Final report

Fermented meat sauce – A proof of concept using beef lung and heart

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Abstract

This project aims to increase the range of applications for under-utilised meat abattoir products. The approach is to apply fermentation concepts to convert them to novel, flavoursome extracts, sauces and cuisine ingredients.

A proof-of-concept used beef lung and heart. We investigated product handling, risk management and yield optimisation. Preprocessing factors included pasteurisation, dose-responses to starter culture and protease enzyme, and fermentation duration. Findings guided a small pilot plant run.

The parameters were coarse chopped non-pasteurised tissue, salt, protease and *Staphylococcus xylosus* (*SX*), a meat-optimised strain. Fermentation was carried out for 1 month for lung and 3 months for heart. The liquid fractions were filtered and clarified. Half were heat-treated.

For lung and heart, yield was 43% vs 51%. pH was 6.1 vs 4.9. Protein concentration was 10% vs 14%, and salt was 16-18%. For comparison, commercial fermented fish sauces contain 2-5% protein and >20% salt. Volatile compounds reflected Maillard reactions due to heating. Aerobic plate counts of non-heated extracts indicated live *SX* activity. No pathogens were detected.

Volatile compound profiles varied substantially. Heat-treated heart extracts were rich in acids, aldehydes, and sulphur compounds that can be perceived as nutty, musty and toasted aromas, while lung extracts, particularly the non-heated, had alcohols, esters, and pyrazines that tend towards fruity and nutty aromas. A semi-formal in-house sensory evaluation confirmed these distinctions. Heart extracts had strong meaty, roasty, and liver flavours, while lung extracts exhibited a fruity aroma with subtle sweetness, and bit of ammonia. Diluting the extracts reduced the intense saltiness and challenging offal notes, presenting an overall better balance.

This project has highlighted how tissue-type and heat treatment shape the compositional and sensory characteristics of fermented beef extracts. The successful creation of prototypes demonstrates their potential for developing distinct food-grade products – that is, new potential usage/opportunity space for Australian red meat industry to explore as a means to grow higher value and potentially create greater demand for offal.

Executive summary

Background

The value and range of applications for abattoir co-products could be increased by diverting them to flavoursome extracts, sauces and ingredients for food service and consumers. Fermentation by beneficial microbes has the potential to transform these rough substrates, in the process creating new compounds that stimulate desirable tastes and aromatics such as umami and kokumi. Findings and prototypes from this proof-of-concept project will underpin further discussions, product development trials and market investigations.

Objectives

The primary aim of project P.PSH.1475 was to evaluate whether *Staphylococcus xylosus* (*SX*; a commercial starter culture advantageous for meat products) is a good candidate in creating fermented meat sauce type materials from beef offal.

Objective 1a was achieved by establishing that lung and heart offal can be efficiently and safely fermented in a modest amount of time using only simple processing parameters.
Objective 1b was achieved by implementing specified conditions at pilot plant 'kitchen scale' to prepare food grade fermentation extracts suitable for testing palatability.

Methodology

Lung and heart organs were procured from Taylor Preston Limited (Wellinton, NZ). Permutations of key factors for efficient and safe fermentation were trialled in the laboratory. The optimised parameters for a pilot plant run were coarse chopped non-pasteurised tissue, salt, protease and SX culture. Fermentation was carried out for 1 month for lung and 3 months for heart. The liquid fractions were filtered and clarified, and half were heat-treated. Physical, chemical and microbiological properties were measured. The extracts were sensory tested as-is without further product development.

Results/key findings

The four types of food-grade sauces met targets for objective measurements. These include SX growth vigour, protease dissolution, microbiological safety, yield from raw material, and complex composition of aromatic volatile compounds. In-house sensory evaluation showed the influences of tissue and treatment. All extracts exhibited flavours of livery offal, ammonia and intense saltiness that may be challenging. The preferred dilutions of heart presented appealing meaty and roasted notes, while lung had a fruity aroma with subtle sweetness.

Benefits to industry

These prototypes demonstrate potential for novel cuisine products. Organ type and heat treatment determine the characteristics of fermented offal. Yield of extract is approximately 50% from tissues. The simple materials and methods could be scaled to industrial production, perhaps following the model of commercial fish sauce.

Future research and recommendations

Our results are raw materials. They need further discussions, product development trials and market investigations. A next step could be experimentation by a trained chef to explore how the extracts might be formulated into consumer-ready sauces or pastes.

