

# Regional variations in iodine content of Malaysian gravies analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

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## ABSTRACT

Iodine is a crucial micronutrient for synthesizing thyroid hormones, vital for metabolism and development. It is an essential part of a healthy diet and can be found in various foods, including seafood and plants like seaweed. While raw food iodine data exists, iodine levels in prepared gravies, which are a staple routinely consumed component of the Malaysian diet, remain unestablished. Hence, this study selected the north (Kedah), central (Selangor) and east (Kelantan) regions to represent diverse geographical and culinary variations in Peninsular Malaysia where iodine deficiency reports vary. The aim of the study was to determine the iodine concentration in selected Malaysian gravies using ICP-MS and assess regional differences. The samples were first collected and prepared according to the Protocol for Sampling and Method of Analysis for Malaysian Food Composition and analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). While comparing the gravy samples across the regions, the highest iodine content was found to be in gravies from the east region. The subsequent analysis showed that the highest iodine content was found in soy sauce mackerel fish gravy (K21/2), with a concentration of  $134.10 \pm 6.54 \mu\text{g}/100\text{g}$ . Meanwhile, the three lowest iodine concentrations were recorded in chicken Tom Yum, K08/3 ( $5.63 \pm 0.99 \mu\text{g}/100\text{g}$ ), followed by beef Tom Yum, K15/3 ( $6.98 \pm 0.28 \mu\text{g}/100\text{g}$ ), then soy sauce beef, K11/3 ( $7.95 \pm 0.70 \mu\text{g}/100\text{g}$ ). Spicy and Sour Tamarind Chicken gravy showed no significant difference, while all other gravies significantly differed in iodine levels between the regions ( $p < 0.05$ ). The results of this study underscore the need to increase iodine consumption among the Malaysian population through both raw and prepared foods. Further comprehensive studies are highly suggested to better understand how different preparation methods of Malaysian gravies impact iodine status and general nutritional health across various Malaysian populations.

**Keywords:** Iodine content; Malaysian gravies; Inductively Coupled Plasma Mass Spectrometry (ICP-MS); food composition and dietary iodine

## INTRODUCTION

Iodine is a type of micronutrient that is essential for maintaining human health. It plays a vital role in the production of thyroid hormones, namely thyroxine (T4) and triiodothyronine (T3), as these hormones are particularly responsible for maintaining homeostasis functions in the body (Shulhai et al., 2024). Inadequate iodine intake can lead to iodine deficiency disorders (IDD), such as goitre, hypothyroidism, and impaired cognitive development in children (Hatch-mchesney & Lieberman, 2022).

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Despite emerging attempts to introduce iodized salt as a preventive measure, iodine deficiency still continues to be a major public health concern on a global scale. Globally, incident cases of IDD increased from 7.51 million in 1990 to 8.08 million by 2021 and projected to reach 8.48 million by 2050 (Liang et al., 2025). While the worldwide incidence rate for IDD stood at 108.32 per 100,000 in 2019, the burden was heavily concentrated in Asia, which reported a staggering 127 million total cases, including 5.47 million new incidents (Wu et al., 2024). In Malaysia, the prevalence of IDD (UI<100 µg/L) in Peninsular Malaysia was found to be 50.7% (95% CI:48.3,53.1) in 2008, with the condition being more prevalent in rural compared to urban areas (Selamat et al., 2010).

Although major sources of iodine include seafood, dairy, and iodized salt (Krela-Kaźmierczak et al., 2021), actual iodine intake remains highly variable due to geographical factors, food preparation methods and ingredient selection (Wang et al., 2021). In Malaysia, gravies are a dietary staple, typically served with rice or noodles and frequently prepared with iodized salt, seafood or soy-based ingredients. Given their ubiquity, gravies serve as significant potential contributors to dietary iodine. Currently, the Malaysian Food Database (MyFCD) provides iodine data for raw foods, ranging from 1.56 µg/100 g to 160.00 µg/100 g (Khalid et al., 2019). However, the iodine levels in locally prepared Malaysian gravies are yet to be established, likely due to variations in cooking practices and environmental factors, which are known to influence iodine retention in foods (Penrose et al., 2024). This data gap is particularly critical as iodine deficiency varies significantly across Peninsular Malaysia.

