand why a bun mitigated the off-flavour more than the tomato sauce.

Overall, the hemp patty had more intense off-flavours than the soy patty and masking by addition of a bun and/or sauce was also different across these two patties, highlighting that masking effects are product dependent. This is in line with previous studies showing that the addition of different carriers affected the sensory perception of the product of interest in different ways. For example, Cherdchu & Chambers IV (2014) investigated the effect of carrier additions on the perception of soy sauce. They found that solid white rice and grilled chicken had a stronger effect than chicken broth on the sensory perception of the sauce (Cherdchu & Chambers IV, 2014). The presence of a companion food reduced consumers' ability to discriminate sensory attributes between regular and sodium-reduced soy sauce but not in regular and sodium-reduced tomato sauce (Nguyen & Wismer, 2020). It should be noted that when interpreting relative comparisons between plant-based patties, these patties were commercially available and differed in composition not only regarding hemp and soy.

Secondly, it was hypothesised that (ii) combining plant-based burger patties with a bun and/or sauce masks texture defects of plant-based

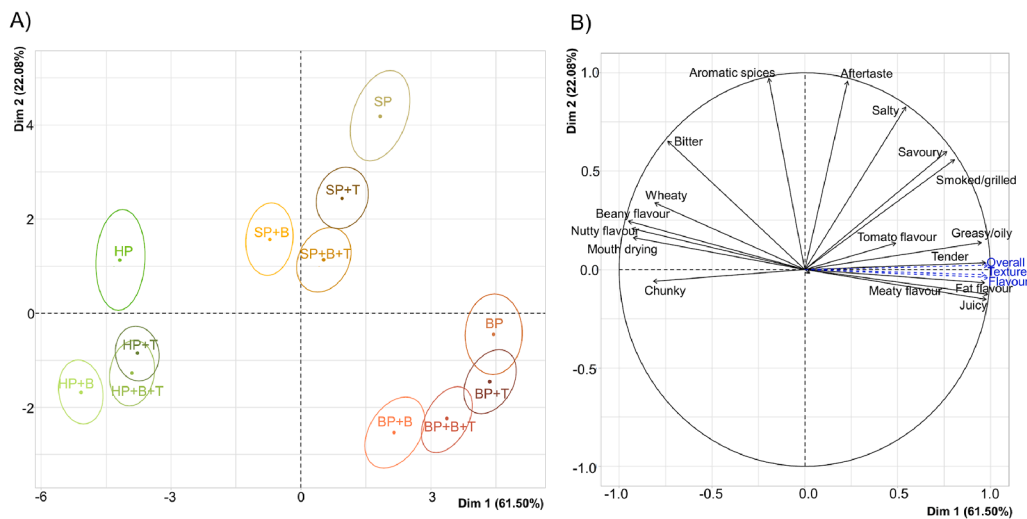


Fig. 2. Principal Component Analysis (PCA) of the RATA intensity scores for all samples. The individual factor map (A) displays samples with confidence ellipses of 0.90. Different colour shades indicate different type of patties (beef; depicted in shades of brown, hemp; depicted in shades of green and soy; depicted in shades of yellow). Correlation circle (B) displays sensory attributes with overall liking, flavour and texture liking scores as supplementary variables (blue hashed arrows). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

