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Physicochemical, sensory analysis and gastronomic significance of Sambal Tumpang as a traditional Javanese fermented condiment

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Abstract

Sambal Tumpang, locally known as tumpang koyor, is a traditional Javanese condiment made from over-fermented tempeh (*tempe semangit*), chillies, coconut milk, and spices. Despite its deep cultural roots and culinary significance in Central Java, especially in Salatiga, there has been limited scientific exploration of this ethnic food. This study presents the first empirical analysis of Sambal Tumpang, integrating historical, socio-cultural, nutritional, sensory, and microbial perspectives. Through this study, we conducted ethnographic interviews with local producers and laboratory analyses of four locally available samples to examine their proximate composition, sensory characteristics, shelf life, and food safety. Nutrient profiles varied significantly due to differences in ingredients and preparation methods, with protein content ranging from 3.38% to 6.60% and water content from 78.73% to 88.95%. Sensory evaluation revealed varying consumer preferences, influenced by texture and spiciness. Microbial testing identified *E. coli* and coliforms in several samples, highlighting hygiene concerns in small-scale production. Beyond its nutritional and culinary value, Sambal Tumpang exemplifies sustainable food practices by valorising over-fermented tempeh and holds potential as a functional food and a tool for gastrodiplomacy. This study emphasises the importance of preserving and innovating traditional foods to ensure cultural continuity while addressing contemporary concerns regarding food safety and marketability.

Keywords Sambal Tumpang, Tempe semangit, Fermented food, Ethnic cuisine, Food safety, Gastrodiplomacy, Indonesia

1 Introduction

Indonesia is renowned for its distinctive food culture; one integral condiment used in many Indonesian dishes is sambal [1]. Sambal is a traditional sauce or paste made primarily from chilli peppers, often mixed with other spices or ingredients [2, 3]. Sambal preparation typically involves slicing the ingredients with a knife or grinding them using a stone mortar and pestle (*ulekan dan cobekan* in Indonesian) (Fig. 1), followed by either cooking or serving them raw [2, 3].

Most sambals are known for their spicy flavour, making them a perfect complement to a variety of dishes such as vegetables (*lalapan* in Indonesian), chicken, fish, tofu, and more [1]. While Indonesian cuisine is renowned for its rich and diverse flavours, many Indonesians have a strong preference for spicy foods [1, 4]. The history of sambal reveals that, before the current chilli pepper (*Capsicum annuum*) became a staple in sambal making, another local pepper, known as Javanese Libya (*Piper retrofractum*), was used [1, 5, 6]. The chilli pepper is a cultivated species introduced during the Columbian Exchange and believed to have originated in Mesoamerica [5, 7, 8].

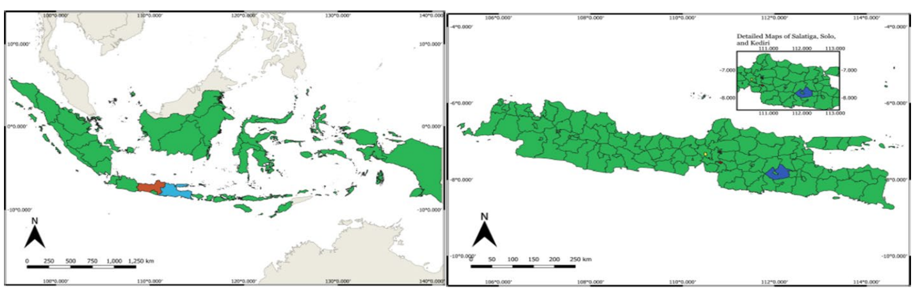
There are more than 100 different sambals in Indonesia, from Aceh to Papua; each region also has its unique characteristics, secondary ingredients, and taste [1]. Secondary ingredients are components other than the chilli itself that contribute to the unique flavours of sambals, including fruits, herbs, fish, and fermented foods [1]. Additionally, most sambals typically include garlic, shallots, fermented shrimp paste (terasi in Indonesian), or lime to enhance their flavour. For example, a sambal from Java, known as Sambal Tumpang (Fig. 2), incorporates tempeh, an Indonesian fermented soybean product, as its secondary ingredient [1, 9, 10]. Tempeh has become a national treasure and is known as a superfood. It is widely recognised as an affordable and nutritious source of protein [11]. However, making Sambal Tumpang does not utilise normal tempeh, but rather over-fermented tempeh (*tempe semangit* in Indonesian) [1, 9, 10]. Over-fermented tempeh is selected for its strong aroma and flavour, resulting from the breakdown of proteins into amino acids, which contribute to the unique flavour characteristics of Sambal Tumpang [1, 12].

Sambal Tumpang, locally known as *tumpang koyor*, is a staple condiment in Central Java, particularly in Solo and Salatiga, and is also found in Kediri, East Java. It is a unique, historically significant Indonesian sambal originating in these regions (Fig. 3).

However, a thorough review that specifically examines Sambal Tumpang from multiple perspectives has yet to be conducted. This research article provides a comprehensive overview of Sambal Tumpang, covering its history, philosophy, socio-cultural aspects,

Fig. 1 Stone mortar and pestle, tools used to grind and mix sambal's ingredients

Fig. 2 Sambal Tumpang, A Javanese sambal that uses over-fermented tempeh as a secondary ingredient, has an umami, sweet, and spicy taste



(A) (B)

Fig. 3 **A** Geographical map of Indonesia highlighting Central Java and East Java (brown and blue, respectively). **B** Salatiga, Solo, and Kediri (yellow, red, and blue, respectively) in Java Island are known for popularising Sambal Tumpang

nutritional value, food safety, and its shelf life. It also addresses challenges and suggests potential future improvements for the development of Sambal Tumpang in the food industry. This study aims to provide in-depth insights into Sambal Tumpang, a valuable resource for scientific research and a contributor to the ongoing exploration of ethnic food.