Notably, Kedah and Kelantan are among the six states identified with higher deficiency rates, with median urinary iodine concentrations ranging from 68 to 88 µg/L (Selamat et al., 2010). To better understand regional dietary iodine exposure, this study examined gravies from three geographically and culturally distinct regions: the north (Kedah), central (Selangor) and east (Kelantan) regions. By examining gravies from these regions, we aimed to capture variability in iodine content attributable to geographic factors, including coastal proximity, and the unique iodine profiles of locally sourced ingredients. Consequently, this study aims to determine the iodine concentrations in frequently consumed Malaysians gravies and evaluate regional differences. These findings will provide updated, region-specific data for the MyFCD, offer valuable insights into the dietary contribution of traditional Malaysian gravies and highlight the necessity for region-specific strategies to address iodine deficiency in Malaysia.

## MATERIALS AND METHODS

### Sample collection of gravy samples

The sampling of the gravy samples was done per the Protocol for Sampling and Method of Analysis for Malaysian Food Composition (National Technical Working Group of Malaysian Food Composition Database, 2011) from 18th August 2023 until 25th June 2024. Inclusion criteria were restricted to Malaysian-owned restaurants and stalls that prepared commonly consumed versions of each gravy within three selected regions in Peninsular Malaysia (north, central and east). Samples were collected without recipe standardization to reflect foods as consumed under routine preparation practices within the selected regions. In accordance with the MyFCD protocol, one state was selected from each region based on the highest population. The north region encompassed Perlis, Kedah and Penang; the central region included Kuala Lumpur, Perak, Putrajaya and Selangor; and the east region comprised Pahang, Terengganu and Kelantan. Based on this criterion, Kedah, Selangor and Kelantan were selected to represent the north, central and east regions, respectively (Figure 1). Each gravy type from each region was collected as three independent samples (n=3). Each sample were analyzed in analytical duplicate (n=2) for iodine determination. Mean iodine concentrations were calculated from the analytical duplicates for each sample and the regional mean ± SD was calculated across the three samples prior to statistical analysis. This approach is consistent with established methodologies for iodine quantification in complex food matrices using ICP-MS analytical practices (Haldimann et al., 2019).

### Sample preparation

After sampling, the samples were coded and labelled according to MyFCD 2011 protocol. They were then homogenised using a food processor. The homogenized samples were stored and chilled at 4°C. Table 1 below shows the list of samples along with their labelled code. The SG region was coded as 1, the KB region was coded as 2, and the AS region was coded as 3.

### Chemicals and reagents

All the chemicals and reagents used were listed in Table 2. Ultrapure water was used to prepare the standard solutions and the sample solutions.

