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Reformulation of soy sauce to reduce sodium content and assessment of manufacturer readiness, consumer acceptance, and shelf life

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Soy sauce is a major source of dietary sodium in Malaysia. Reformulating soy sauce to reduce its sodium content may help lower population salt intake. This study aimed to (1) assess sodium content of Malaysian soy sauces; (2) evaluate manufacturer readiness for reformulation; (3) develop reduced sodium soy sauce formulations; and (4) determine consumer acceptability and shelf life stability. A mixed-methods study was conducted in two phases: (1) needs assessment through sodium analysis of 102 soy sauces from supermarkets and interviews with 19 employees; and (2) development of reduced sodium soy sauce formulations, followed by consumer sensory testing (n = 52) and accelerated shelf life assessment. Salty (4987 ± 1429 mg/100 g) and light soy sauces (5710 ± 1488 mg/100 g) contained significantly higher sodium than sweet soy sauces (3368 ± 863 mg/100 g; $p < 0.05$). Manufacturers acknowledged the importance of salt reduction but cited barriers including consumer acceptance, regulatory requirements, costs, and limited research and development capacity. Among the reformulated products, soy sauce with 9% salt plus yeast extract (≈3600 mg sodium/100 g) was most preferred and remained shelf-stable for one year. Reformulation of soy sauce with lower sodium content is feasible without compromising safety or palatability. Wider adoption by manufacturers, supported by incentives and regulatory adjustments, could reduce population salt intake in Malaysia.

Keywords Soy sauce, Sodium reduction, Reformulation, Manufacturer readiness, Consumer acceptance, Shelf life

List of abbreviations

ASL	Accelerated shelf life
CVD	Cardiovascular disease
EC	E. coli
FSA	Food standard Agency
FGD	Focus group discussion
HCL	Healthier choice logo

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ICPOES	Inductively coupled plasma optical emission spectrometry
IDI	In-depth interview
KCl	Potassium chloride
MARDI	Malaysian Agriculture Research and Development Institute
$MgCl_2$	Magnesium chloride
$MnCl_2$	Manganese chloride
MSG	Monosodium glutamate
NaCl	Sodium chloride
NCD	Non-communicable disease
SD	Standard deviation
TC	Total coliform
Tn	Total nitrogen
TPC	Total plate count
WHO	World Health Organization
YE	Yeast extract
YM	Yeast and mold

Background

Cardiovascular disease (CVD) is the main cause of non-communicable disease (NCD) mortality, with an estimated 19 million deaths in 2021[1]. In Asia alone, CVD accounted for 35% of all deaths (10.8 million in 2019)[2]. Hypertension is the major risk factor for CVD, and is common amongst the Southeast Asia population. In Malaysia, one third of adults have hypertension[3]. Excessive salt intake has a direct causal link to hypertension; thus, the World Health Organization (WHO) recommends a maximum salt intake of 5 g/day (2000 mg sodium)[4]. However, salt intake in Asian countries is amongst the highest in the world, double the WHO's maximum recommended intake[5,6]. It is estimated that Malaysians consume an excessive quantity of salt, with an average intake of 7.3 g/day salt as reported in the National Health and Morbidity Survey (NHMS) 2024, based on 24-h urinary sodium excretion[3].

Cooked foods or main meals are two of the saltiest food categories due to the use of salty sauces in their preparation[7]. Specifically, soy sauce (salty, sweet, light and dark varieties), used in cooking or as a condiment is one of the top contributors to salt intake in the region[8]. A market survey conducted by Shahar et al.[9] found four main types of soy sauce being sold in Malaysian supermarkets: salty soy (mean sodium 4780 ± 988 mg/100 g), sweet (mean sodium 3696 ± 2000 mg/100 g), dark (mean sodium 3680 ± 2180 mg/100 g) and light (mean sodium 5116 ± 2084 mg/100 g). Soy sauces available in the market could potentially be reformulated with less sodium, given the variability in their sodium content.

The quality of soy sauce is strongly influenced by raw materials, fermentation conditions, and processing techniques. Variations in temperature, microbial activity, and salt concentration during fermentation can significantly affect amino acid composition, aroma profile, and overall product quality[10,11]. In addition, changes in salt concentration alter microbial dynamics during fermentation, influencing both flavor development and product stability[12].

Generally, in Malaysia, soy sauce is regulated under the Malaysia Food Regulation 1985 and production of soy sauce is following the requirement by the Malaysian Standard. Soy sauce is a clear, salty, dark brown liquid that is prepared from the fermentation of soybean (Glycine max) and cereal or flour; and shall contain not less than 0.6% of (w/v) of total nitrogen (Tn) and not less than 7% of salt. Soy sauce also may contain permitted preservatives and flavour enhancers as well as caramel as a coloring substance. Other requirement that has also been outlined by Malaysia Standard including the halophilic yeast count that should not exceed 100 count/ml[13–15].

There are two main types of soy sauce production: traditional fermentation and acid hydrolysis. The traditional fermentation uses microorganisms as a starter culture to produce enzymes that breaks the protein, lipid and starch into peptides, free amino acids, volatiles, and saccharide[10]. While for acid hydrolysis, high concentration of acid is used to initiate the breakdown of the polymer and this process might produce a harmful compound called 3-Monochloropropane-1,2-diol (3-MCPD). In China, since 2018, acid hydrolysis is no longer an accepted method to produce soy sauce. The high sodium content in the soy sauce is contributed particularly during moromi fermentation using 18–22% of brine solution which favors the specific growth of halotolerant microorganisms and prevents further growth of the koji molds[10].

Numerous studies have explored strategies for salt reduction in soy sauce processing. Approaches include partial replacement of sodium chloride (NaCl) with potassium chloride (KCl), magnesium chloride ($MgCl_2$) or manganese chloride ($MnCl_2$); incorporation of yeast extract (YE) or amino acids to enhance saltiness perception; and physical methods such as nanofiltration, reverse osmosis, and fermentation modifications. However, these physical techniques often increase operating cost. Salt reduction to 4.6–5% NaCl has also been achieved using combined treatments, including high-temperature fermentation (40.7 °C) and sonication. Among chloride salt substitutes, KCl has shown some effectiveness but imparts a bitter taste at concentrations above 10%, while $MgCl_2$ and manganese chloride $MnCl_2$ do not adequately compensate for reduced saltiness[11]. Another approach involves the addition of herbs, spices, and chili to soy sauce, as seen in commercially available chili soy sauces in Malaysia[16]. Such products are typically consumed as dipping sauces, with chili serving not only to enhance flavor but also acting as a natural preservative due to its capsaicin content[17]. Thus, the use of herbs and spices in soy sauce production may provide both sensory and preservative benefits.