2 Materials and methods

2.1 Methodology

This study was conducted by critically assessing and synthesising data from multiple databases and search platforms, including ScienceDirect, MDPI, Springer, and Google Scholar. We also interviewed 4 locals who produce Sambal Tumpang in Salatiga, Central Java, and analysed its nutritional values through proximate analysis.

2.2 Experimental methodology

The experimental trial was conducted using four samples obtained from our local producer, whom we interviewed to analyse their nutritional value. All samples were stored in the freezer (-20℃) prior to analysis. All samples were analysed five times before statistical analysis to identify differences among them Fig. 4.

2.2.1 Proximate analysis

a. Moisture Content Analysis (AOAC, 950.46)

The water content was determined by thermogravimetry. A clean crucible was preheated overnight before weighing; then approximately 10 g of each sample was added. The sample was then placed in the oven overnight until it reached a constant weight. The cup will be allowed to cool in a desiccator. The water content was calculated using the following formula.

$$moisture\,content\,(\%) = \frac{W1 - W2}{W1} \times 100$$

W1: Weight (g) of sample before drying.
W2: Weight (g) of sample after drying.

b. Ash Content Analysis (AOAC, 920.153)

A clean crucible and a preheated crucible were prepared before weighing. Approximately 10 g of each sample was placed into a cup and weighed along with the cup. The cup containing the sample was heated in a furnace at 550 °C for 3–5 h. The heating process was completed when a constant weight was achieved. The cup was allowed to cool in a desiccator and then placed in an oven at 105 °C for 24 h. It was subsequently placed in a desiccator for 15 min. The weight of the cup and ash was measured, and the ash content was calculated using the formula below.

$$ash\,content\,(\%) = \frac{W2 - W0}{W1 - W0} \times 100$$

W0: Weight (g) of crucible.
W1: Weight (g) of sample before drying.
W2: Weight (g) of sample after drying.

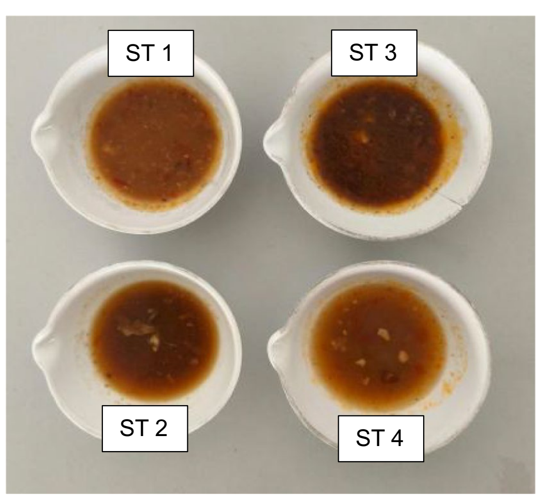


Fig. 4 Four different samples of Sambal Tumpang were sold in Salatiga. From the colour, there are slight differences with brown as the main colour

c. Total Fat Content Analysis (AOAC, 991.36)

The flask and filter paper were dried in an oven at 105 °C for 24 h. Each 0.5-g dried sample was placed on a filter paper and treated with hexane solvent. The flask was put on a Soxhlet apparatus and heated for 3 h until all lipids were extracted. The sample was removed from the Soxhlet apparatus, and the solvent in the flask was transferred to a crucible, which was then heated in an oven at 105 °C overnight. The heated sample will be placed in a desiccator for 15 min. The sample was then weighed until a constant weight was achieved. The dry-based fat content is calculated using the formula above and must be converted to wet-based content using the following formula.

$$fat\,content\ (\%)\ =\ \frac{100-moisture\ content}{100}\times dry\ based\,fat\,content\ (wet\,base)$$

d. Protein Content Analysis (AOAC, 928.08)

The protein content was determined using the Kjeldahl method. 0.25 g of the dried sample was added to the Kjeldahl flask. Then, 10 g of K_2SO_2, 0.4 g of $CuSO_2$, and 12 ml of H_2SO_4 were added to the flask. The solution in the Kjeldahl flask was digested until it turned a clear green colour. The solution was transferred into a distillation flask and cooled to room temperature. Once it reached room temperature, 100 ml of distilled water and 10 ml of 30% NaOH were slowly added through the side wall of the distillation flask, forming a layer beneath the acid solution. The distillation flask was assembled and connected to a condenser, with the condenser tip inserted into the liquid reservoir. The Erlenmeyer flask was filled with 10 mL of 0.1 M boric acid solution and a few drops of methyl red-blue indicator. The distillate is then titrated with 0.1 N HCl until a colour change to blue-purple marks the endpoint. The protein content will be calculated using the following formula:

$$protein\,content\,(\%)\ =\ \frac{(V\ HCl-V\ blank)\times N\ HCl\times Mr\ HCl}{weight\ sample\,x\,10}\times 6.25\,(dry\ base)$$

$$protein\,content\,(\%)\ =\ \frac{100-moisture\,content}{100}\ \times\ dry\,based\,protein\,content\,(wet\,base)$$

e. Carbohydrate Content Analysisd

The carbohydrate content was determined using the carbohydrate-by-difference method, based on the results of analysing the moisture, ash, protein, and fat content in each sample. The formula for calculating the carbohydrate content is:

$$carbohydratecontent\,(\%) =\ 100\% - (\%moisture + \%ash + \%fat + \%protein)$$

2.2.2 Physical and chemical analysis

The shelf-life evaluation was conducted by monitoring pH changes in samples stored at room temperature and refrigeration (6–8 °C). Samples were stored for 3 days, and measurements were taken at 24, 48, and 72 h. Briefly, a calibrated pH meter probe was immersed in 15 ml of the sample until a stable reading was obtained. Changes in this parameter over time were used to assess product stability during storage. Colour was measured using a calibrated chroma meter placed against a sealed transparent plastic bag containing the sample.