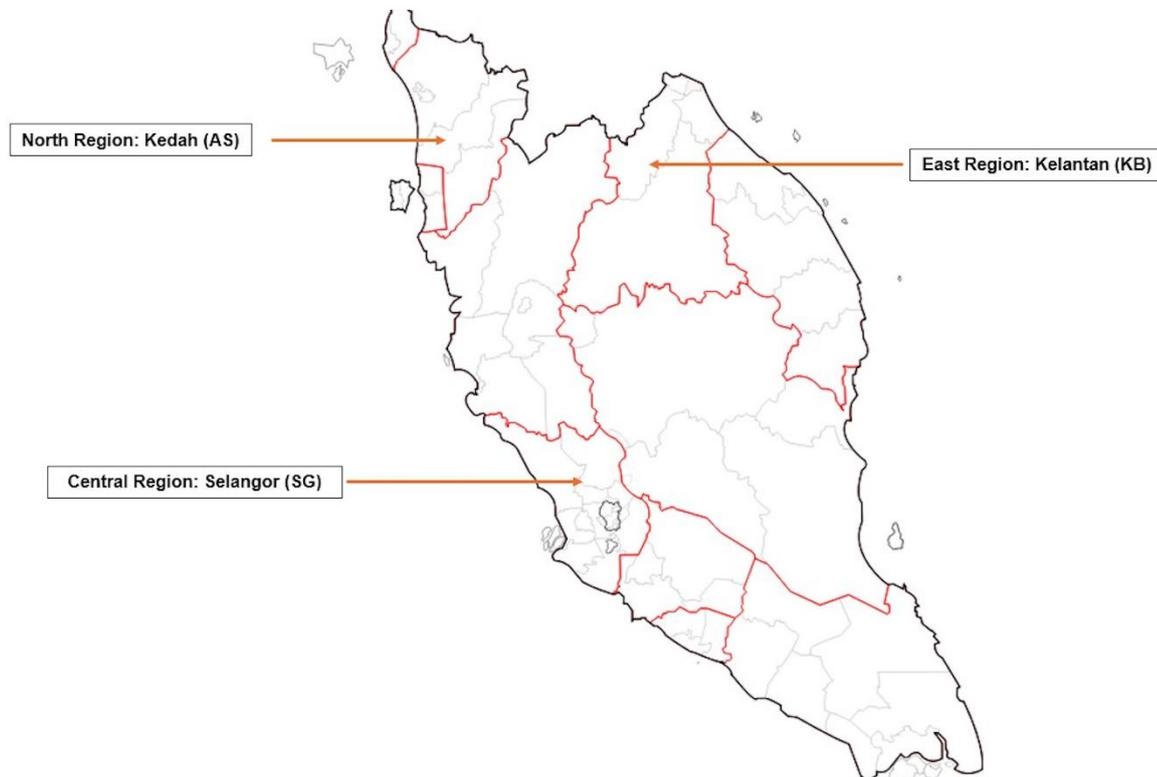
### Iodine digestion

The analysis of the iodine content in the gravy samples was conducted using PerkinElmer Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Waltham, Massachusetts, USA) by referencing the method described by Khalid

Boutakhrit and Fabien Bolle (2010). Each gravy sample was first homogenised to ensure matrix uniformity. Approximately 0.20 g of each homogenized sample was transferred into 15 mL polytetrafluoroethylene (PTFE) digestion tubes. Then, 4.5 mL of ultrapure water (UPW) and 1.0 mL of 25 % tetramethylammonium hydroxide (TMAH) were added. Samples were then heated in the oven at 90°C for 3 hours, brought to cool for 15 minutes and subsequently diluted with UPW to a final volume of 10 mL. The samples were then centrifuged at 3000 rpm for 15 minutes and filtered using 0.45 µm cellulose acetate syringe filters. Iodine concentrations obtained from ICP-MS analysis (µg/L) were normalized to the original sample mass and dilution factor. The results were expressed as µg iodine per 100 g of gravy sample (µg/100 g).

## Figure 1

*Chosen states for sampling of gravy samples in Peninsular Malaysia*



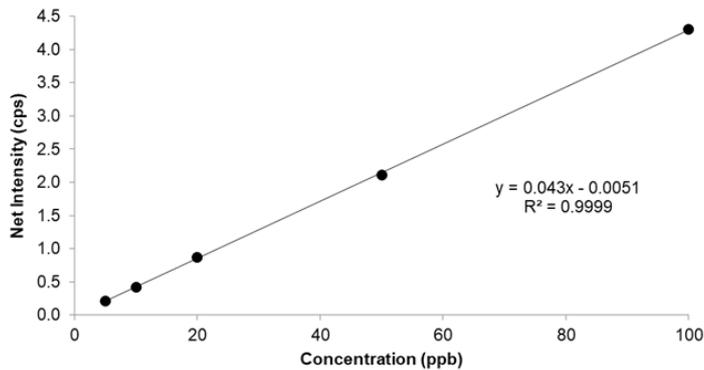
*Note: North region is coded as AS, east region as KB and central region as SG.*

## Iodine analysis

The sample solutions were analyzed directly using the ICP-MS. 5 to 100 µ/L of calibration standards were prepared and analyzed before sample analysis. Figure 2 shows the calibration curve of the iodine standard. The internal standard used was Indium whereas the control chosen was non-fat milk powder by referencing internal quality control and National Institute of Standards and Technology (NIST) standard reference material 1549 (SRM) (Beary et al., 2013). The control was analyzed simultaneously with the calibration of standards. Analyzed iodine results will be deemed acceptable if they fall within the control limits established by the quality control material. Analytical performance was validated before sample analysis. The method showed adequate sensitivity with LOD and LOQ values of 0.06 µg/100 g and 0.20 µg/100 g respectively. Method accuracy was also confirmed through recovery analysis, with iodine recovery 116%.