Salt reduction is one of the "best buy" strategies for reducing NCD. Food reformulation, the process of gradually removing excess salt, sugar and fat from processed food and drink products to make them healthier,

is recommended by the WHO as a strategy to reduce population salt intake[18]. Malaysia's salt reduction strategy also outlines voluntary reformulation as a key strategy to reduce population salt intake[19]. As part of the implementation of this strategy, the Ministry of Health has proposed a set of maximum sodium targets for 15 food categories to encourage food manufactures to reduce sodium levels in their products, including a target for sweet, salty and dark soy sauce of ≤ 4400 mg sodium/100 g and light soy sauce of ≤ 6700 mg sodium/100 g[20,21].

Our previous study found that food manufacturers in Malaysia have a positive attitude towards reformulation of foods to reduce the sodium content[22]. To our knowledge, there are only a few lower-sodium soy sauce products on the market, for example, Kikkoman (43% less salt; 9.1 g/100 ml) =[23], Hamadaya (25% less salt; 5.7 g/100 ml) =[24]. This shows that, there has been little work to reduce the salt content of the main brand, which would be more successful than creating a special low-salt product for health-conscious consumers. Nevertheless, as yet little has been done to systematically reformulate soy sauce based on need assessment for reformulation of soy sauce with less sodium, development and assessment of consumer acceptance and shelf life stable. Thus, this study aimed to assess feasibility and acceptability of commercial soy sauce manufacturers reformulating their soy sauces, with the following objectives: (1) assess the sodium content of Malaysian soy sauces, (2) assess food manufacturers' knowledge, attitudes and practices regarding reformulation of soy sauce as a need assessment for reformulation of soy sauce with less sodium; (3) develop a series of reduced-sodium soy sauces using base ingredients provided by commercial soy sauce manufacturers; and (4) assess consumer acceptance and shelf life stability of the reduced-sodium soy sauces. This study is part of a larger scale study to develop strategies for salt reduction among out of home sector in Malaysia[25]. This article is among the first to provide a comprehensive assessment of sodium reduction in soy sauce within the Malaysian context. The novelty of this study lies in three areas: (1) it combines a market survey with qualitative insights from manufacturers to assess readiness for reformulation; (2) it develops reduced sodium soy sauce formulations in collaboration with industry partners and evaluates consumer sensory acceptance and shelf life stability; and (3) it provides empirical evidence that the reformulated soy sauce is both consumer preferred and shelf life stable for one year. Together, these findings strengthen the case for sodium reduction in condiments and provide practical recommendations for both policy and industry adoption.

Methods

A mixed method study design was used, which comprised of two phases. The first phase was a need assessment for reformulation of soy sauce with less sodium, the second phase involved producing reduced-sodium soy sauces.

Phase I: Need assessment for reformulation of soy sauce with less sodium

Food sampling and sodium analysis

Our previous study reported on the sodium content of Malaysia-manufactured soy sauces based on the information reported on the nutrition label[9]. Samples were collected between June and August 2021 from major supermarkets in Kuala Lumpur, including Giant Hypermarket, Lotus's Malaysia, Mydin, AEON BiG, and Jaya Grocer. Each sample was obtained from two randomly selected supermarkets. However, since sodium labeling was not mandatory in Malaysia during the data collection period, many products did not report their sodium content on the packaging. To obtain a comprehensive understanding of the sodium content in locally manufactured soy sauces, samples without sodium labeling were collected and analyzed for their sodium content. Following the implementation of mandatory sodium labeling in January 2024, data collection resumed in February 2024 to expand the sample size and update the sodium content data.

Qualitative study: In-depth interview (IDI) and focus group discussion (FGD)

Based on the companies identified through the product sampling, Malaysia-based soy sauce manufactures were invited for an in-depth interview (IDI) or focus group discussion (FGD). Four IDI and four FGD sessions, either online of face-to-face were conducted between November 2021 and April 2022 to understand their readiness (i.e. perception, barriers and motivation) for reducing sodium in their soy sauces. The interview sessions were conducted based on the number of representatives from each of the manufacturer; one representative was interviewed via IDI while more than one representative was interviewed in group by FGD. A trained interviewer from the research team carried out the interview sessions with the assistance of a rapporteur for about 60–90 min using a semi-structured interview questionnaire, modified from a previous study[25]. The interview session was recorded with the participants' consent and translated verbatim. Thematic analysis of the transcripts was conducted using Nvivo software (version 12; QSR International, Doncaster, Victoria, Australia).

Phase II: Reformulation of soy sauce

In this study, eight soy sauce manufacturers were invited to provide their moromi samples to be used as the base for the reduced-sodium soy sauces. Five soy sauce manufacturers (labelled as Manufacturer A – E) agreed to take part in the study and their moromis were analysed for sodium and Tn content to identify the most suitable moromi for reformulation. The monosodium glutamate (MSG) content in the moromi also was determined at baseline. The selected moromi was then used as the base in the formulation of the soy sauce. The nutrient content of newly reformulated soy sauce was also determined. Sensory analysis and accelerated shelf life study of the newly reformulated soy sauce also were investigated.

Determination of sodium, salt, total nitrogen (Tn), monosodium glutamate (MSG) of the moromi sample

Sodium and Tn content were determined using a standard technique according to QWI-OF17-041 and analysed using inductively coupled plasma optical emission spectrometry (ICPOES) (ICPOES 5100; Agilent

Technologies, Malaysia) method. An average 1.5 g samples were digested using 30 mL nitric acid 3% into hot block for 1 h and 30 min. Sample was markup with distilled water and filtered before introduced to instrument ICPOES. Salt content was calculated based on the sodium value by multiplying the sodium value by 2.5. Gas chromatography-tandem mass spectrometry (GC–MS/MS) (GC7890, MS > > 7000D; Agilent Technologies, Malaysia) was used to analyse the MSG content based on AOAC 994.12 method. About 10 g liquid sample was weighted into 100 mL extraction bottle. Approximately 60 mL of hot water was added, and the solution was transferred to 100 mL volumetric flask. The sample solution was filtered through filter paper and syringe filter. About 100 uL of the solution was pipetted and proceeded with derivatisation using Bis(trimethylsilyl) trifluoroacetamide (BSTFA) with 1% Trimethylchlorosilane (TMCS). The sample was injected into GC–MS/MS. Sugar profiling was determined using ion chromatography system (ICS-5000; Thermo Scientific Dionex, USA) with electrochemical detector according to QWI-OF17-129 method. Samples were diluted, filtered and injected into carbohydrate column under alkaline conditions. The method allows accurate separation and quantification of mono- and disaccharides in food matrices.