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1. Background

The value and range of applications for under-utilised abattoir co-products could be increased by using them in flavoursome extracts, sauces and ingredients. Fermentation by beneficial microbes has the potential to transform these rough substrates, in the process creating new compounds that stimulate desirable tastes and aromatics such as umami and kokumi.

Our proof-of-concept project is using beef lung and heart as readily available substrates that have disparate compositions and structures. We selected the bacterial starter culture *Staphylococcus xylosus* (*SX*), which is known for generating desirable notes in fermented meaty foods (salami etc.), as well as generating the strong acidification that is advantageous for food safety.

In the final milestone of the project, we translated our earlier laboratory fermentation experiments to a larger scale in the Massey/Te Rourou FoodPilot plant. We made sufficient quantities to use for current and future sensory evaluation and product applications. Fermentation times were optimised separately for beef lung and beef heart based on their distinct characteristics. The goal of this project was to produce fermented sauces suitable for food-grade applications.

2. Objectives

The aim of the project P.PSH.1475 is "to evaluate whether the selected bacteria strain *SX* is a good candidate in creating 'fermented meat sauce' type materials from offal. The outcomes from this project will initiate further discussion regarding the potential to develop the proof of concept into a flavourful ingredient."

Project Objective 1a) Establish a relationship between beef heart and lung offal and fermentation and whether lung and heart offal can be efficiently and safely fermented at a reasonable pace under simple conditions.

Project Objective 1b) In addition to evaluating the viability of this, the outcomes will be used to understand and optimise specified conditions for preparing food grade concepts at "kitchen scale" to evaluate palatability."

Milestone 4 has now been completed which completes the entire project. It met the aims of the second part of Project Objective (1b) by demonstrating that organs, protease and bacteria can be fermented as food grade.

3. Methodology

3.1 Materials and preparation

The lung and heart organs were procured from Taylor Preston Limited (Wellinton) with appropriate E-cert status and stored at –20 °C until required. The lung and heart were thawed at 10 °C and manually chopped into 4 cm × 4 cm pieces. These were transferred to plastic pails and mixed with kilned (sterilised) sea salt at 20% weight-for-weight. Protease and starter culture were added. Three batches of lung and heart were prepared, with each utilising 5 kg of raw material. Photos of the manual steps are shown in **Fig. 1**.

Figure *1*. Pre-fermentation stages of offal preparation (here lung is shown), including manual chopping of thawed tissue, and subsequent mixing with sea salt, Protease, and starter culture.

Fermentation Step - Each mixture was thoroughly combined and placed in a fermentation room for approximately **one month for beef lung**, and **three months for beef heart**. Progress of the fermentation was assessed at 2 and 5 weeks for beef lung and 2, 5 and 12 weeks for beef heart.

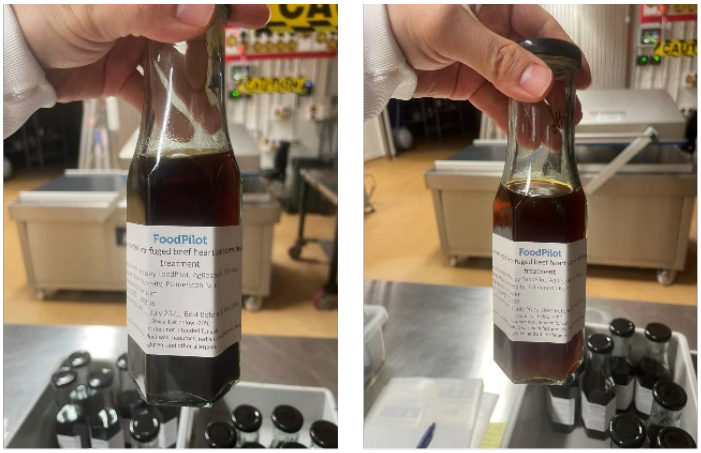
Heating Step - Following fermentation, the liquid was separated from the solids. The resulting liquid fraction, which included remaining suspended particles, was transferred into food-grade glass bottles (**Fig. 2**). Half of the bottles were subjected to heat treatment using a retort-type process.

Clarifying Step - After cooling, precipitation and flocculation was observed in the sauces, particularly in the heated extracts. This was likely aggregation of denatured protein. Although small in mass (i.e. fluffy and diffuse) it was unsightly. To address this, the bottles were reopened, and a secondary separation was performed using centrifugation. All finished and sealed bottles were stored at -20 °C.

Thus, our pilot plant process created four variations of sauces: 1-month lung (non-heated & heated); 3-month heart (non-heated & heated). Labelled bottles are shown in **Fig. 3**.