## Statistical analysis

Statistical Packages for Social Science (SPSS) (version 27) was used to analyze the descriptive statistics of the data. The iodine contents of the gravy samples were expressed as mean ± standard deviation. The Shapiro-Wilk test was used to examine whether the data were normally distributed. The Kruskal-Wallis test was used to analyze the non-normally distributed data. All pairwise comparisons with a Bonferroni correction were performed to pinpoint the regions where the differences originated. The comparison of several type of gravies across regions were analyzed using one-way ANOVA and Tukey's post-hoc analysis. The confidence interval was accepted at 95% for all statistical tests in this study, while the significance level was evaluated at  $p < 0.05$ .

**Figure 2***Calibration curve of iodine standard*

Note: Concentration is expressed in parts per billion (ppb); net intensity is measured in counts per second (cps).

**Table 1**

List of sample names with its corresponding group and sample codes

Sample name (Local name)	Group with Sample code		
	SG	KB	AS
Chicken Curry with Coconut Milk (Kari Ayam Bersantan)	K01/1	K01/2	K01/3
Chicken Curry (Kari Ayam)	K02/1	K02/2	K02/3
Soy Sauce Chicken (Ayam Masak Kicap)	K03/1	K03/2	K03/3
Korma Chicken (Ayam Kurma)	K04/1	K04/2	K04/3
Spicy Tomato Chicken (Masak Merah Ayam)	K05/1	K05/2	K05/3
Chicken Soup (Sup Ayam)	K06/1	K06/2	K06/3
Chicken Tom Yum (Tom Yum Ayam)	K08/1	K08/2	K08/3
Beef Curry with Coconut Milk (Kari Daging Bersantan)	K09/1	K09/2	K09/3
Beef Curry (Kari Daging)	K10/1	K10/2	K10/3
Soy Sauce Beef (Daging Masak Kicap)	K11/1	K11/2	K11/3
Korma Beef (Kurma Daging)	K12/1	K12/2	K12/3
Spicy Tomato Beef (Masak Merah Daging)	K13/1	K13/2	K13/3
Beef Soup (Sup Daging)	K14/1	K14/2	K14/3
Beef Tom Yum (Tom Yum Daging)	K15/1	K15/2	K15/3
Spicy And Sour Tamarind Mackerel Fish (Asam Pedas Ikan Kembung)	K16/1	K16/2	K16/3
Spicy And Sour Tamarind Chicken (Asam Pedas Ayam)	K17/1	K17/2	K17/3
Spicy And Sour Tamarind Beef (Asam Pedas Daging)	K18/1	K18/2	K18/3
Mackerel Fish Curry with Coconut Milk (Kari Bersantan Ikan Kembung)	K19/1	K19/2	K19/3
Mackerel Fish Curry (Kari Tanpa Santan Ikan Kembung)	K20/1	K20/2	K20/3
Soy Sauce Mackerel Fish (Kicap Ikan Kembung)	K21/1	K21/2	K21/3
Korma Skipjack Tuna Fish (Kurma Ikan Tongkol)	K22/1	K22/2	K22/3
Ginger Mackerel Fish Soup (Masak Singgang Ikan Kembung)	K23/1	K23/2	K23/3
Red Snapper Soup (Sup Ikan Merah)	K24/1	K24/2	K24/3
Mixed Tom Yum (Tom Yum Campur)	K25/1	K25/2	K25/3

Note: Sample codes (e.g., K01/1) indicate the specific dish and its corresponding location code.

**Table 2***List of chemicals and reagents*

Chemicals and Reagents	Purpose
Iodine standard	Stock solution and working standard
Indium	Internal standard
Tetramethylammonium hydroxide, 25% (TMAH)	Standard iodine preparation and sample preparation
Tetramethylammonium hydroxide, 0.5% (TMAH)	Standard iodine preparation
Nitric Acid (HNO <sub>3</sub> )	Internal standard preparation

**RESULTS****Comparison of Iodine content between regions**

Overall, the iodine content of gravy samples across different regions is showed at the Table 3. The KB region shows the highest iodine content within their gravy samples ( $52.31 \pm 32.03 \mu\text{g}/100\text{g}$ ) followed by SG ( $27.74 \pm 17.34 \mu\text{g}/100\text{g}$ ) and AS region ( $18.97 \pm 8.96 \mu\text{g}/100\text{g}$ ). The iodine content in gravy samples showed significant difference across Malaysia's north, central, and east regions. Despite no significant difference between the north and central regions ( $p=0.086$ ) in Figure 3, the east region has a significantly higher iodine content compared to both the north and central regions ( $p<0.001$ ).