Production of soy sauce

A standard method from the Biotechnology Laboratory at the Malaysian Agriculture Research and Development Institute (MARDI) was used to produce the reformulated soy sauces. Soy sauce production comprises four major steps: (a) preparation of soy sauce starter culture; (b) koji fermentation; (c) moromi fermentation; and (d) preparation of the final mixture of soy sauce (Fig. 1). Moromi provided by manufacturer A was chosen in this study to be reformulated as it contained high sodium content and Tn value. Eight reformulated soy sauces were prepared. These new formulations were prepared with about 50–80% less sodium compared to the original baseline formulation (23% of salt content). In addition, flavouring agents including caramel and sugar (7–16%), MSG (0.05%), YE (0.05%) and citric acid (0.20%) were added, mixed well with the moromi, and moderate heat

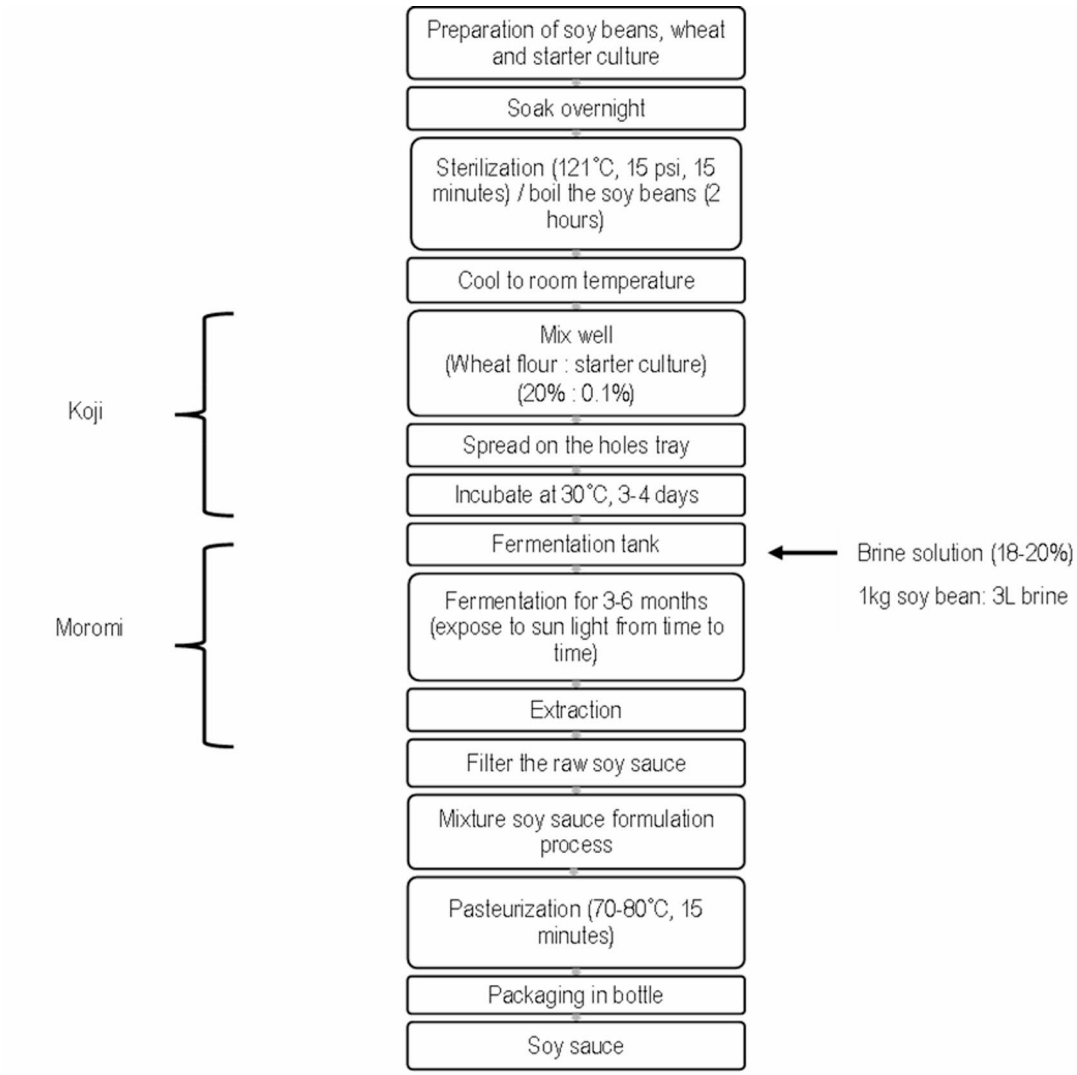

Fig. 1. Flow chart of soy sauce processing.

applied to the mixture. The mixture was pasteurized at 70–80 °C for 15 min with moderate heat to avoid burnt smell. Finally, potassium was added as a preservative during the last 10 min.

Sensory analysis of newly reformulated soy sauce

Sensory analysis was conducted on the eight reformulated soy sauces by 52 untrained panellists. A convenient sampling technique was adopted to gather all the panellists at the Faculty of Health Sciences, Universiti Kebangsaan Malaysia between 27th February and 3rd March 2023. Inclusion criteria of the panellists included being aged ≥ 18 years, not pregnant, non-smokers, consuming soy sauce at least once a week, having no soy bean or wheat allergy. The study was conducted in accordance with the Declaration of Helsinki and approved by the Universiti Kebangsaan Malaysia Research and Ethics Committee (UKM JEP-2022-062). Written informed consent was obtained from all the panellists. Each panellist was given a 5–10 ml sample of each reformulated soy sauce to consume with plain rice, and were asked to rinse their mouth with drinking water between samples. The panellists tasted all nine samples, scoring them using a 9-points hedonic scale sensory evaluation form (9 points = extremely like; 1 point = extremely dislike) based on seven attributes: colour, odour, viscosity, saltines, taste, aftertaste, and overall acceptance. Sociodemographic information was also obtained from the panellists. A commercial soy sauce from Manufacturer A was used as the control in this study.

Shelf life assessment of newly reformulated soy sauce

Approximately 300 ml of each pasteurized soy sauce was poured into sterilized ambient bottles. The accelerated shelf life (ASL) assessment of the reformulated soy sauce was carried out using a climate chamber (Binder GmBH, Germany). The temperature and relative humidity of the chamber were set to 40 °C and 75% respectively. The microbial counts i.e. total coliform (TC), *E. coli* (EC), total plate count (TPC) as well as yeast and mold (YM) were determined at 0-day, 7-days, 22-days and 90-days of the assessment which represented baseline, one month, three months and one year of shelf life following standard method by MARDI.