2.2.3 Sensory analysis

A total of 30 semi-trained panellists who enjoy and tolerate spicy food were selected to evaluate four samples. Prior to testing, each panellist was briefed on the sample presentation and scoring procedures. The samples were then presented in a randomised order, and participants were asked to evaluate seven sensory attributes, including colour, saltiness, spiciness, sourness, aftertaste, aroma, and texture, using a 9-point intensity scale. In addition to the sensory evaluation, panellists also performed a hedonic test to rate their overall liking of each sample using the same 9-point scale.

2.2.4 Escherichia coli and coliform contamination of Sambal Tumpang

Contamination was determined using the Compact Dry EC. As many as 1 mL of sample was diluted in 9 mL of sterile aquades, then 1 mL of the suspension was added to the compact dry and incubated at 41–43 °C for 48 h. Then the growth colonies were counted, with blue colonies indicating E. coli growth and pink colonies indicating coliforms.

2.2.5 Statistical analysis

All data were analysed using IBM SPSS Statistics 25 at a confidence level of $\alpha = 0.05$, employing one-way ANOVA with Tukey Post-Hoc Tests, except for the hedonic test, which used the Kruskal–Wallis test followed by the Mann–Whitney test with the same level of confidence.

3 Results and discussion

3.1 Observational study result

The observational study, conducted through interviews and on-site visits with a local producer, revealed the production process, equipment, and ingredients used to make Sambal Tumpang. Among the observed producers, 75% were female, and the rest were male. Ost producers operated from kitchens integrated with their selling stalls, whereas one producer transported her dishes daily to a mobile selling cart (*gerobak jualan*). An interesting cultural note is that many of these stalls are named after their owners, possibly reflecting a sense of familiarity and personal connection with their customers. Producers generally have similar production flows, but with different timing and ingredients. Beginning with ingredient preparation, then prolonged simmering on a wood- or gas-burner. Then the finished products are transferred into stainlesssteel pots.

A wide range of carbohydrate bases and toppings were readily available, allowing customers to personalise their orders. The dish was typically served on a rattan plate lined with brown, flower-shaped rice paper or on a standard ceramic plate. Customers generally selected their carbohydrate first, either rice or porridge, after which the vendor ladled Sambal Tumpang over it, along with tofu. Additional protein options were offered, either cooked within the Sambal Tumpang, such as beef tendon and beef tongue, or prepared separately, such as gizzard, boiled egg, and other items that varied between producers. A portion of blanched vegetables was added at the end to provide dietary fibre. Overall, the dish can be considered a complete meal due to its combination of diverse nutrient sources. The price varied slightly among producers, ranging from IDR 15,000 to 25,000, depending on the selected toppings.

3.2 Nutritional content of Sambal Tumpang

Sambal Tumpang is one of the many traditional sambals present in Indonesia. It has been mentioned in several historical manuscripts, particularly Serat Centhini, a Javanese literary work written by Pakubuwana V, the King of Kasunanan Surakarta, which discusses various aspects of Javanese culture [14, 15]. In this manuscript, Sambal Tumpang is referred to as "gudhang tumpang", which implies a variety of boiled vegetables topped with Sambal Tumpang or "sambal lethok", another name for Sambal Tumpang from what is now known as Boyolali [14]. Nutritionally, Sambal Tumpang can be considered an affordable source of protein, as its main ingredient is over-fermented tempeh. According to our respondent, over-fermented tempeh is used as a response to food scarcity; rather than discarding food deemed unfit for consumption, people repurpose it into something edible. This action embodies a mindset of resourcefulness and appreciation, transforming ingredients that some might consider unsuitable into something valuable and nourishing, and reflecting local food sustainability practices. However, no studies have yet examined the nutritional content of Sambal Tumpang. Therefore, we conducted a proximate analysis for four different Sambal Tumpang, as shown in Table 1.

As shown in Table 1, there are significant differences in the nutritional composition of Sambal Tumpang samples ($P < 0.05$). Despite using similar main ingredients, the nutritional value of Sambal Tumpang can vary, depending on the additional ingredients chosen by the cook, such as different parts of the beef tendon and the cooking method. Of the 4 samples, ST2 has the highest protein and fat content. The lowest fat content is observed in ST3, while the lowest protein levels are found in ST4 and ST1; however, the difference between ST4 and ST1 is not statistically significant ($P > 0.05$). In general, the results of the proximate analysis suggest that Sambal Tumpang can serve as a nutritious food source at an affordable price (approximately IDR 15,000 per serving). Its composition provides a balanced mix of macronutrients, making it accessible to a wide range of consumers. In particular, sample ST2 had relatively higher fat and protein content than the other variants, which may contribute to better satiety and reduced energy intake. The high fat content can result from the fat extracted during the tendon boiling process or the addition of external oil during cooking. At the same time, protein content can vary with different tempeh concentrations and tempeh processing methods.

Although we did not identify each component specifically, Andriani et al. [15, 27] conducted a physicochemical characterisation of over-fermented tempeh flour and found that it has a high fat and protein content. The fat is mainly composed of linoleic acid (C18:2), followed by palmitic acid (C16:0), approximately around 82% and 14%

Table 1 Proximate content of four different Sambal Tumpang

Nutritional content (%)	ST1	ST2	ST3	ST4
Water	82.86 ± 0.11^{b}	78.73 ± 0.08^{a}	85.32 ± 0.10^{c}	88.95 ± 0.24^{d}
Ash	2.45 ± 0.02^{d}	1.22 ± 0.02^{a}	1.82 ± 0.02^{b}	2.15 ± 0.01^{c}
Fat	2.38 ± 0.21^{b}	8.65 ± 0.33^{c}	1.50 ± 0.45^{a}	2.52 ± 0.11^{b}
Protein	3.86 ± 0.36^{ab}	6.60 ± 0.64^{c}	4.43 ± 0.84^{b}	3.38 ± 0.38^{a}
Carbohydrate	8.44 ± 0.21^{d}	5.79 ± 0.84^{b}	6.65 ± 0.67^{c}	3.00 ± 0.41^{a}