**Table 3***Iodine content of gravy samples by regions*

Region	n	Iodine content ( $\mu\text{g}/100\text{g}$ ) <sup>#</sup>	p-value
SG - Selangor (central region)	48	$27.74 \pm 17.34$	
KB - Kelantan (east region)	48	$52.31 \pm 32.03$	<b>&lt;0.001</b>
AS - Kedah (north region)	48	$18.97 \pm 8.96$	

Note: #Kruskall-Wallis test. The p-value indicates the statistical significance of the difference in iodine content between regions. Significant p-value <0.05 are bolded.

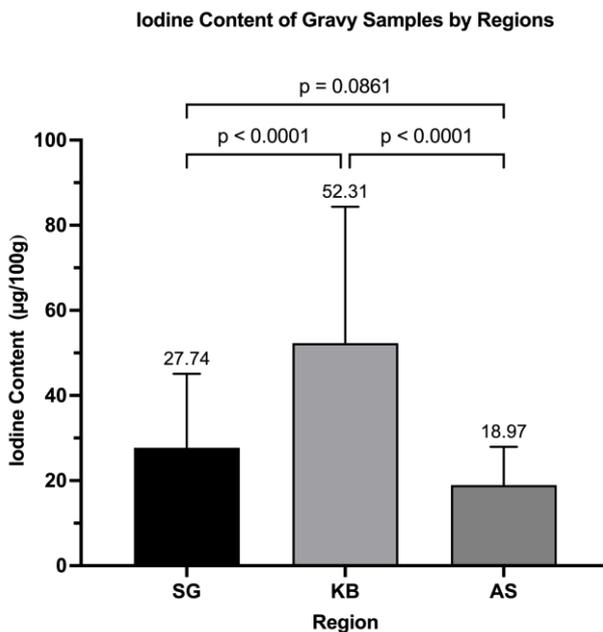
**Iodine content of several types of gravies across regions**

The iodine content in the different gravy samples ranged from approximately 5 to 140  $\mu\text{g}/100\text{g}$  (Table 4). The highest iodine concentrations were found to be in gravies that combined marine fish (saltwater fish) with salt-rich or fermented condiments. Soy sauce mackerel fish gravy (K21/2) recorded the highest iodine content ( $134.10 \pm 6.54 \mu\text{g}/100\text{g}$ ), followed by spicy and sour tamarind mackerel fish gravy, K16/2 ( $124.18 \pm 0.86 \mu\text{g}/100\text{g}$ ) then ginger mackerel fish soup, K23/2 ( $100.88 \pm 3.46 \mu\text{g}/100\text{g}$ ). All three of these gravies share common ingredients which are marine fish and uses salt-rich and fermented condiments, such as soy sauce, along with other seasoning bases that are typically prepared using added salt during cooking. This suggests that iodine contribution depends on the combined effects of protein source and seasonings composition rather than fish content alone.

Meanwhile, the lowest iodine concentrations were predominantly meat-based, lacking fermented condiments and marine-derived ingredients gravies. The three gravies that recorded the lowest iodine content were found in chicken Tom Yum, K08/3 ( $5.63 \pm 0.99 \mu\text{g}/100\text{g}$ ) followed by beef Tom Yum, K15/3 ( $6.98 \pm 0.28 \mu\text{g}/100\text{g}$ ) then soy sauce beef, K11/3 ( $7.95 \pm 0.70 \mu\text{g}/100\text{g}$ ). These findings indicate that iodine levels in Malaysian gravies are primarily influenced by inclusion of marine seafood and ingredient formulation, particularly the use of fermented seasonings and iodized salt. Otherwise, all types of gravies were noted to be significant between regions ( $p<0.05$ ), except spicy and sour tamarind chicken, in which were not significant in either between regions or pairwise comparison of the regions.