Statistical analysis

Data were analysed statistically using IBM SPSS Statistic 31 software (SPSS Inc. Chicago, USA) and were presented as mean ± standard deviation (SD). The data tested for its distribution using normality test revealed that all the data were not normally distributed. Hence, nonparametric test was used to analyse the data. The comparison of the sodium, salt, Tn and MSG content of the moromi samples as well as the sensory analysis of the reformulated soy sauce were analysed using the Kruskal Wallis test with significant value of $p < 0.05$.

Results

Market survey

The total sample size of the collected soy sauce was 102. The results of the sodium and salt content analysis are presented in Table 1. Salty soy sauce and light soy sauce had significantly higher levels of sodium compared to sweet soy sauce ($p < 0.05$).

Data from the present study were combined with a previous study by Shahar et al.[9]. A scatter plot showing the level of sodium (Fig. 2) was drawn. Results showed that most of the sweet soy sauce (85.7%) had sodium below 4000 mg/100 g (mean = 3368 ± 863 mg/100 g, median = 3267 mg/100 g). The sodium level was below 5000 mg/100 g for salty soy sauce (mean = 4987 ± 1429 mg/100 g, median = 4782 mg/100 g) and dark soy sauce (mean = 4292 ± 2089 mg/100 g, median = 4445 mg/100 g). Whilst, most of the light soy sauce (54.5%) fell below 6000 mg/100 g (mean = 5710 ± 1488 mg/100 g, median = 5711 mg/100 g). With regards to sodium content, there were 19 sweet soy sauces (85.7%), five salty soy sauces (22.7%) and seven dark soy sauces (46.7%) met the ≤ 4400 mg/100 g sodium target. Whilst, there were 31 light soy sauces (70.5%) that achieved the ≤ 6700 mg/100 g sodium target [20,21].

Manufacturer readiness: perception, motivation and barriers towards salt reduction in soy sauce

A total of 19 employees from eight soy sauce manufacturers agreed to participate in the IDI (n = 4) or FGD (n = 15). The sociodemographic characteristics of the participants are presented in Table 2.

Perception on salt intake and salt reduction among soy sauce manufacturer

In this study, the respondents were asked about their general opinion on salt intake in Malaysia and perception on salt reduction in soy sauce. Table 3 summarizes the finding from the interviews/discussion on the perception of salt intake and salt reduction in Malaysia as well as its barriers and enablers among the soy sauce manufacturers.

Type of Soy Sauce	N	Sodium (mg/100 g)	Salt (mg/100 g)
Sweet	21	3368.14 ± 862.63	8420.00
Salty	22	4986.55 ± 1428.99[a]	12,466.00
Dark	15	4292.18 ± 2088.50	10,730.00
Light	44	5710.32 ± 1488.05[a]	14,276.00

Table 1. Mean ± SD of sodium and salt content of soy sauce. [a]Significant difference of mean of sodium compared to sweet soy sauce (p-value < 0.05, Independent Sample-Kruskal Wallis Test, Pairwise Comparisons).

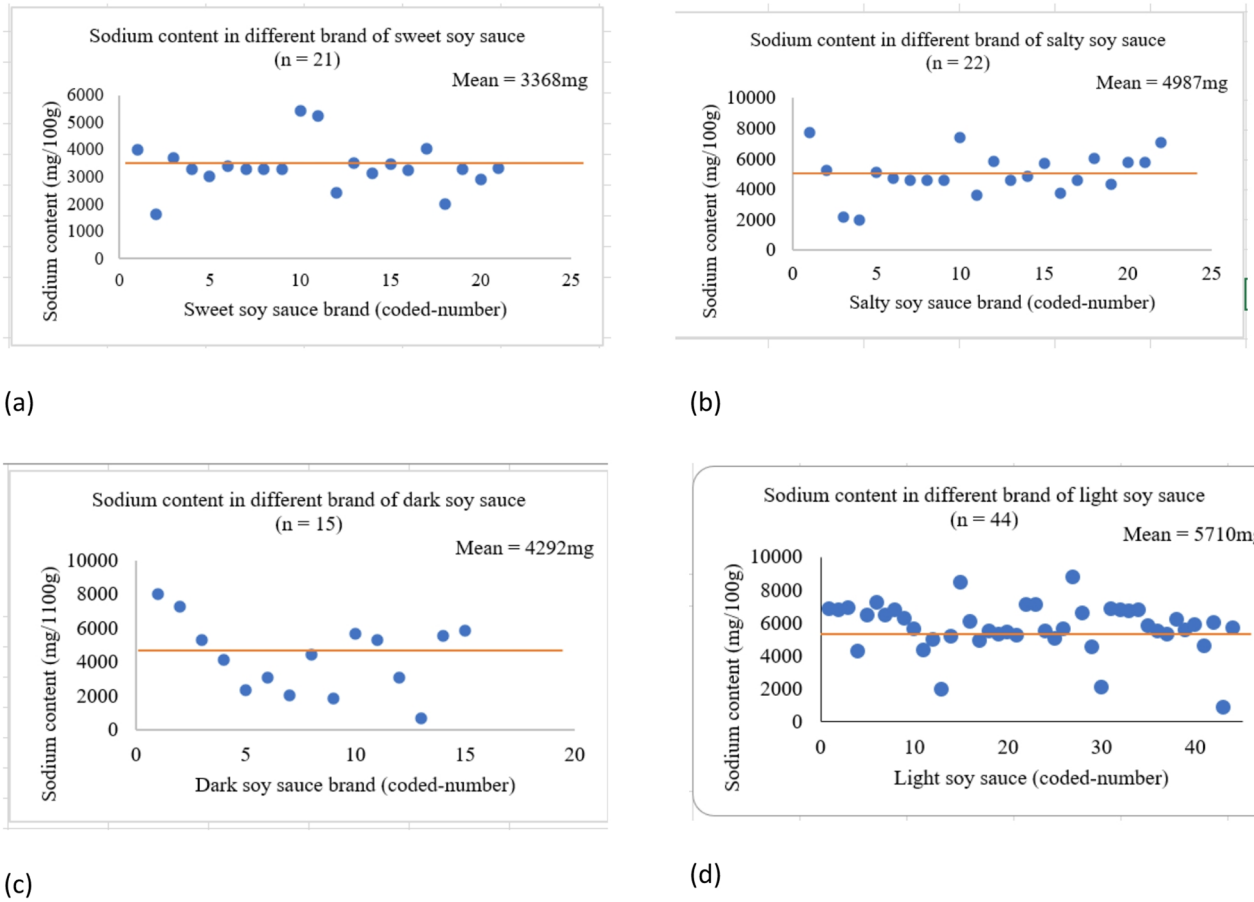

Fig. 2. Sodium content of different brands of soy sauce. (a) Sweet soy sauce. (b) Salty soy sauce. (c) Dark soy sauce. (d) Light soy sauce.