[a–d]differences in alphabet indicate a significant difference between samples at $p < 0.05$; *ST1* Sambal Tumpang 1; *ST2* Sambal Tumpang 2; *ST3* Sambal Tumpang 3; *ST4* Sambal Tumpang 4 respectively. In contrast, the protein content is composed of L-Lysine HCl, L-Arginine HCl, L-Leucine HCl, and L-Valine + L-Tryptophan amino acids with respective amounts of 3492, 3376, 3177, and 3014 ppm. L-Tryptophan and L-Leucine are responsible for the bitter flavour of fermented tempeh, while the others also contribute but are barely noticeable [16]. Uniquely, with similar fat and protein content, ST1 exhibits the highest carbohydrate content, whereas ST4 has the lowest, likely due to the amount of brown sugar added to give a sweet and brown colour, while also improving the sambal's texture. This is because ST1 has a sweeter taste compared to the other samples.

Besides being a source of nutrients, the ingredients in Sambal Tumpang can also offer several health benefits. Ongoing research on chilli has found that moderate consumption may have a therapeutic effect due to its active ingredient, capsaicin. Capsaicin has been shown to prevent neurological disability by activating the transient receptor potential vanilloid 1 (TRPV1), which, in turn, promotes the release of neuropeptides such as calcitonin gene-related peptide (CGRP) and substance P [17]. Additionally, chilli flavonoids have been shown to have anti-inflammatory and antioxidant properties. A study by Cho et al. [18] found that the ethanol extract of chilli leaves has more potent anti-inflammatory and antioxidant properties compared to its fruit. It is worth noting that sambal primarily uses the chilli fruit, not an extract; therefore, some bioactive compounds may not be fully extracted. However, their effect still cannot be diminished [19].

Tempeh has been recognised as a superfood due to its exceptional nutritional value and benefits [11]. Over-fermented tempeh can have an advantage over normal tempeh; however, its taste might become a drawback for daily consumption. A study by Astawan et al. [20] found that the IC_{50} for over-fermented tempeh flour is lower than that for fresh tempeh flour. This result can be attributed to changes in isoflavone content during fermentation. These results align with findings by Prativi et al. [12], who found an increase in aglycone isoflavones, including daidzein and genistein, which are responsible for the antioxidant activity during fermentation for up to 72 h. As a fermented product, tempeh also has probiotic properties. Radita et al. [21] identify several lactic acid bacteria isolated for tempeh that are *Lactobacillus fermentum*, *L. delbrueckii*, and *L. mucosae*. Although the cooking process kills probiotics, it does not diminish their beneficial role; they become killed probiotics, also known as parabiotics [22]. Besides, Teoh et al. [23] summarise other benefits of tempeh consumption, including anti-diabetic, cognitive improvement, anti-tumour, anti-cancer, antihypertensive, and antidepressant effects due to its bioactive peptides, isoflavones, and probiotic properties.

3.3 Shelf-life analysis and production safety of Sambal Tumpang

Its ingredients and processing steps mostly determine a product's shelf life. Sambal Tumpang, due to its high water content, generally has a short shelf life and is best consumed fresh. However, when stored under appropriate conditions, its shelf life can be extended. Refrigeration at temperatures below 5 °C can slow microbial growth, while freezing can further prolong its shelf life [24]. To determine the shelf life of Sambal Tumpang, we measured the pH over 3 days at both room temperature and chilled temperatures (Table 2). This parameter can serve as an indicator of food spoilage [25]. As shown by the pH value of Sambal Tumpang during storage at relatively stable chilled temperatures, compared to those at room temperature. The pH of Sambal Tumpang ranges from 6.22 to 5.14, making it an optimal condition for bacterial growth [25].

Table 2 pH and color of four different Sambal Tumpang

Parameter	ST1	ST2	ST3	ST4
pH	5.87 ± 0.15^{b4}	5.14 ± 0.02^{a45}	6.22 ± 0.13^{c4}	5.86 ± 0.03^{b4}
Room temperature				
24 h	5.05 ± 0.15^{c3}	4.59 ± 0.04^{a3}	4.67 ± 0.01^{b1}	4.64 ± 0.02^{b2}
48 h	4.52 ± 0.02^{b2}	4.44 ± 0.02^{a2}	4.64 ± 0.02^{c1}	4.46 ± 0.01^{a1}
72 h	4.35 ± 0.03^{b1}	4.17 ± 0.04^{a1}	4.62 ± 0.02^{d1}	4.44 ± 0.00^{c1}
Refrigerated (6–8 ℃)				
24 h	6.11 ± 0.02^{c7}	5.18 ± 0.00^{a5}	6.23 ± 0.02^{d4}	5.98 ± 0.00^{b5}
48 h	6.07 ± 0.03^{c6}	5.17 ± 0.02^{a5}	5.99 ± 0.01^{b3}	5.99 ± 0.01^{b5}
72 h	6.00 ± 0.02^{d5}	5.11 ± 0.02^{a4}	5.57 ± 0.03^{b2}	5.66 ± 0.02^{c3}
Color				
L	48.31 ± 1.52^{b}	44.91 ± 1.22^{b}	37.23 ± 1.24^{a}	45.27 ± 2.80^{b}
a	12.27 ± 0.30^{a}	12.11 ± 0.48^{a}	16.09 ± 1.67^{b}	12.70 ± 1.42^{a}
b	26.62 ± 3.19^{a}	27.87 ± 2.02^{a}	35.24 ± 3.73^{b}	32.19 ± 4.37^{ab}

a–d differences in alphabet indicates significant difference between sample

1–7 differences in number indicates significant difference between storage condition