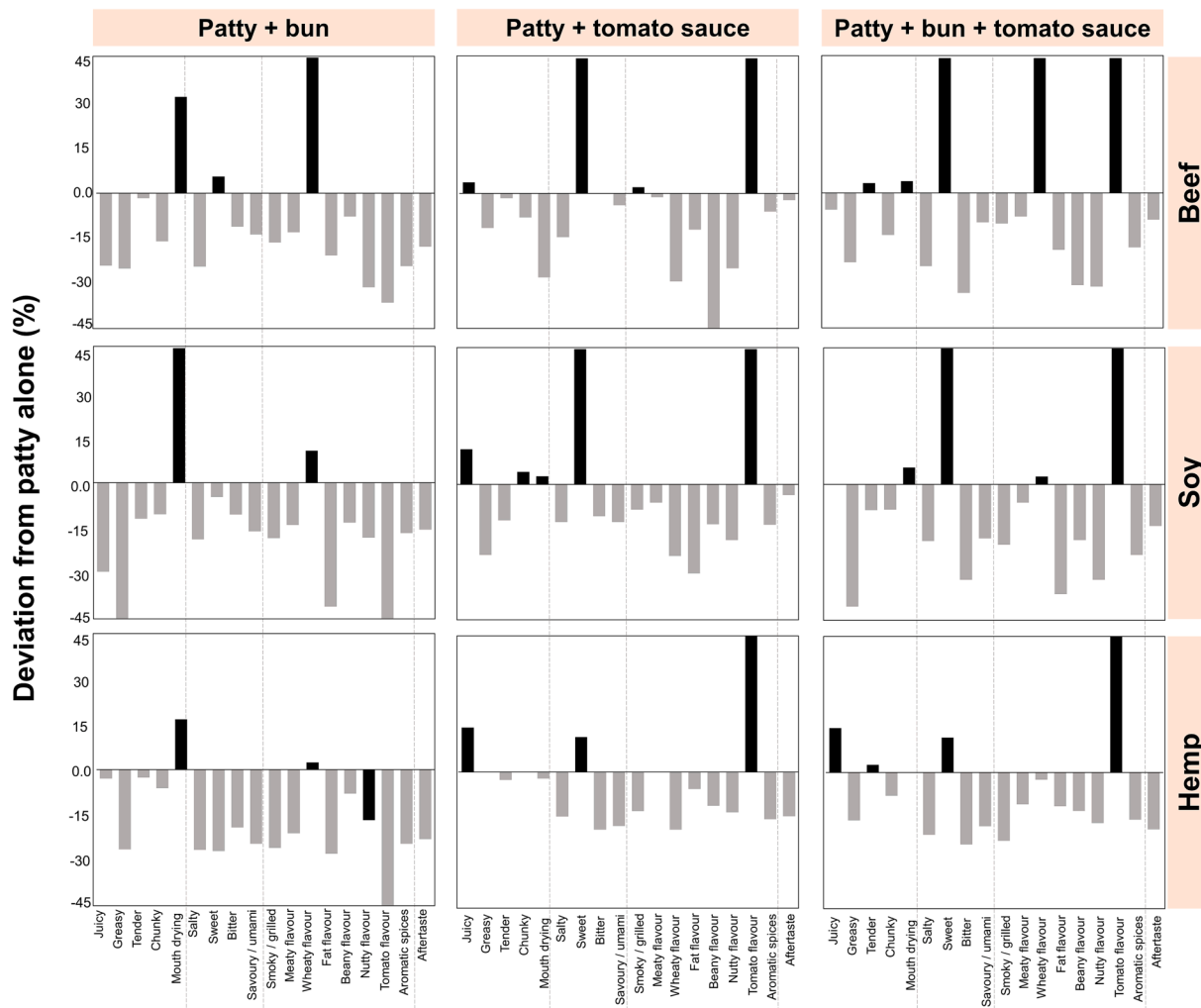


Fig. 3. Relative intensity change (%) for each attribute when patties were combined with a bun and/or sauce in comparison to patties consumed alone [Relative intensity change (%) = $(I_{\text{Patty alone}} - I_{\text{Patty with bun and/or sauce}}) / I_{\text{Patty alone}} \times 100$].

burger patties. As expected, mouth drying increased while juiciness decreased upon addition of a bun to patties. The addition of a dry bun absorbed moisture and saliva during consumption, which reduced the lubricity of the bolus and led to an increase of mouth drying and a

decrease of juiciness. Texture defects such as dryness and lack of juiciness and tenderness have been shown to have a strong negative impact on hedonic response to plant-based products (Carter et al., 2020; Chigwedere et al., 2022; Sha & Xiong, 2020; Yeom et al., 2020).