**Figure 3**

Mean comparison of iodine content between different regions



Note: Comparison of mean iodine concentration ( $\mu\text{g}/100\text{ g}$ ) in Malaysia gravies across three geographical regions. SG - Selangor (central region); AS - Kedah (north region); KB - Kelantan (east region). Bars represent regional means and error bars denote the standard deviation (SD) across samples within each region. Horizontal brackets indicate pairwise comparisons between regions performed using the Kruskal-Wallis test followed by post-hoc multiple comparisons. A  $p$ -value  $<0.05$  was considered statistically significant.

## DISCUSSION

The recommended daily intake of iodine, as established by the World Health Organization (WHO), varies by life stage to ensure optimal thyroid function. Children need  $120\ \mu\text{g}/\text{day}$ , while adolescents and adults require  $150\ \mu\text{g}/\text{day}$ . The requirement is significantly higher for pregnant and lactating women, who need  $250\ \mu\text{g}/\text{day}$  to support both their own health and the development of the fetus or infant. Recommended daily intake of iodine for Malaysia-children;  $72\text{--}108\ \mu\text{g}/\text{day}$ , adolescent;  $98\text{--}144\ \mu\text{g}/\text{day}$ , adults;  $98\text{--}124\ \mu\text{g}/\text{day}$ , pregnant and lactating women;  $200\ \mu\text{g}/\text{day}$  (National Coordinating Committee on Food and Nutrition (NCCFN), 2005). Gravy samples with a low iodine content ( $5\text{--}20\ \mu\text{g}/100\text{g}$ ) provide only a minimal contribution to these daily recommendations, making them an unreliable for meeting iodine needs, particularly for groups with higher requirements like pregnant and lactating women. In contrast, gravies with a high iodine content ( $>100\ \mu\text{g}/100\text{g}$ ) can contribute substantially to the daily intake. While this can benefit those with a low dietary intake, excessive iodine can be problematic. Both insufficient and excessive iodine intake can disrupt thyroid function. This is especially concerning for pregnant women, as thyroid hormones are crucial for fetal brain development. Excessive iodine intake can lead to adverse effects such as hyperthyroidism or goitre, highlighting the importance of balancing iodine consumption to prevent both deficiency and toxicity (Smyth, 2021).

The iodine content in food is significantly influenced by cooking methods, with seafood being a primary source of dietary iodine (Dydykin et al., 2023). Seafood, particularly marine fish like mackerel, absorbs iodine from seawater, making it a naturally rich source. Our current findings are aligned with a study on Nigerian raw and cooked mackerel, with both studies showing a high concentration of  $114.84 \pm 3.59\ \mu\text{g}/100\text{g}$  (Awodi & Nwokem, 2022).

The present findings also indicate that iodine content in Malaysian gravies is driven by ingredient composition rather than protein source alone. Gravies incorporating marine fish generally exhibited higher iodine concentrations, however, the highest values were observed specifically in preparations incorporating salt-rich and fermented condiments, such as soy sauce-based gravies. Soy sauce can contribute iodine indirectly through the use of iodized salt during fermentation and processing, which resulting in potentially substantial iodine levels in the final dish. A previous study have reported that light and salty soy sauces sold in Malaysian supermarkets contained the highest sodium levels as compared to other type of sauces, such as tomato sauce, chili sauce and fish sauce, marking them as a primary dietary salt sources (Shahar et al., 2019). The iodine content in these gravies likely reflects the added iodized salt used during seasoning production. This is consistent with findings in Taiwan, where iodized salt was identified as the principal iodine source in soy sauce (Huang et al., 2023). In Malaysian cuisines, combining fermented seasonings with iodine-rich marine fish are commonly used in Malaysian cooking and may amplify iodine content significantly. This synergy explains why

soy sauce mackerel fish gravy exhibited higher iodine levels compared to fish gravies prepared without fermented condiments.