The finding was divided into several themes, sub-themes and supported by appropriate quotes (written in italic) from the respondents (coded as gender, age, and state).

In general, most respondents agreed that consumption of high salt foods including soy sauce contributed to high salt intake in Malaysia. They aware that salt is one of the important ingredients in soy sauce because it is used during fermentation and acted as preservative to prolong its shelf life. According to them, soy sauce is widely used as a cooking ingredient and often used as a condiment especially in Chinese culture.

Some of the respondents expressed their concern on the consumers' acceptance to reduction of salt in soy sauce. Less salt soy sauce, will be assumed as not tasty by consumers. Hence reformulation of soy sauce was never carried out by most of the manufacturers. However, in this study, there were some manufacturers that have carried out reformulation in soy sauce for overseas markets as well as to get recognition such as the Healthier Choice Logo (HCL). While there were also other manufacturers interested in doing reformulation due to awareness on the health benefit from the salt reduction.

There were several barriers that warrant attention especially from the government to make reduction of salt in soy sauce a success. These including lack of expertise and cost to do reformulation; and lack of incentives given to the manufacturers that want to reduce salt in their product. Besides, reduction of salt in soy sauce would be halted with the current regulation of soy sauce in the Food Act which requires soy sauce to contain not less than 7% of salt and 0.6% of Tn to avoid contamination. At the moment, continuous education and awareness are needed for consumers and soy sauce manufacturers for them to slowly adapt and accept the reduction of salt in soy sauce.

Analysis of the moromi from the commercial soy sauce manufacturer

Five moromi that were provided by Manufacturer A – E showed variation in the sodium content and Tn value. This could be explained by different fermentation times, which were around 3–12 months and would influence the amount of salt being used in the processing. In addition, only Manufacturer B added inoculum during the second fermentation, explaining the high Tn value reported by the company. Table 4 shows the analysis of the moromi at the baseline. From the finding, moromi from Manufacturer A was selected as the most suitable base to be used in the soy sauce reformulation because it contained high sodium and Tn value.

Sociodemographic characteristics	Value
Years of Experience (years)	0.6–38
Age (years; mean ± SD)	38 ± 25
Gender (%)	
Male	32
Female	68
Race (%)	
Malay	55
Chinese	40
Indian	5
Position (%)	
Research and Development	30
Food Technologist	15
Quality Control, Product Manager, Plant Manager	25
Chief Executive Officer	10
Others	20
Education level (%)	
Malaysian Certificate of Education	5
Bachelor Degree	90
Master Degree	5
Area of Education (%)	
Food Science/Food Technology	48
Business Administration	26
Account	5
Nutrition	5
Others	16

Table 2. Sociodemographic characteristics of the participants (n = 19).

Theme	Sub-theme	Quotes
Perception	High salt intake in Malaysia	"…*Malaysian consumed high salt dishes such as salted eggs, salted fish, belacan (fermented salted shrimp), in addition of soy sauce…*" (F, 38 YO, Sarawak)
	Salt usage in soy sauce manufacturing	"…*salt is an important ingredient during fermentation process…*" (F, 63 YO, Pulau Pinang,) "…*during sterilization we added food preservative, salt, food enhancer such as monosodium glutamate…*" (F, 38 YO, Sarawak)
	Soy sauce as cooking ingredient and condiment	"…*I added sauces such as oyster sauce, chili sauce, ketchup and soy sauce during cooking…*" (F, 57 YO, Kedah) "…Chinese likes to dip in the soy sauce but Malays used the soy sauce during cooking…" (F, 46 YO, Negeri Sembilan)
Barrier	Consumer's acceptance	"…*our company is not interested to change our formulation due to the familiarity of the consumers toward our soy sauce…*" (M, 34 YO, Johor) "…*our company never reformulate because our customer already familiar with our product…*" (M, 34 YO, Johor) "…*consumers will assume the food products with a healthy food label as not delicious and tasteless…*" (F, 46 YO, Negeri Sembilan)
	Lack of awareness among manufacturers	"…*our company is not interested to change our formulation due to the familiarity of the consumers toward our soy sauce…*" (M, 34 YO, Johor)
	Lack of resources i.e. cost and expertise to do reformulation	"…*we need to do the analysis for reformulation of the product which is expensive for us…*" (F, 46 YO, Negeri Sembilan) "…*we are lacking in expertise to reformulate our product…*" (M, 57 YO, Kedah)
	Spoilage of soy sauce	"…*soy sauce is easily contaminated if using less salt…*" (F, 32 YO, Sarawak)
	Food Act and Food Regulation	"…*we can never reformulate the soy sauce for Malaysia market because we need to follow the standard from the Food Act and Food Regulation in which the product shall be more than 7% of salt and 0.6% of total nitrogen (TN)…*" (F, 46 YO, Negeri Sembilan)
Enabler	To cater oversea demand on low salt soy sauce	"…*our company have reformulated the soy sauce for oversea production with 20% of salt reduction in dark soy sauce…*" (F, 41 YO, Negeri Sembilan)
	Healthier Choice logo (HCL) recognition	"…*our soy sauce had been recognized in the Healthy Choice Logo (HCL) by Ministry of Health Malaysia…*" (F, 63 YO, Penang)
	Health awareness	"…*as a personal opinion I am looking forward in the reformulation project due to health benefits…*" (M, 34 YO, Johor) "*I am looking forward to participate in reformulation project so I can claim my product is healthy*" (F, 63 YO, Penang)

Table 3. Perception, barriers and enablers of salt reduction in soy sauce. M = Male; F = Female; YO = Years old.