Figure 2. Post-fermentation processing steps for fermented offal (here lung is shown), including straining of the fermented mixture to separate solids, bottling of the liquid extract, and heat treatment using a retort-type process.

Figure 3. Photos of sauce prototypes.



3.2 Yield of sauce from raw materials

Separating the liquid and solid fractions determines yield of the sauce-making process. While laboratory-scale fermentation in previous milestones used centrifugation to exhaustively collect the liquid extract, the larger scale pilot plant process employed a strainer and then coarse filtration steps. For yield calculations, *initial sample weight* refers to the total mass of the mixture, including the chopped offal and salt:

$$Liquid\ yield\ (\%) = \frac{Liquid\ fraction\ weight\ (g)\ \times\ 100}{initial\ sample\ weight\ (g)}$$

3.3 Physical, chemical and microbiological tests

3.3.1 pH

The pH of the fermenting liquid fraction was measured during fermentation for beef lung (at 2 and 5 weeks) and beef heart (at 2, 5, and 12 weeks).

3.3.2 Salt concentration

The salt concentration of the final bottled sauce prototypes was measured using a salt meter (EC-SaltTestr11, Eutech Instruments).

3.3.3 Microbiological safety

Contamination by pathogenic microbes was judged by testing for *Salmonella* spp., *Staphylococcus aureus*, *Escherichia coli* spp., *Clostridium perfringens*, and aerobic plate count. To evaluate the effect of heat treatment on microbiological safety, both the non-heated and heated extracts were analysed.

3.3.4 Proximate composition

Dry matter, crude protein, fat, and ash contents were measured using accredited analytical protocols. As mentioned above, the heat-treated sauce contained substantial precipitation and flocculation. Therefore, in order to provide a well-defined sample for composition measurements, we did an additional laboratory filtration step to clarify the heat-treated sauce. Both the non-heated and heated extracts were analysed.

3.3.5 Volatile compound analysis

Volatile compounds (responsible for aromas) were collected from the headspace above samples of sauces. This is similar to what one would smell when opening a bottle. We used solid-phase microextraction (SPME) and analysed by gas chromatography-mass spectrometry (GC-MS) as described by (Hutchings *et al.* 2025). To amplify the release of volatiles the extracts were warmed at 40°C for 30 minutes with agitation. The SPME fibre was exposed to the headspace for 30 min, then desorbed in a split-less injector. Chromatographic separation was performed using a Shimadzu QP-2010 Plus GC system, and mass spectra were acquired using a Shimadzu TQ 8040 mass spectrometer. Peaks were analysed using the NIST14 database (≥ 90% similarity). Z-scores of concentrations were used to standardise the data and minimise distortions caused by widely different concentrations of the diverse compounds.

3.4 In-house sensory evaluation

This was a semi-formal evaluation by Jihan Kim and Scott Knowles undertaken at the Te Rourou test kitchen. The sauces were consider as-is, without any further product development steps such as sweetening, acidification, or cooking. Dilution series (100%, 75%, 50%, and 25%) were prepared using water for each of the four sauces. Three examples of commercial savoury sauces (fish, soy and Worcestershire) were on-hand for context and comparison. Palate cleansers were plain crackers and water, with ground raw coffee beans provided to refresh nose perception.

We scored the sauces against ten terms for flavours that had been gleaned from published lexicons related to the attributes of fish sauce (the closest commercial equivalent). Note that these are not the only possible attributes of meat sauce; other flavours might be identified that are more directly descriptive. The initial ten flavours were: meaty, sour, umami, salty, ammonia, cheesy, faecal, fishy, rancid and roasted.

Sensory evaluation had two sections: plain and added to soup. We started with a round of sniffing tests followed by taste testing using a wooden stick. The stick was dipped into the sauce, then placed on the tongue for several seconds.

In the second section, 0.5 mL of the original sauce was added to 20 mL of Maggi instant French onion soup (prepared with hot water as per package). Aliquots of 0.5–1 mL of the seasoned soup were tasted via a dropper and spoon.

4. Results

4.1 Summary of food safety controls

The aim of Milestone 4 was small scale food grade production of prototype sauces for inhouse tasting, so food safety was paramount. Multiple safety hurdles are applicable to this product to prevent, inhibit or eliminate the risks of microorganisms: clean techniques for processing; high salt formulation; low pH development; high temperature treatment; and low temperature storage.

The FoodPilot plant has strict supervised procedures suited to food production. Risk management protocols (RMP) were developed specifically for this fermentation project with Compliance Manager Andrea Holman.