Conversely, meat-based gravies and non-fermented preparations, such as chicken and beef Tom Yum, showed consistently low iodine content, reflecting limited iodine contribution from both the primary protein source and seasoning profile. Specifically, chicken Tom Yum gravy, which uses chicken as its primary protein source, was found to have the lowest iodine content, likely because poultry are typically raised on plant-based diets, which are naturally low in iodine, contrasting sharply with the iodine-rich diets of marine fish. Consequently, individuals or livestock on predominantly plant-based diets may be at risk of iodine deficiency unless supplemented by iodized salt (Nicol et al., 2024). These findings highlight that iodine intake from prepared foods depends not only on protein sources, but also on

**Table 4**

*Iodine content of different types of gravies across region.*

Sample name (Local name)	Sample code	n	Iodine content ( $\mu\text{g}/100\text{g}$ )	p-value			
				Overall#	SG vs. AS*	SG vs. KB*	AS vs. KB*
Chicken Curry with Coconut Milk (Kari Ayam Bersantan)	K01/1	3	71.20 $\pm$ 2.87	<0.001	<0.001	<0.001	0.090
	K01/2	3	25.73 $\pm$ 1.87				
	K01/3	3	19.01 $\pm$ 0.82				
Chicken Curry (Kari Ayam)	K02/1	3	10.10 $\pm$ 0.66	<0.001	0.003	<0.001	<0.001
	K02/2	3	31.91 $\pm$ 1.24				
	K02/3	3	19.45 $\pm$ 0.34				
Soy Sauce Chicken (Ayam Masak Kicap)	K03/1	3	14.52 $\pm$ 0.68	0.049	0.106	0.536	0.047
	K03/2	3	15.27 $\pm$ 0.59				
	K03/3	3	12.57 $\pm$ 0.63				
Korma Chicken (Ayam Kurma)	K04/1	3	47.64 $\pm$ 1.54	<0.001	<0.001	0.005	<0.001
	K04/2	3	37.08 $\pm$ 1.03				
	K04/3	3	15.49 $\pm$ 0.54				
Spicy Tomato Chicken (Masak Merah Ayam)	K05/1	3	12.56 $\pm$ 0.58	<0.001	0.004	<0.001	0.003
	K05/2	3	47.51 $\pm$ 0.46				
	K05/3	3	29.69 $\pm$ 2.69				
Chicken Soup (Sup Ayam)	K06/1	3	49.59 $\pm$ 3.37	0.001	<0.001	0.021	0.003
	K06/2	3	38.18 $\pm$ 0.50				
	K06/3	3	16.26 $\pm$ 0.28				
Chicken Tom Yum (Tom Yum Ayam)	K08/1	3	51.16 $\pm$ 1.34	<0.001	<0.001	<0.001	<0.001
	K08/2	3	33.24 $\pm$ 0.55				
	K08/3	3	5.63 $\pm$ 0.99				
Beef Curry with Coconut Milk (Kari Daging Bersantan)	K09/1	3	25.89 $\pm$ 1.77	<0.001	0.005	<0.001	<0.001
	K09/2	3	47.01 $\pm$ 0.12				
	K09/3	3	16.23 $\pm$ 0.03				

*Note: # One-way ANOVA; \* Tukey's post-hoc. SG - Selangor (central region); AS - Kedah (north region); KB - Kelantan (east region). Sample codes (KXX/1, KXX/2, and KXX/3) correspond to SG, KB, and AS, respectively. For each gravy type, iodine content values represent regional mean  $\pm$  SD from three independent gravy samples per region (biological replicates, n=3), each analyzed in analytical duplicate (n=2) and were averaged prior to calculation of regional means. Overall  $p < 0.05$  indicates a significant difference exists among the three regions, while pairwise p-values (e.g., SG vs. AS) identify specifically which regions differ. Significant p-values <0.05 are bolded.*