Nutrient / proximate analysis of newly reformulated soy sauce

As shown in Table 5, eight reformulated soy sauces were produced using the moromi provided by Manufacturer A. From the table, the sodium content in the newly reformulated soy sauce was reduced to 5% salt (78% reduction from baseline), 7% salt (70% reduction from baseline), 9% salt (60% reduction from baseline) and 11% salt (52% reduction from baseline). About 0.05% YE or 0.05% MSG and 0.05% YE were added to compensate for the

Manufacturer	Time of fermentation, months	Additional of inoculum during the second fermentation	Sodium, mg/100 g	Salt, %	Total nitrogen content, mg/L	Tn, %	MSG, g/100 g
A	9	No	9115.00 ± 445.48[a]	22.78	11,050.00 ± 353.55[b]	1.11	1.08 ± 0.06[abc]
B	3	Yes	6260.00 ± 410.12	15.65	12,550.00 ± 212.13[a]	1.26	1.18 ± 0.08[abc]
C	12	No	10,455.00 ± 1053.59[a]	26.14	6580.00 ± 155.56[c]	0.66	0.3 ± 0.01
D	9	No	8050.00 ± 296.99[a]	20.13	10,350.00 ± 70.71[b]	1.04	0.90 ± 0.07[ab]
E	6	No	11,150.00 ± 777.82[a]	27.88	5195.00 ± 91.92[d]	0.52	0.33 ± 0.03

Table 4. Sodium, total nitrogen, monosodium glutamate content for baseline moromi. Significant different ($p < 0.05$, Independent Sample-Kruskal Wallis Test, Pairwise Comparisons). 1) Sodium: [a]Significant difference of mean of sodium compared to Manufacturer B (p-value < 0.05); 2) Total nitrogen content: All manufacturers showed significant different of Tn; 3) MSG: [ab]Significant difference of mean of MSG compared to Manufacturer C and E, [c]Significant difference of mean of MSG compared to Manufacturer C, D and E .

	5% Salt		7% Salt		9% Salt		11% Salt	
	(2000 mg sodium)		(2800 mg sodium)		(3600 mg sodium)		(4400 mg sodium)	
Analysis	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE
Sodium (mg/100 g)	2185	2140	2705	2570	3410	3370	4035	4265
Total carbohydrate (g/100 g)	25.4	24.05	27.3	27.2	33.85	33	38.3	39.5
Energy (kcal/100 g)	116	111	121.5	120.5	147.5	143.5	170	175
Energy (kJ/100 g)	487	465.5	511	507.5	621.5	603	715	733.5
Moisture Content (g/100 g)	65.7	67.35	62.8	62.95	53.35	54.8	46.55	44.65
Ash Content (g/100 g)	5.95	5.65	7.15	7.05	9.65	9.3	11.2	11.6
Fat (g/100 g)	0.55	0.6	0.25	0.2	< 0.1	< 0.1	< 0.1	< 0.1
Protein (g/100 g)	2.4	2.3	2.55	2.55	3.15	2.95	3.6	3.7
Total Nitrogen Content (mg/kg) (%)	3845 (0.4)	3680 (0.4)	4070 (0.4)	4080 (0.4)	5015 (0.5)	4695 (0.5)	5710 (0.6)	5845 (0.6)
Total Sugar (g/100 g)	19.55	20	21.75	23.35	24.2	21.2	25.95	28.15

Table 5. Nutrient content of newly reformulated salty soy sauces. MSG = monosodium glutamate, YE = yeast extract.

		5% of Salt		7% of Salt		9% of Salt		11% of Salt	
		(2000 mg sodium)		(2800 mg sodium)		(3600 mg sodium)		(4400 mg sodium)	
Sensory Attributes	Control (23% of salt)	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE
Color	6.41 ± 1.95	6.90 ± 1.73	7.02 ± 1.67	7.08 ± 1.61	7.00 ± 1.62	6.94 ± 1.54	6.92 ± 1.72	7.08 ± 1.83[a]	6.86 ± 1.79
Odor	5.59 ± 2.39	5.35 ± 1.92	5.45 ± 1.77	5.41 ± 2.16	5.25 ± 1.91	5.59 ± 1.82	5.24 ± 1.88	5.71 ± 1.89	5.49 ± 2.19
Viscosity	5.92 ± 2.00	6.45 ± 1.58	6.41 ± 1.60	6.37 ± 1.72	5.84 ± 1.94	6.41 ± 1.69	6.18 ± 1.73	6.47 ± 1.95	6.73 ± 1.69[a]
Saltiness	5.65 ± 2.34	4.75 ± 2.10[a]	5.16 ± 1.94	5.51 ± 2.33	5.31 ± 2.06	5.98 ± 1.86	5.55 ± 2.18	4.86 ± 2.29	5.25 ± 2.29
Taste	5.88 ± 2.34	4.55 ± 2.04[a]	5.04 ± 2.18[a]	5.33 ± 2.32	5.24 ± 2.14	5.69 ± 1.86	5.35 ± 1.94	4.90 ± 2.23[a]	5.53 ± 2.34
After Taste	5.88 ± 2.40	4.47 ± 1.98[a]	4.88 ± 2.24[a]	5.49 ± 2.19	5.16 ± 2.06	5.63 ± 1.70	5.53 ± 1.90	4.67 ± 2.17[a]	5.31 ± 2.38
Overall Acceptability	6.06 ± 2.33	4.86 ± 1.84[a]	5.00 ± 2.02[a]	5.67 ± 2.22	5.33 ± 2.02[a]	5.90 ± 1.70	5.78 ± 1.79	4.84 ± 2.11[a]	5.55 ± 2.41

Table 6. The score (mean ± SD) of the reformulated soy sauce according to sensory attributes. [a]Significant difference of mean of sensory attributes compared to control soy sauce (p-value < 0.05, Independent Sample-Kruskal Wallis Test, Pairwise Comparisons).

taste after reduction of the salt. The total amount of YE and MSG used in these formulations (0.1% w/w) was far reduced from the amount of MSG used in the commercial soy sauce (1.1% w/w). Analysis showed that the sodium content in the formulations ranged from about 2000–4000 mg/100 g. The sodium content in the newly reformulated soy sauce was in a similar range to sweet, salty and dark soy sauce with no sodium labelling from the market survey.

Duration	Analysis	5% Salt (2000 mg sodium)		7% Salt (2800 mg sodium)		9% Salt (3600 mg sodium)		11% Salt (4400 mg sodium)	
		0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE	0.05% YE	0.05% MSG + 0.05% YE
0 month (baseline)	TC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	EC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	TPC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	YM (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1 month (7-days ASL)	TC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	EC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	TPC(CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	YM (CFU/g)	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
3 months (22-days ASL)	TC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	EC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	TPC(CFU/g)	< 10	< 10	10	< 10	< 10	< 10	< 10	< 10
	YM (CFU/g)	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
1 year (90 days ASL)	TC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	EC (CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	TPC(CFU/g)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
	YM (CFU/g)	< 100	< 100	< 100	< 100	< 10	< 100	< 100	< 100

Table 7. Shelf life of the reformulated soy sauce. ASL = Accelerated shelf life, TC = Total coliform, EC = *E. coli* count, TPC = Total plate count, YM = Yeast & mold, MSG = monosodium glutamate, YE = yeast extract.