During storage at room temperature, the pH decreases over time, with the most significant drop observed after 72 h. Among the samples, ST2 exhibited the lowest pH after 72 h at 4.17, followed by ST4, ST1, and ST3 at 4.44, 4.35, and 4.62, respectively. In contrast, samples stored in a refrigerator at 6–8 °C exhibited more stable pH values throughout the storage period, even displaying a slight increase in pH during the 24- to 72-h storage time. Samples stored at room temperature can harbour spoilage bacteria that break down sugars and proteins into acids, producing hydrogen ions and lowering the pH [26, 27]. Respondents in our study reported that Sambal Tumpang stored in the freezer can last between 7 and 10 days. Similarly, other traditional sambals, such as sambal terasi and sambal matah, have been reported to last 4–5 days and 1–2 days, respectively, under refrigeration [1]. There was no significant difference in colour among samples ST1, ST2, and ST4. However, sample ST3 showed the most distinct colour variation among the others.

This shelf life is relatively short compared to commercial chilli sauces, which benefit from added preservatives [28] or sterilisation [29] processes to achieve longer shelf life. On the other hand, innovations in packaging and processing can significantly extend shelf life. For example, Bungi et al. [30] found that sambal Payangka fish (*Ophiocara porocephala*) can last up to 48 days when packaged in glass jars at room temperature. On the other hand, sambal bete-bete fish (*Leiognathus equulus*) has a shelf life of only 18–19 days at room temperature when stored in a plastic jar. Airtight containers or glass bottles are ideal as they help prevent contamination and minimise quality degradation.

Beyond packaging, innovations in processing, such as drying and rehydration, offer potential for long-term preservation. A study by Septhianty et al. [5] demonstrated that Sambal Tumpang subjected to cabinet drying techniques could achieve a shelf life of up to 28 days, possibly longer, due to its low water content of 4–5%, significantly expanding its usability and commercial potential. Additionally, we conducted a screening for pathogenic bacteria on the sample prior to storage. We choose to monitor *E. coli* and coliforms in the samples because their presence indicates fecal bacterial contamination, and E. coli further suggests contamination during processing steps [31].

Based on Table 3, all four Sambal Tumpang samples showed bacterial contamination, particularly from *E. coli* and coliforms. Among them, the highest level of contamination

Table 3 The growth of *Escherichia coli* and coliform in Sambal Tumpang

Patogen (CFU/ml)	ST1	ST2	ST3	ST4
Escherichia coli	$<1\times10^2$	$<1\times10^2$	$<1\times10^2$	–
Coliform	3.9×10^3	1.6×10^3	2.3×10^3	$<1\times10^2$

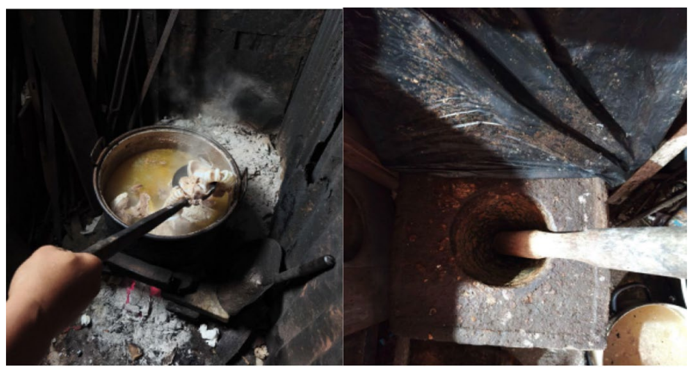
was observed in ST1, with coliform counts exceeding 10^3 CFU/ml and *E. coli* counts exceeding 10^2 CFU/ml. ST4 had the lowest coliform count and showed no detectable *presence of E. coli*. Product contamination can occur during ingredient sourcing or processing. Many Sambal Tumpang are home-scaled production or categorised as Micro, Small, and Medium Enterprises (MSMEs). However, food production by MSMEs often lacks proper hygiene practices, making products more susceptible to contamination and posing a significant risk of foodborne disease. To obtain a Household Industry Food Production Certificate (SPP-IRT), MSME food producers must comply with the Good Manufacturing Practices for Household Industry (CPPB-IRT) [32]. This regulation encompasses requirements across several categories, including location, building, equipment, hygiene, and maintenance, which are graded into four levels: shall, should, may, and can, depending on their significance [33].

Ensuring food safety is particularly critical for sambal production. Although there is currently no specific national food safety regulation for Sambal Tumpang, its primary ingredient, over-fermented tempeh, is covered under Indonesian food safety regulation Document No. 13 Year 2019, which outlines maximum microbial contamination levels in processed foods [34]. According to this regulation, fermented soybean products (code 06.8.6) are permitted a maximum of 3 MPN/g for coliforms. While no specific threshold for E. coli is stated, its presence remains hazardous to human health and may cause illnesses such as diarrhea [35]. A similar result was also found in a study by Hassan et al. [36], which found that several other sambals contained pathogenic bacteria, such as Bacillus cereus and coliforms, suggesting unsanitary processing. Therefore, it is essential to maintain both personal and equipment hygiene. This can be achieved by washing hands before handling food, using protective covers when touching ingredients, and regularly cleaning equipment after use to avoid possible pathogen contamination that cause foodborne diseases. Additionally, it is essential to verify the quality of raw ingredients. Fermented tempeh made from soybeans must ensure the absence of contaminants capable of producing aflatoxin, such as Aspergillus flavus and A. parasiticus [37], and must undergo a controlled, clean fermentation process. Similarly, chilli is also susceptible to fungal contamination, which can produce aflatoxin [38].