The raw beef tissues were harvested and packed by a commercial firm Taylor Preston Limited. These were transported chilled and confirmed as pathogen free before intake to the plant.

Sterilised salt was added to the raw tissue at the maximum possible concentration that still allowed *SX* fermentation. *SX* is only modestly salt tolerant. Its growth under 20% salt is 15% of growth under 0% salt (see results from Milestone 1). In final products, the relevant regulations stipulate > 10% in the ‘water phase’—the percentage of salt dissolved in the aqueous (moisture) phase (Secretariat, 2014).

Bacterial fermentation typically lowers pH by producing organic acids. *SX* is not a strong acidifier compared to say, Lactobacilli. It would not be expected to lower pH to the 4.6 benchmark of safety in fermented meat products. However, any acidification contributes to hurdles against undesirable microorganisms.

Heat treatment of sauces at 115 °C is a robust step to eliminate microbes. Our retort-style heating was not under high pressure (i.e. at atmospheric) so conceivably bacterial spores could survive, but that was not considered a risk for this product. Of course, the unheated versions of sauces remain live fermentation cultures rich with *SX*.

The bottled and sealed products are stored either refrigerated or frozen. This is necessary for the unheated versions. It is unnecessary and merely convenient for the shelf stable heated versions.

4.2 Changes in pH during fermentation and post-fermentation yield

The liquid fraction of lung fermentation (the 'extract') maintained a pH of 6.1 ± 0.3 at 2 and 5 weeks, indicating consistent fermentation conditions and minor acid production by *SX*. The heart extract had a more acidic profile, with a pH of 5.3 ± 0.1 at 2 weeks, dropping to 4.9 ± 0.1 at 5 weeks, and stabilising at 4.9 ± 0.2 by 12 weeks (**Table 1**).

This difference could be due to heart tissue containing a greater initial concentration of glycogen, which would be a substrate for vigorous *SX* growth. That leads to more acid production. In contrast, lung tissue, with a lower carbon source availability, may have prompted *SX* to utilise alternative, less efficient substrates.

Table 1. pH and yield of sauce prototypes derived from protease-treated beef lung and heart fermented by *SX*, measured before heating and bottling.

Type	pH			Yield (%)
	2 weeks	5 weeks	12 weeks	
Fermented lung extract	6.1 ± 0.3	6.1 ± 0.3	-	43 ± 2.3
Fermented heart extract	5.3 ± 0.1	4.9 ± 0.1	4.9 ± 0.2	51 ± 4.8

Fermentation of heart achieved a yield of 51% liquid extract compared to the lung's 43%. This may be attributable to its higher protein content (typically 25% greater than lung on a raw basis), because broken down and solubilised protein contributes much of the mass of the extracts. Also, lung tissue is rich in collagen (responsible for its elasticity), which is resistant to proteolysis; see discussion in Milestone 3 report.

For each batch of tissue prepared from 5 kg of raw material (plus 1.1 kg of salt and adjuvants), an average of approximately 2.5 kg of fermented lung extract was recovered and 3.0 kg of fermented heart extract. As the sum of all three batches per tissue, the total production was 7.6 kg of lung extract and 8.9 kg of heart extract.

4.3 Microbiological safety

Microbiological analyses were conducted for confirming food safety compliance. Risky concentrations of pathogenic bacteria were not detected in the non-heated and heated extracts of lung and heart.

Aerobic plate counts estimate the total number of viable bacteria in a sample under oxygen conditions. These are not dangerous bacteria but rather the microbial content one would expect in live-culture fermented foods. The non-heated extracts produced much higher plate counts compared to their heat-treated (i.e. killed) counterparts (**Table 2**).

This was encouraging to see as evidence that *SX* thrived under our fermentation conditions. Recall that in Milestone 1 we demonstrated that *SX* is modestly salt-tolerant. Kilinc *et al.* (2006) reported comparable aerobic plate counts ranging from 10^4 CFU/g to 10^8 CFU/g during 57 days of fermentation of fish sauce.

Table 2. Microbiological result of meat sauce derived from protease-treated lung and heart extracts fermented by *SX*. Colony Forming Unit, CFU/g material).

Type	Heat treatment	Pathogenic bacteria				Aerobic plate count (CFU)
		Salmonella spp.	*Staphylococcus* aureus	*Escherichia coli* spp.	*Clostridium perfringens*	
Lung	Non-heated	ND	<100	<10	<10	210,000
	Heated	ND	<100	<10	<10	<10
Heart	Non-heated	ND	<100	<10	<10	200,000
	Heated	ND	<100	<10	<10	<10

4.4 Proximate composition and salt load of sauce prototypes

Composition of the four sauce prototypes is shown in **Table 3**. Comparing lung and heart extracts, the most notable difference was crude protein content, at 10% versus 14%. Moisture content was reciprocally different. Heat treatment had minimal effect. That suggests that little material was actually lost when the heated sauces were clarified by centrifugation (Step 12).