Sensory analysis of newly reformulated soy sauce

Table 6 summarizes the reported sensory attributes for each of the formulations. The results from the sensory test revealed that reformulated soy sauces at 9% of salt with YE were mostly preferred by the respondents, followed by 9% of salt with YE and MSG and 7% of salt with addition of YE. Salt concentration at 11% with addition of YE also most accepted for aroma and viscosity and scored number two for taste. In terms of color, odor and viscosity, and saltiness, generally there were no significant differences between most of the samples and control. Nevertheless, the score for color of soy sauce at 11% of salt with 0.05% YE significantly higher than control ($p < 0.05$). While the score of viscosity of soy sauce at 11% of salt with 0.05% YE and 0.05% MSG significantly higher than control ($p < 0.05$). For taste and after taste attributes, the score for soy sauce at 5% of salt with 0.05% YE, 5% of salt with 0.05% YE and 0.05% MSG and soy sauce at 11% of salt with 0.05% YE were significantly lower than control ($p < 0.05$). Overall acceptability shows that only formulation soy sauce at 5% of salt with 0.05% YE, at 5% of salt with 0.05% YE and 0.05% MSG, soy sauce at 7% of salt with 0.05% YE and 0.05% MSG and soy sauce at 11% of salt with 0.05% YE were significantly lower in score compared to control. This indicates that, the newly reformulated soy sauce especially in the 9% of salt could be accepted by the consumers and reduction of salt did not influence their acceptability.

Shelf life of the newly reformulated soy sauce

Microbiological analysis can be used to assess the quality of food products and hygiene of the food processing. Shelf life of a food product could be changed by many things including exposure to heat and light, mechanical stress microorganisms' contamination. Table 7 shows that the reformulated soy sauce can withstand up to one-year ASL of storage duration at ambient temperature without significant presence or growth of microbes. From the results, all of the analysis of the microbes were less than 100 CFU/g which is in the range of the permitted level of microbes in foods. Malaysian Standard allows the soy sauce to contain yeast < 100 count/ml. According to Singapore Food Agency ready-to-eat processed foods should contain *E. coli* < 100 CFU/g[26]. Food and Environmental Hygiene Department of Hong Kong also stated that in general, ready-to-eat foods should contain < 100 CFU/g of *E. coli* to indicates hygiene of ready-to-eat foods[27]. Whereas, for total coliform, most of the processed food listed by the Ministry for Primary Industries (New Zealand) should contain ≤ 10 CFU/g[28].

Discussion

This study demonstrated that reducing salt in soy sauce, particularly to 9% of salt with YE supplementation, was preferred by consumers and remained safe for consumption for up to one year. These findings have successfully addressed two main barriers raised by the food manufacturer representatives that concerned on the consumer acceptance and shelf life of the food products with the reduction of salt. Consumer's acceptance that leads to rejection of the food products in the market and profit lost has been one of the biggest challenges faced by the food industries to reduce the sodium in their products[29]. In fact, our research demonstrated that consumers prefer lower sodium soy sauce compared with higher sodium formulations. Our current findings strengthened the previous findings among policy makers and food industries[22]. In brief, salt reduction in soy sauce, like any other foods could be done without effecting the consumer's acceptance and its shelf life as perceived by most of

the respondents. This study emphasized on the effectiveness to reformulate food products to reduce salt intake in the general population.

Reformulation is an effective upstream strategy to reduce population sodium intake, with evidence from several countries. For instance, the United Kingdom implemented a comprehensive salt reduction programme coordinated by the Food Standards Agency (FSA), which set voluntary category-specific sodium targets and monitored compliance. By combining industry collaboration with public accountability (i.e., praising companies that made progress and naming those that did not), the programme achieved significant reformulation. For example, 71% of bread products met the FSA target of ≤ 1.0 g salt per 100 g. The salt content of many other foods also decreased. This contributed to a 15% reduction in population salt intake between 2003 and 2011, alongside declines in blood pressure and cardiovascular mortality[30]. Similar benefits have been projected in the United States, where modeling studies projected that even modest population-wide sodium reductions could prevent tens of thousands of cardiovascular deaths annually[31].

Comparable initiatives have been implemented elsewhere with encouraging outcomes. In South Africa, mandatory sodium targets introduced in 2016 for 13 food categories including bread, margarine, and savory snacks led to a mean salt intake reduction of 1.15 g/day between 2015 and 2018/early 2019[32]. In Argentina, national law enacted in 2013 established mandatory maximum sodium levels for processed foods, including soups, sauces, and bread. By 2015, average daily salt consumption had declined from 11.2 to 9.2 g (a reduction of 2 g/day, or 18%)[33]. In South Korea, the National Plan to Reduce Sodium Intake, launched in 2012, employed multiple strategies, including voluntary reformulation of processed foods, and resulted in a 23.7% reduction in dietary sodium among adults between 2010 and 2014[34]. Taken together, experiences from other countries demonstrate the feasibility and effectiveness of reformulation policies, both voluntary and mandatory, in reducing population sodium intake. These provide strong evidence to support soy sauce reformulation as a viable strategy to lower salt consumption in Malaysia.

The sensory evaluation showed that reformulated soy sauce with 9% salt added with YE were the most preferred by consumers, followed closely by other reduced-salt formulations. These findings indicate that moderate sodium reduction in soy sauce, supported by flavor enhancers, can maintain overall consumer acceptability. Recent studies support this outcome. A Japanese modeling study demonstrated that incorporating umami substances such as glutamate, inosinate, and guanylate into traditional foods like soy sauce and miso could reduce population salt intake by up to 22.3%, without compromising flavor perception[35]. Similarly, a 2024 Hong Kong sensory trial of reduced-sodium dim sum reported that 10–20% sodium reduction in products such as shrimp siu mai and steamed pork ribs was not detectable by consumers, confirming that modest reductions can be well accepted[36,37]. Beyond soy sauce, large-scale reformulation programs reinforce these findings. For instance, Australia's Healthy Food Partnership reported steady progress in sodium reduction across sauces, gravies, and other condiments between 2018 and 2022, with evidence that consumer acceptance was maintained[37]. Singapore has also reported a success through public–private partnerships, reformulating sauces and condiments with up to 25% less sodium while maintaining consumer acceptance[38]. A global systematic review further confirmed that sodium in processed foods can be reduced by 20–30% without significantly affecting consumer acceptability[39]. In addition, voluntary reformulation with gradual reduction of salt in food products will not affect the taste and will be feasible to be carried out[29]. Taken together, these findings strengthen study finding of 50–80% sodium reduction in salty soy sauces through incorporating umami-rich enhancers such as YE. This formulation has successfully compensated for lower saltiness, while ensuring both sensory appeal and public health benefit.