Currently, most Sambal Tumpang production is home-based and relatively simple, though time-consuming. Tempeh is produced from soybeans inoculated with Rhizopus oryzae and Rhizopus oligosporus as fermentation starters, then wrapped in banana leaves. The fungus added will form a dense white mycelium that binds the soybeans together into a compact cake within approximately 2–3 days. These fungi also help in breaking down complex proteins, fats, and carbohydrates in soybeans into simpler, more digestible forms. The fermentation also reduces anti-nutritional factors, such as phytic acid, and enhances the bioavailability of nutrients [21, 39, 40]. To create tempe semangit, this process is extended, resulting in a product with a brownish-yellow colour, pungent aroma, and reduced white mycelium (Fig. 5A) [40]. Although often considered inferior by general market standards, this ingredient is crucial to achieving the unique flavour profile of Sambal Tumpang. Due to its limited availability in commercial markets, many

(A) (B) (C)

Fig. 5 The main ingredients in making Sambal Tumpang **A** Over fermented tempeh **B** Koyor **C** Fried Tofu



(A) (B)

Fig. 6 The traditional process of making Sambal Tumpang involves cooking the koyor under a wood fire to tenderise it for five to six hours at a boiling temperature **A** and the traditional mortar and pestle to crush ingredients **B** After that, the water for cooking is discarded. The pre-cooked, crushed spices and over-fermented tempeh. After that, all the crushed ingredients and coconut milk are added to the stockpot, along with the tenderised koyor, for further cooking, which takes about 1–2 h

warung owners ferment regular tempeh longer on their own to produce tempe semangit as needed. Other than over-fermented tempeh, koyor, and fried tofu are also often added to Sambal Tumpang as affordable protein sources. Koyor refers to the cow's vein or muscle that is attached to the meat in the knee or backbone (Fig. 5B) [41]. Koyor was chosen because it is cheaper than beef. Koyor needs to be prepared and cleaned first before being added to the dish. Tofu is made by curdling soy milk with acids, salts, or enzymes. The curd is then pressed and cut [42]. The tofu is then fried (Fig. 5C) and added to Sambal Tumpang, where it is further cooked. The frying process will develop a crust in the outer part of the tofu, which can hold its shape when further cooked in the coconut milk-spice mixture [43] .

The step-by-step process of making Sambal Tumpang is illustrated in Fig. 6. The preparation begins with cleaning and boiling koyor (cow tendon), which is thoroughly washed and cooked for approximately 6 h to tenderise the connective tissues. During this prolonged cooking process, a significant amount of fat is released. The water used for boiling is typically discarded, as incorporating it into the sambal would result in an excessively oily mouthfeel known locally as "*ngendal*" in Javanese culinary terms. Following this, the over-fermented tempeh and kitchen spices are crushed using a traditional mortar and pestle, known as "*lumpang*" in Javanese. The spices are prepared, and the spice blend used in Sambal Tumpang, often referred to as bumbu pawon, typically includes garlic, shallots, aromatic ginger, candlenuts, bay leaves, lime leaves, lemongrass, red chilli, and bird's eye chilli [44]. The crushed tempeh and spices are then sautéed together for a short time until the mixture becomes fragrant. At this stage, additional aromatics such as bay leaves and lemongrass can be added. Once the base mixture is prepared, it is transferred to a large stockpot and combined with pre-boiled koya, fried tofu, and coconut milk. The entire mixture is then simmered over a wood fire for several hours. The use of wood fire not only reflects traditional cooking practices but also contributes to the development of a richer, smokier flavour profile [45] but some producer also use modern gas burner. Interestingly, the cooking duration varies among cooks, often depending on inherited techniques or individual preferences. Some prefer to cook Sambal Tumpang continuously for up to 6 h, while others opt for a shorter cooking time of about 2 h, then allow the dish to rest overnight before serving. This resting period allows the flavours to absorb into the ingredient, contributing to a more complex and layered taste. As a result, Sambal Tumpang exhibits subtle variations in flavour, texture, and aroma depending on the cooking method used. These differences influence consumer preferences, with some favouring the deeper, caramelised notes of long-simmered sambal, while others prefer the lighter, fresher taste of shorter preparations.

3.4 Sensory acceptance of Sambal Tumpang

Sambal Tumpang is commonly sold at small local food stalls, known as "*warung*" in Indonesian, which typically operate either in the morning (7:00 AM—11:00 AM) for breakfast or in the evening (5:00 PM—10:00 PM) for dinner. It is commonly served with rice, porridge, or boiled vegetables (Fig. 7a–c). Numerous *warung* owners have been selling Sambal Tumpang for decades, often from stalls attached to their homes or small rented spaces, and have maintained personal relationships with their regular customers. For many, this small business serves as their primary source of income. One respondent shared that selling Sambal Tumpang is not only a means of earning a living but also an essential part of her daily routine, especially since her children have moved out of the house.

This dish has been passed down through generations, primarily through Javanese women. However, this cultural practice is not exclusive to women. One of our respondents shared that their Sambal Tumpang recipe has been in the family for nearly 80 years and was even recognised with an honorary plaque from the Mayor of Salatiga, designating them as a "Culinary Legend". Traditionally, Javanese society, shaped by patriarchal norms, emphasises three primary roles for women, often summarised as *masak*

(A) **(B)** **(C)**

Fig. 7 **A**, **B** Sambal Tumpang eaten with rice, **C** Sambal Tumpang eaten with porridge, both are added with boiled vegetables, including white cabbage, spinach, bean sprouts, spiced shredded coconut, or soybean powder (cooking), *macak* (beautifying oneself), and *manak* (bearing children) [46]. Despite this, our fieldwork reveals that cooking is no longer viewed solely as a woman's responsibility. For example, one respondent explained that her husband is the primary cook for their Sambal Tumpang business, while she focuses on serving customers. This shift represents a broader cultural trend in which domestic and economic roles are being increasingly shared between men and women.

Recognising that Sambal Tumpang is a vital component of Salatiga's culinary culture, a hedonic test was conducted to assess its acceptance among consumers outside the region. Thirty semi-trained panellists, university students in Semarang who regularly consume spicy food, participated in the test. Before the evaluation, the panellists were introduced to the product, its ingredients, and the hedonic scaling procedure. The results provide a basis for further consideration in promoting Sambal Tumpang as an Indonesian delicacy to a broader consumer market.