Tenderness and juiciness are attributes related to high quality and influence overall liking of meat and meat analogue products such as patties, steaks and sausages (Chen et al., 2022; Schreuders et al., 2021). Their perception in meat is partly impacted through lubrication by fats, oils, water and stimulation of saliva during mastication (Calkins & Sullivan, 2007; Legako, 2019). When plant-based patties were combined with sauce, juiciness increased, suggesting the addition of sauce assisted patty lubrication. This increased lubrication by a liquid component in composite foods resulting in a reduced dryness perception has been previously described (Gonzalez-Estanol, et al., 2022; van Eck et al., 2019b). However, addition of tomato sauce did not increase tenderness perception, indicating that tenderness might be more related to in-mouth sample fragmentation, while juiciness might be related to saliva incorporated into the bolus and product moistness (Rizo et al., 2019). Lastly, chunky perception was most present in the hemp patties. Hemp patties displayed a very heterogeneous structure as exemplified in Table 1. These structural heterogeneities likely restricted matrix breakdown during mastication preventing formation of a cohesive bolus, ultimately leading to the perception of chunky texture. This texture defect decreased with the addition of a bun and a bun and sauce but not with the addition of sauce. It is speculated that during mastication the bun acted as glue binding the hemp patty particles together to form a more cohesive bolus, decreasing the perception of chunky texture, which did not happen with the addition of sauce.

Thirdly, it was hypothesised that (iii) combining plant-based burger patties with a bun and/or sauce increases liking of the plant-based burger patties. Liking scores did not change for the plant-based patties when patties were combined with a bun and/or sauce. This was unexpected as it was speculated that liking increases with increasing sensory complexity and with increasing texture and flavour contrast by addition of a bun and/or sauce. Although only one patty type was assessed within a session, allowing for direct comparison between samples by the participants, only differences in liking between patties which were assessed in different sessions were significant with beef patties having the highest liking followed by soy and hemp patties. Here, adding a bun and tomato sauce to patties did not change liking. As described above, flavour and texture defects of these plant-based burger patties could only be mitigated to a limited extent by combining them with a bun and tomato sauce. Notably, these reductions in off-flavour and texture defects were not sufficient to impact liking. Addition of other burger components such as mayonnaise, pickles, lettuce and tomatoes may increase liking of the burger compared to the patty consumed alone.

5. Conclusions

This is the first study to explore the impact of the addition of two components (bun and tomato sauce) to beef and plant-based burger patties to create a simplified burger model for assessing patty sensory properties and liking. This study compared sensory perception and liking of beef and plant-based patties consumed alone and in combination with a bun and/or tomato sauce. When combined with a bun and/or sauce, inherent off-flavours and texture defects of the hemp- and soy-based patties could be mitigated but only to a limited extent. The off-flavours and texture defects of the hemp- and soy-based patties were too strong to be fully masked by the addition of a bun and/or tomato sauce. Flavour and texture defects of plant-based burger patties can only be mitigated to a limited extent by combining them with a bun and sauce. Reductions in off-flavour and texture defects of the plant-based patties were not sufficient to impact liking but the data demonstrates the importance of understanding product performance in realistic consumption scenarios.

This study did not explore the effect of combining patties with additional components such as mayonnaise, pickles, salad, onions, tomatoes, and cheeses into a burger. Addition of further components with strong and desired flavours and texture might be beneficial to reduce off-flavours and texture defects further and consequently increase liking.

Future studies should explore the impact of addition of these components to plant-based patties on off-flavours and texture defects.

Ethical statement

The study was submitted according to the Massey University's Human Ethics procedure, reference number 4000026311 on 07/05/2023 and was deemed to be low risk. Participants gave written informed consent prior to the study and received financial compensation for their time in form of a gift card after completing the study.

CRedit authorship contribution statement

Karina Gonzalez-Estanol: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Investigation, Writing – original draft. **Rebekah Orr:** Methodology, Data curation, Writing – review & editing. **Joanne Hort:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Markus Stieger:** Conceptualization, Methodology, Supervision, Writing – review & editing.

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

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodqual.2023.104920>.

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