The baseline moromi analysis (Table 4) showed considerable variation in sodium, Tn, and MSG levels among different soy sauces, which aligns with previous findings that fermentation conditions (such as duration, salt concentration, microbial strains) substantially influence both nitrogenous compounds and flavor-enhancing constituents (e.g., free amino acids, amino acid nitrogen)[10,40]. For instance, Luo et al.[40] found that in soy sauce samples, amino acids accounted for 50–75% of the total nitrogen, underlining the relevance of Tn and amino acid nitrogen as quality indicators. Higher Tn indicates better quality of the soy sauce in terms of its taste as this value is directly proportional to amino acids present in the soy sauce[40]. In our reformulated soy sauces (Table 5), reduced salt formulations had lower Tn and MSG than baseline moromi, which would be expected since sodium reduction often entails dilution or changes in moromi composition. Despite these lower Tn values, the inclusion of YE and MSG in the 9% salt formulation preserved sensory quality. This pattern parallels findings in a recent study on low-salt soy sauce with enhanced flavor[41]. It indicates that reduced-salt formulations, added with flavor enhancers, showed Tn and amino acid nitrogen levels close to or only slightly lower than traditional soy sauces, yet acceptance remained high[41]. This study also showed that soy sauce with 5% salt and Tn around 0.4% remained microbiologically stable for up to one year. As the Malaysian Food Act currently stipulates a minimum of 0.6% Tn for soy sauce[42], these findings suggest the need to revise the regulatory thresholds at 0.4% Tn to allow for lower-sodium formulations without compromising safety or acceptability.

In this study, the reduced salt soy sauce has been successfully developed by adding flavoring such as caramel, sugar, YE and MSG. Future studies could explore usage of others such as odorants to increase saltiness perception[12]. The use of herbs and spices and their mix also have been reported to enhance the saltiness especially with replacement of salt with salt substitute and could mask the absence of salt[43]. However, the overall cost of addition of such ingredients to compensate for the reduced taste after the salt reduction, should also need to be taken into consideration as it also could influence its feasibility to be implemented in commercial setting. Hence, a larger study on taste of the newly reformulated soy sauce should be carried out and a more comprehensive shelf life study to assess the safety of the product, together with cost evaluation should also be determined.

As such, a multifaceted strategy is needed to incentivise manufacturers to reduce sodium in their soy sauces in line with the findings of this research, providing support in terms of financial, technology and incentives. This is important as acknowledged food reformulation policies are more likely to succeed if the private sector

collaborates with or responds to the government regulatory process. In addition, mandatory salt reduction targets are the most effective and recommended by WHO. A gradual reduction of salt should be adopted in the food reformulation in achieving the salt reduction target in the population without being noticed by the consumer[44]. New technology for food reformulation might be complex and may take longer to implement in developing economies[45]. Thus, reformulation by reducing the amount of salt in the foods could be achieved in a short time of period without involving so much cost if more food industries venture into such reformulation. This will create a healthy environment in which more low sodium foods would be available in the market and thus give more option to the consumers. With reduction of salt in the soy sauce, loyal consumer can continue to buy the same soy sauce thus could reduce their daily salt intake without the need to alter their own purchasing behavior. In terms of monitoring, law enforcement should be implemented to ensure food industries abide to the mandatory sodium labelling that will enable the consumers to make an informed choice on purchasing the low sodium soy sauce.

Conclusion

Soy sauce is a major contributor to dietary salt intake in Malaysia and this study demonstrates that reformulation to lower sodium content is both feasible and acceptable to consumers. In particular, the 9% salt formulation supplemented with YE was preferred in sensory testing and remained shelf life stable for up to one year. These findings address key industry concerns regarding consumer acceptability and product safety, providing a practical foundation for sodium reduction in staple condiments. For future utilization, our results suggest that soy sauce manufacturers could gradually adopt reduced-sodium formulations while maintaining flavor through natural enhancers such as YE and umami compounds. Reformulated soy sauces may also be positioned for recognition under healthier food labeling schemes, such as the HCL, to increase consumer trust and marketability.

To accelerate industry adoption, guidelines for gradual sodium reduction should be integrated into national food policies, accompanied by regulatory flexibility to revise current salt content thresholds in the Malaysia Food Act. Incentives, such as technical support and financial subsidies for research and development, could further encourage reformulation.

Looking ahead, future development should focus on (1) implementation of soy sauce reformulation involving larger samples of food industries, (2) extended shelf-life and safety assessments under real-market storage conditions, and (3) exploration of other technique to reduce salt in soy sauce through direct reduction and alternative salt substitutes, herbs, and spices to enhance palatability without increasing cost. These steps will be critical to ensure sustainable reformulation strategies leading to an impactful outcome on the population salt intake and the burden of NCD in Malaysia and beyond.

Availability of data and materials

Data are available upon reasonable request from our corresponding and main author: SS (suzana.shahar@ukm.edu.my) and ZH (zaliha.harun@city.edu.my).

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Authors' contributions
SS, HH, YYX, MAM, WZWI, HM, VM, HB, GAM, FJH and MKB have designed the study. Data collection was carried out by SS, HH, YYX, MAM, WZWI, HM, VM, AFMT, ZH and SM. The recordings were transcribed by AFMT. Data analyses were conducted by AFMT, ZH and YQO. ZH prepared the manuscript under supervision of SS and edited by YQO. All authors have read, edited and approved the final draft of this manuscript by providing critical revision of the manuscript for optimum intellectual content.

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Declarations

Competing interests
FJH is an unpaid member of Action on Salt and World Action on Salt, Sugar and Health (WASSH). Graham A MacGregor is the unpaid chairman of Blood Pressure UK, and chairman of Action on Salt and Chairman of WASSH. The other authors declare no competing interests.

Ethics approval and consent to participate
This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Universiti Kebangsaan Malaysia Research and Ethics Committee (MREC) with UKM approval number (JEP-2022-062). Written informed consent was obtained from all the participants.

Additional information

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