As shown in Table 4 and Fig. 8, the flavour profiles of Sambal Tumpang differ among the samples. ST2 recorded the highest intensity across all flavour attributes, including saltiness, spiciness, and sourness, compared to the other three samples. While the differences in saltiness and sourness among the remaining samples were not statistically significant ($P > 0.05$), the spiciness level showed a significant difference ($P < 0.05$), with ST1 scoring the lowest and based on the comment, it is mostly sweet, which aligns with the proximate analysis that has high carbohydrate content. Similarly, no significant differences in aftertaste or aroma were observed across the samples. In terms of texture, ST3 had the lowest score, indicating a thinner consistency compared to the other samples, which were thicker but not significantly different from one another. Based on consumer acceptance, ST2, ST3, and ST4 were generally more preferred, while ST1 received the lowest acceptance score.

Besides being sold in food stalls, Sambal Tumpang is also served during traditional ceremonies. Indonesia is home to a rich variety of traditional ceremonies, including those performed before weddings. During this ceremony, various items and steps must be prepared and performed. These include water from seven sources, seven types of flowers, coconut shells, and other symbolic elements [47]. Additionally, food is served as part of the tradition; Sambal Tumpang is one of the many dishes served during this ceremony. This dish becomes a culinary symbol that represents the hope that God's blessings will be bestowed upon the bride and groom. The term "tumpang" is derived from the Javanese word "tertumpang" and signifies "to be on top". Sambal Tumpang serves as

Table 4 Sensory analysis of four different Sambal Tumpang

Parameter	ST1	ST2	ST3	ST4
Color	5.83^{b}	4.37^{a}	4.80^{a}	7.03^{c}
Taste				
Spicy	1.83^{a}	4.43^{d}	3.60^{c}	2.63^{b}
Salty	3.6^{a}	5.37^{b}	3.97^{a}	3.90^{a}
Sour	2.50^{a}	3.67^{b}	2.97^{ab}	3.07^{ab}
Aftertaste	4.60	4.17	4.73	4.67
Aroma	4.70	4.83	4.40	4.97
Texture	4.47^{b}	5.23^{b}	3.27^{a}	4.67^{b}
Acceptance	4.03^{a}	5.97^{b}	5.43^{b}	6.07^{b}

$^{a\text{-}d}$differences in alphabet indicates significant difference between samples

1: extremely dislike 9: extremely like (color, taste, aroma, acceptance)

1: extremely thick 9: extremely thin(texture)

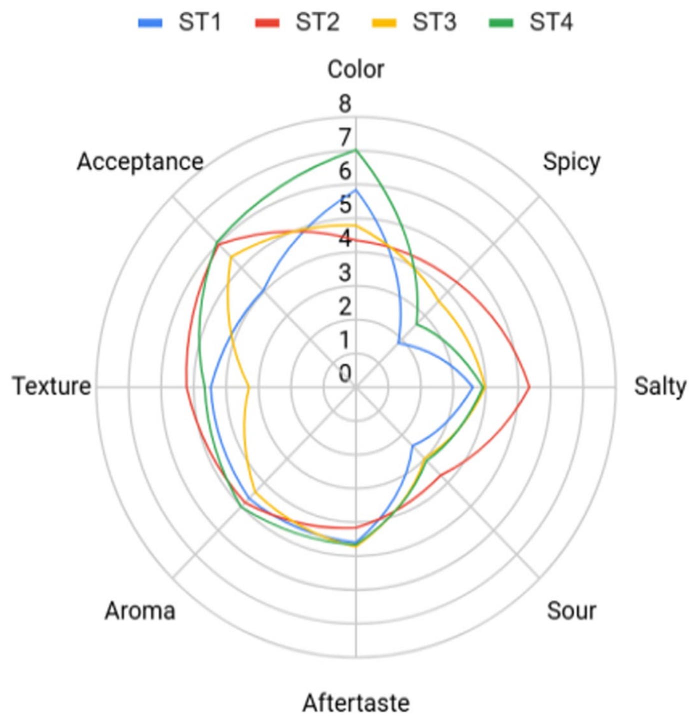


Fig. 8 Spider web chart for sensory analysis of four different Sambal Tumpang

a metaphor for the aspiration that the bride and groom's future will be characterised by success and prosperity [10]. Since then, Sambal Tumpang has become a staple for locals and a must-try dish for tourists visiting Salatiga.

3.5 Challenges and future prospects of Sambal Tumpang in the food industry

One of the primary challenges in producing Sambal Tumpang is its lengthy and labour-intensive cooking process. While adopting modern technologies, such as pressure cooking, can significantly speed up preparation, they may encounter resistance from traditionalists who prefer established cooking methods to maintain authenticity and flavour [48]. Hygiene and safety are also crucial concerns in Sambal Tumpang production. As the dish involves fermented ingredients and perishable components, maintaining sanitary standards is essential to ensure product quality and shelf life. Producers must comply with the Good Manufacturing Practices for Household Industry as stipulated by Indonesia's Food and Drug Agency (BPOM) [34]. These regulations are key to preventing microbial contamination and ensuring consumer safety. Another major obstacle is consumer acceptance. The dish's strong and pungent aroma of over-fermented tempeh [12] may not appeal to a broader audience. Consumers who are not accustomed to fermented foods may find the taste and smell overwhelming [49], making it difficult for Sambal Tumpang to gain traction in mainstream markets. Creating a long shelf-life product is also essential to promote Sambal Tumpang worldwide. Moreover, the high water content in Sambal Tumpang requires a cold-chain distribution, which can be expensive and necessitates refrigeration for further storage, resulting in high capital costs [50]. Overall, the challenges of Sambal Tumpang commercialisation revolve around mass production, product formulation for broader acceptance, and shelf-life stability. Addressing these barriers requires a balanced approach that integrates modern cooking technologies while retaining traditional flavours. One strategy involves modifying the recipe to include a mix of regular and over-fermented tempeh, which helps temper its pungency. Additionally, enhancing shelf life through advanced processing methods and safer packaging, such as converting Sambal Tumpang into a powder [9] or using hot-fill techniques [51].