Very low levels of fat were as expected due to the liquid-soluble nature of the extracts.

Ash comprises the inorganic mineral content of a sample. It is usually low in hydrolysed meat solutions, but here it is substantial, at 16 to 18%. This is a consequence of adding 20% salt to the raw tissues during processing. High salt contributes to food safety and shelf stability. The concentrations recommended for commercial fish sauce to inhibit and delay the growth of bacteria is >10% of the 'water phase', which is the percentage of salt dissolved in the aqueous (moisture) phase (Secretariat, 2014).

A useful comparison is with familiar commercial fermented sauces. Examples that we measured were Golden Sun fish sauce and Kikkoman soy sauce, at 26% and 17% salt, respectively.

Table 3. Proximate composition of meat sauce prototypes derived from protease-treated lung and heart extracts fermented by *SX*.

Type	Heat treatment	Proximate composition				Salt %
		Moisture %	Crude protein %	Fat %	Ash %	
Lung	Non-heated	70.0 ±0.2	10.4 ±0.1	0.2 ±0.1	19.1 ±0.2	18.4 ±0.1
	Heated	69.5 ±0.1	10.1 ±0.1	0.1 ±0.1	18. 9±0.2	18.2 ±0.1
Heart	Non-heated	65.8 ±0.4	14.4 ±1.1	<0.1	18.4 ±na	16.2 ±0.1
	Heated	65.8 ±0.4	14.4 ±0.3	<0.1	18.4 ±na	16.5 ±0.1

4.5 Profile of volatile compounds

Volatiles analysis is used to separate and identify the many chemical compounds that contribute to aroma and flavour. They are central to the sensory characteristics of foods. A typical profile of volatiles covers a range of chemical classes, each including various specific compounds. Each of

those can have an intrinsic odour, although whether it is detectable by sense of smell depends on concentration. Research by the fragrance industry and others has assigned aroma descriptions to most volatile chemicals. An important caveat is that the perceived smell of a chemical in isolation may be quite different if present in complex mixtures.

We measured volatiles from the four sauce prototypes and identified 55 compounds. These are arranged in **Table 4** in a way to emphasise the differences between the sauces. It is tempting to consider the apparent groupings of compounds and imagine what that combination of aroma descriptions might smell like.

The profiles differed notably between lung and heart, as well as with heat treatment. Acids such as nonanoic and propanoic acid were particularly elevated in heated heart extract, likely derived from thermal degradation of lipids in the tissue (Han *et al.* 2023). In contrast, lung samples, especially under non-heated conditions, showed higher levels of branched-chain acids like isovaleric and isobutyric acid, which may stem from microbial or enzymatic processes (Elsden and Hilton 1978; Bhatia and Yang 2017).

Alcohols were generally more abundant in lung extracts, suggesting active oxidation or fermentation of precursor lipids. Their levels tended to decrease after heating, indicating thermal degradation or loss by volatilisation. Aldehydes, particularly Strecker-type (e.g. methional, phenylacetaldehyde), were more prominent in heat-treated heart tissues, reflecting Maillard reaction activity (Soares da Costa *et al.* 2004).

Esters, which impart fruity and sweet notes, were highly abundant in heat-treated lung extracts, likely formed by heat-induced esterification of free fatty acids and alcohols (Aldai *et al.* 2005). Pyrazines, known for their roasted and nutty aromas, were strongly enhanced in H_LU, indicating intense Maillard reactions and interaction with free fatty acids (Wang *et al.* 2021). Furans and lactones, such as furaneol and pantolactone, were more specific to H_HE, contributing caramel-like notes.

Sulphur-containing compounds (e.g. 2-acetyl-2-thiazoline) were also significantly elevated in heat-treated heart tissues, associated with umami and meaty flavours through thermal transformation of sulphur amino acids (Yu and Zhang 2010). In addition, it has been reported that higher pH values can enhance the formation of thiazoles and pyrazines, both key Maillard reaction products. This may explain why lung tissues, which generally exhibit a higher pH than heart, produced greater levels of these compounds.

In summary, heart extract, especially when heated, produced volatiles associated with meaty, roasted, and fatty notes, while lung extracts may have more fruity, fermented, and nutty aromas, particularly under non-heated or mildly heated conditions. Heat treatment was a key driver in enhancing Maillard-derived and lipid-degradation volatiles, contributing to greater flavour intensity and complexity.