The increasing global appreciation for traditional and authentic foods presents a promising future for Sambal Tumpang. Consumers are becoming more interested in heritage foods that offer unique flavours and cultural significance [52]. The rise of Indonesian cuisine on the global stage, with dishes such as rendang, nasi goreng, and satay gaining international recognition [53], creates an opportunity for lesser-known yet equally flavorful dishes like Sambal Tumpang to emerge. With the right marketing strategies, including branding as a unique Indonesian delicacy, Sambal Tumpang can appeal to both local and international markets. This product can serve as a means of gastrodiplomacy. Today, gastronomy extends beyond food and beverages, serving as a medium that connects history, culture, and societal life, making it a key attraction in international tourism. In recent years, a new concept known as gastrodiplomacy has emerged, blending culinary traditions with diplomatic efforts. This approach offers a subtle yet effective means of fostering diplomatic relations [54].

Zhang [55] reported that diplomacy is no longer confined to heads of state and politicians; instead, culinary products with socio-cultural significance now play a role in international relations. Gastrodiplomacy goes beyond merely promoting a nation's cuisine abroad; it seeks to win hearts and minds through the universal appeal of food. Additionally, the growing interest in plant-based diets contributes to its potential success. Made primarily from tempeh, a high-protein soybean product, Sambal Tumpang aligns with the preferences of vegetarians, vegans, and health-conscious consumers seeking sustainable, nutritious food options [56]. Its unique fermentation process could also be leveraged as a selling point, similar to how products like kimchi, miso, and kombucha have gained widespread popularity as a functional food [57–59]. Promoting Sambal Tumpang as a functional food requires further research on its bioactive components and the evidence-based claims for its health benefits.

It is also pertinent to consider artisanal food products. According to the definition provided by the School of Artisan Food in Ligham et al. [60], a food product may be regarded as artisan when it is produced using traditional, non-industrial methods that are often transmitted across generations but are increasingly at risk of disappearing. Such products are characterised by the producer's expertise and deep respect for raw materials, combining historical, experiential, intuitive, and scientific knowledge, while simultaneously acknowledging the broader social and environmental implications of the production process. Moreover, artisan producers demonstrate an ongoing commitment to learning, refinement, and the continual advancement of their craft.

As artisanal food products, they can compete with large-scale products by positioning themselves in niche markets and offering unique qualities, authenticity, and craftsmanship that mass-produced goods often lack [61]. The process of crafting artisan Sambal Tumpang begins with the careful selection of premium ingredients, such as high-quality coconut milk and properly aged fermented tempeh. These ingredients are then slow-cooked to develop a deep, complex flavour profile before being packaged in sterilised glass jars to preserve freshness and extend shelf life. However, to remain competitive in a market saturated with commercial hot sauces, Sambal Tumpang must strike a balance between maintaining traditional authenticity and appealing to a broader consumer base.

Sambal Tumpang, as a condiment, offers a wide potential for culinary fusion. As noted by Spence [62], modern diners and consumers are seeking novelty in their dishes, which can be done by combining distinct flavours to create more complex and exciting taste experiences. One intriguing fusion concept is the use of Sambal Tumpang as a stew or dipping sauce for the Nigerian staple dish, fufu, which is traditionally paired with meat, fish, or vegetable stews [63]. Additionally, Sambal Tumpang could be thickened to resemble a gravy, broadening its applications in various international cuisines. With continued research and innovation in its formulation and processing, Sambal Tumpang has the potential to reach a wider global audience and gain recognition as a valuable component of Indonesia's rich culinary heritage.

4 Conclusion

Sambal Tumpang exemplifies Indonesia's rich culinary heritage, its strong ties to local ingredients, and its commitment to sustainability and tradition. Originating in rural Java, this ethnic sambal has endured across generations, remaining relevant in both traditional households and modern culinary settings, thereby reflecting the ingenuity and adaptability of Javanese cuisine. As Indonesian food culture continues to evolve, Sambal Tumpang underscores the importance of safeguarding and promoting indigenous culinary practices, ensuring that the cultural wisdom they embody is transmitted to future generations. Beyond its cultural significance, Sambal Tumpang also offers significant nutritional value, providing protein, beneficial fats, and probiotics that support overall health. Incorporating this dish into a balanced diet allows individuals to enjoy its distinctive flavour while also gaining its associated health benefits. Nevertheless, adherence to proper hygienic practices and production standards is essential to guarantee both safety and quality. With appropriate handling and continued innovation, Sambal Tumpang has the potential to achieve broader recognition and contribute to the global appreciation of Indonesia's diverse and flavorful culinary heritage.

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Author contributions

DW, AB, RHBS designed the research. SR, JASH, and HZW collected the data and did the Laboratory work. DW, SR analysed the data. DW, SR, RHBS wrote the manuscript and supervised the process.

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Data availability

All data and materials are presented in the manuscript.

Declarations

Ethics approval and consent to participate

The organoleptic analysis was conducted using a panel of 30 consumer participants. Two organoleptic analyses were conducted simultaneously by the panellists: a hedonic test analysis and a descriptive analysis. The studies involving human participants were reviewed and approved by the Research Ethics Approval Commission. Soegijapranata Catholic University has determined that the study above complies with the ethical standards in the discipline, as evidenced by ethical clearance No. 0033/B.7.2/UN.KKEP/7/2025. The participants provided their written informed consent to participate in this study. The study was conducted in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki and its subsequent amendments.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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