Table 4. Fifty-five volatile compounds were identified in sauces derived from fermented lung and heart, whether Non-Heated or Heated. Darker blue shades in the table indicate higher values, while red shades indicate lower values. Data expressed as Z-scores.

		HEART		LUNG		
Chemical class	**Volatile compound**	**NH**	**H**	**NH**	**H**	**Aroma description[1]**
Alcohols	2-Ethylhexanol					Sweet, fatty
Alcohols	1-Butanol					Fruity
Alcohols	1-Hexanol					Green, fruity
Sulphur compounds	Dimethyl-trisulfide					Sulphurous, cooked onion, savoury meaty
Terpenes	Limonene					Herbal, citrus
Alcohols	3-Phenyl-1-propanol					Spicy
Hydrocarbons	Styrene					Sweet, floral plastic
Acids	Valeric acid					Acidic
Ketones	Acetoin					Creamy, buttery
Phenols	p-Cresol					Phenolic
Acids	Isobutyric acid					Acidic
Acids	Isovaleric acid					Cheesy
Acids	5-Methylhexanoic acid					Fatty
Hydrocarbons	Indole					Animal, faecal, earthy
Alcohols	2-Phenylethanol					Floral
Alcohols	Propanol					Alcoholic, nutty
Alcohols	Isobutanol					Fusel, whiskey
Alcohols	2-Methyl-1-butanol					Whiskey, fatty
Alcohols	Benzyl alcohol					Cherry, almond
Pyrazines	2,5-Dimethylpyrazine					Musty, nutty
Pyrazines	2,3-Dimethylpyrazine					Mitti, roasted, coffee
Alcohols	Methionol					Onion, Garlic like
Pyrazines	2-Ethylpyrazine					Nutty, woody, potato
Aldehydes	Benzaldehyde					Fruity, cherry, woody
Ketones	Acetophenone					Almond, bitter
Others	2-Acetylpyridine					Corn, nutty
Pyrazines	2,3,5-Trimethylpyrazine					Musty, nutty, potato
Esters	Ethyl valerate					Fruity, strawberry
Esters	Ethyl isocaproate					-
Esters	Ethyl 3-phenylpropionate					Honey, fruity
Ketones	2-Pentanone					Sweet, fruity
Alcohols	2-Pentanol					Alcoholic, fruity
Alcohols	trans-2-Penten-1-ol					Mushroom
Aldehydes	Methional					Potato, beefy, onion
Esters	Benzyl acetate					Fruity, sweet, floral
Acids	Acetic acid					Acidic
Others	2-Acetylpyrrole					Nutty, musty
Thiazoles	2-Acetyl-2-thiazoline					Toasted, salty, chips
Esters	Hexyl butyrate					Green, waxy, fruity
Alcohols	1-Penten-3-ol					Green, truffle
Alcohols	1-Octen-3-ol					Mushroom
Aldehydes	Nonanal					Fatty, green, lemon
Lactones	Pantolactone					Cotton candy
Aldehydes	Heptanal					Green, oily
Aldehydes	Phenylacetaldehyde					Honey, sweet, floral
Lactones	gamma-Butyrolactone					Milky, creamy, fruity
Acids	Propanoic acid					Acidic

		HEART		LUNG		
Chemical class	**Volatile compound**	**NH**	**H**	**NH**	**H**	**Aroma description[(1)]**
Acids	Nonanoic acid					Fatty
Alcohols	Furfuryl alcohol					Musty, caramel, coffee
Furans	Furaneol					Caramel, butterscotch
Furans	Furfural					Bready, nutty, brown
Furans	2-Pentylfuran					Cocoa, nutty, coffee
Pyrazines	2-Methylpyrazine					Nutty, brown, roasted
Alcohols	1-Octanol					Waxy
Ketones	2-Heptanone					Cheesy, fruity

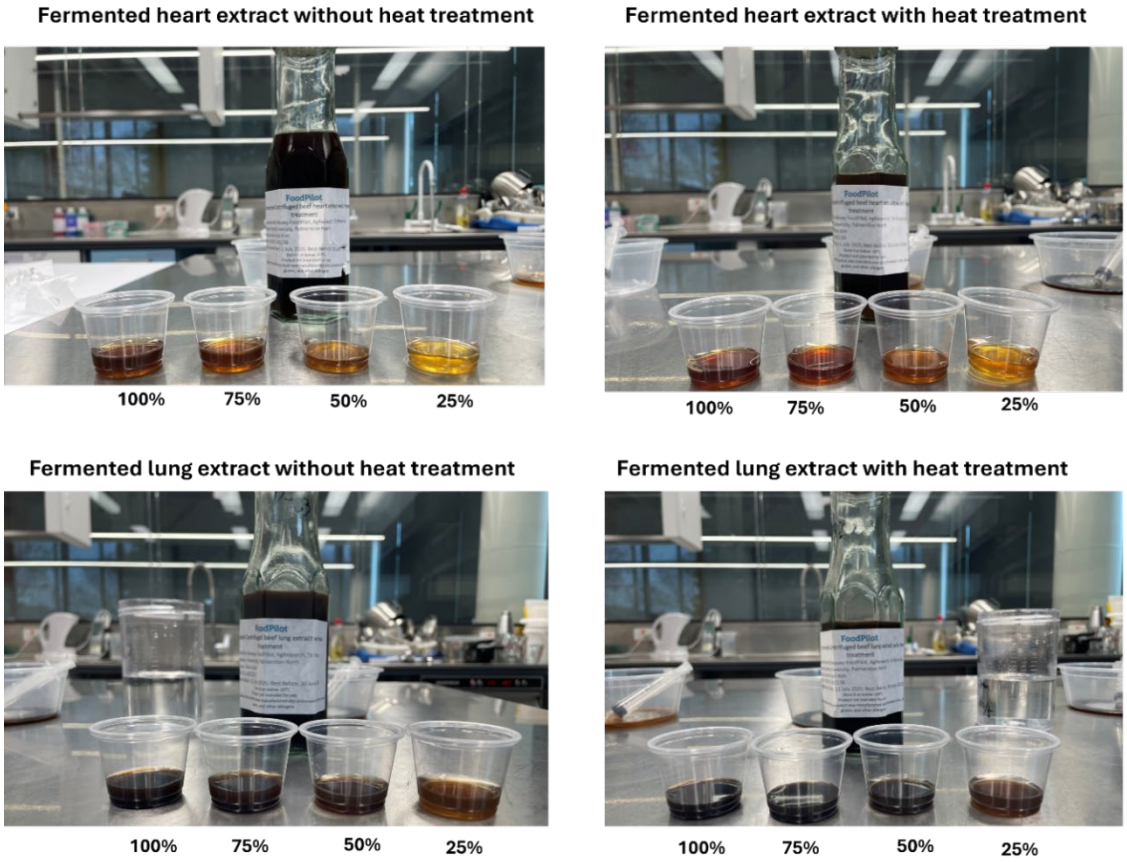
[(1)]Aroma descriptions are based on data from The Good Scents Company Information System (https://www.thegoodscentscompany.com/search.php).

4.6 In-house sensory assessment

4.6.1 Colour

The heart samples exhibited a bright, attractive red-orange hue, whereas the lung samples appeared darker brown with an olive tint and a somewhat murky appearance (**Fig. 4**). Heat treatment had little effect on the colour of lung samples. In contrast, the colour of heart samples intensified to a deeper red-orange, likely due to Maillard reactions occurring during the retort-style heating.

Figure 4. Photos of fermented meat sauce samples prepared by serial dilution for sensory analysis.



4.6.2 Aroma

We perceived distinct differences between the lung and heart dilution-series samples. All samples presented meaty and roasty aroma notes, accompanied by varying intensities of liver character, sometimes quite potent. The non-heated lung sample displayed a notable fruity/green aroma with subtle sweetness, which was particularly intriguing. A little bit of ammonia-like odour was also detected in the lung sample. Retort heating altered the aroma profiles by enhancing the cheesy and roasted meaty notes in heart samples. In lung samples, heating helped reduce faecal odour but did not significantly increase roasted meaty aromas to the same extent as in heart samples.

4.6.3 Taste

Saltiness was intense in the less-diluted samples. Meaty and roasty favours were consistently present but did not strictly follow a dose-response pattern of the dilution. The flavour profile was reminiscent of liquid roast beef. The liver-like or organ meat notes we detected were more pronounced in lung samples and presented a serious challenge at certain concentrations. Cooking the sauces (i.e. retort heating) added complexity and balance, especially in heart samples, with subtle sweetness and coffee notes noted at mid-range dilutions. Some samples exhibited an extended flavour finish, notably longer than that of the commercial sauces we had for comparison.

4.6.4 Food matrix interaction

Maggi instant French onion soup was prepared and supplemented with sauce at 10% and 2.5% (v/v) concentrations. At 10%, the added saltiness overwhelmed the soup's flavour across all samples. At 2.5%, the sauces contributed noticeable flavour enhancements and greater complexity. However, the lung samples failed to integrate well with the soup, resulting in a less harmonious flavour profile (impression as 'this is soup with something added to it). Similarly, the non-heated heart sauce did not unify with the soup, although its liver notes were subdued to a pleasant background flavour. The heat-treated-fermented heart sauce demonstrated superior synergy with the soup, enhancing its weight, depth, and roundness, while complementing the onion flavour and improving overall authenticity. By comparison, the plain soup was bland and watery.

Among the commercial controls, soy sauce and Worcestershire sauce did not harmonise well with the French onion soup due to their dominant flavour notes, specifically the beany aroma of soy sauce and the sweet, vinegary character of Worcestershire sauce. Fish sauce performed slightly better in the soup, although a residual fishy odour was still perceptible.

5. Conclusion

Milestone 4, the final one of this project, aimed to conduct a small-scale, food-grade fermentation trial of beef lung and heart extracts, integrating insights from all the prior milestones. This was achieved. Success is defined here as meeting key targets for objective measurements:

- *SX* fermentation growth
- Protease-driven tissue dissolution
- Manageable durations of fermentation
- Microbiological safety
- pH acidification response
- Adequate salt levels
- Yield per input raw material
- Commercially comparable proximate composition
- Complex volatile profiles differentiated by tissue and treatment

The four food-grade sauces were tasted. Semi-formal in-house sensory evaluation showed distinct flavour profiles influenced by tissue and treatment. The preferred dilutions of heart extract exhibiting strong meaty, roasted, and rich flavours, while lung extract had a fruity aroma with subtle sweetness.

It is important to remember that differences we observed between lung and beef extracts are a consequence of the different tissue-type AND different duration of fermentation. This was approximately one month for beef lung, and three months for beef heart. We did not find any strong reasons to change or extend the durations.

5.1 Key findings

Co-Product Influence: The type of organ affected not only yield and chemical composition but also sensory properties, as confirmed by GC-MS analysis of aroma-related volatile compounds and in-house sensory evaluation.

Consequences of Heat Treatment: Heat applied to ensure microbiological safety significantly altered flavour profiles, with notable effects linked to the Maillard reaction that produces appealing baked flavours. This was particularly evident in the beef heart extracts.

Sensory Outcomes: These experimental conditions of fermentation did not substantially diminish the typical offal aromas and tastes that can be off-putting for some consumers. However, that may

not be a fatal flaw. For comparison, fish sauce when tasted alone can be intensely 'unusual', yet it is a fundamental flavour principle for Asian cuisine. Our results should be considered raw materials. They need further product development trials to discover how they might best be utilised.

5.2 Benefits to industry

These prototypes demonstrate potential for novel cuisine products. Yield of extract from tissues (with no additional liquid added) was 43-51%. This is good conversion from such a simple process. The side stream of solids needs to be managed by subsequent use or disposal, but it is non-toxic without out chemicals requiring recovery.

The pilot plant run at 'kitchen scale' was not intended to mimic the logistics and mechanics of industrial scale processing. Nevertheless, each step of our methods is similar to conventional unit operations for food manufacturing. Production of commercial fish sauce has parallels that are worth investigating.

6. Future research and recommendations

Whilst at this stage the ultimate profitability of meat sauce cannot be estimated the technical possibility suggests a future potential for Australian red meat industry to consider. Acknowledge by the research team is that we do not yet know what format and use case suits this novel material, nor who might use it in what range of cuisines.

We recommend an inexpensive next step to understand the potential of the raw material, essentially to partially validate the value proposition and concept viability. This could involve experimentation by a professional chef exploring how the extracts might be formulated into consumer-ready sauces or pastes:

Flavour Enhancement: Add reducing sugars during post-fermentation heat treatment to promote the Maillard reaction, potentially improving flavour profiles.

Acidity Adjustment: Modify acidity to enhance taste and further improve food safety.

Salt Reduction: Consider salt levels in line with current trends, while exercising caution due to its role in food safety. Post-fermentation desalting methods, such as ethanol precipitation.

Microbial Variation: Apply different culture microorganisms, such as halophilic bacteria (used in fish sauce) or fungi strains (used in soy sauce), to achieve diverse flavour profiles.

Following that, an analysis of relevant markets could be conducted, for instance for condiments and food service. If the values are attractive, then doing a systematic assessment of the research, process development, and operational planning needed for scale-up may be warranted.

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