**Table 4 (continued)***Iodine content of different types of gravies across region.*

Sample name (Local name)	Sample code	n	Iodine content ( $\mu\text{g}/100\text{g}$ )	p-value			
				Overall#	SG vs. AS*	SG vs. KB*	AS vs. KB*
Beef Curry (Kari Daging)	K10/1	3	10.71 $\pm$ 0.42	<0.001	0.004	<0.001	<0.001
	K10/2	3	70.90 $\pm$ 2.18				
	K10/3	3	24.49 $\pm$ 0.63				
Soy Sauce Beef (Daging Masak Kicap)	K11/1	3	10.90 $\pm$ 0.41	0.019	0.021	0.815	0.029
	K11/2	3	10.57 $\pm$ 0.37				
	K11/3	3	7.95 $\pm$ 0.70				
Korma Beef (Kurma Daging)	K12/1	3	39.06 $\pm$ 0.73	<0.001	<0.001	0.093	<0.001
	K12/2	3	36.20 $\pm$ 1.16				
	K12/3	3	11.30 $\pm$ 0.65				
Spicy Tomato Beef (Masak Merah Daging)	K13/1	3	9.31 $\pm$ 0.02	<0.001	0.199	<0.001	<0.001
	K13/2	3	56.27 $\pm$ 2.03				
	K13/3	3	12.01 $\pm$ 0.11				
Beef Soup (Sup Daging)	K14/1	3	9.12 $\pm$ 0.16	<0.001	<0.001	<0.001	<0.001
	K14/2	3	36.18 $\pm$ 0.94				
	K14/3	3	20.83 $\pm$ 0.60				
Beef Tom Yum (Tom Yum Daging)	K15/1	3	17.13 $\pm$ 1.66	0.001	0.030	0.004	<0.001
	K15/2	3	37.04 $\pm$ 3.05				
	K15/3	3	6.98 $\pm$ 0.28				
Spicy And Sour Tamarind Mackerel Fish (Asam Pedas Ikan Kembung)	K16/1	3	51.38 $\pm$ 0.40	<0.001	<0.001	<0.001	<0.001
	K16/2	3	124.18 $\pm$ 0.86				
	K16/3	3	31.90 $\pm$ 0.76				
Spicy And Sour Tamarind Chicken (Asam Pedas Ayam)	K17/1	3	49.34 $\pm$ 0.50	0.488	0.691	0.426	0.842
	K17/2	3	31.48 $\pm$ 0.18				
	K17/3	3	38.58 $\pm$ 21.35				
Spicy And Sour Tamarind Beef (Asam Pedas Daging)	K18/1	3	17.13 $\pm$ 1.20	<0.001	0.031	<0.001	<0.001
	K18/2	3	56.41 $\pm$ 2.24				
	K18/3	3	24.67 $\pm$ 0.60				
Mackerel Fish Curry with Coconut Milk (Kari Bersantan Ikan Kembung)	K19/1	3	23.71 $\pm$ 0.83	<0.001	0.003	<0.001	<0.001
	K19/2	3	75.65 $\pm$ 1.16				
	K19/3	3	14.10 $\pm$ 0.18				
Mackerel Fish Curry (Kari Tanpa Santan Ikan Kembung)	K20/1	3	15.32 $\pm$ 0.06	<0.001	0.026	<0.001	<0.001
	K20/2	3	96.56 $\pm$ 3.91				
	K20/3	3	27.40 $\pm$ 0.39				

Note: # One-way ANOVA; \* Tukey's post-hoc. SG - Selangor (central region); AS - Kedah (north region); KB - Kelantan (east region). Sample codes (KXX/1, KXX/2, and KXX/3) correspond to SG, KB, and AS, respectively. For each gravy type, iodine content values represent regional mean  $\pm$  SD from three independent gravy samples per region (biological replicates, n=3), each analyzed in analytical duplicate (n=2) and were averaged prior to calculation of regional means.

Overall  $p < 0.05$  indicates a significant difference exists among the three regions, while pairwise  $p$ -values (e.g., SG vs. AS) identify specifically which regions differ. Significant  $p$ -values  $< 0.05$  are bolded.

**Table 4 (continued)**

*Iodine content of different types of gravies across region.*

Sample name (Local name)	Sample code	n	Iodine content ( $\mu\text{g}/100\text{g}$ )	p-value			
				Overall#	SG vs. AS*	SG vs. KB*	AS vs. KB*
Soy Sauce Mackerel Fish (Kicap Ikan Kembung)	K21/1	3	28.45 $\pm$ 1.22	<0.001	0.997	<0.001	<0.001
	K21/2	3	134.10 $\pm$ 6.54				
	K21/3	3	28.16 $\pm$ 0.36				
Korma Skipjack Tuna Fish (Kurma Ikan Tongkol)	K22/1	3	26.60 $\pm$ 0.21	<0.001	<0.001	<0.001	<0.001
	K22/2	3	32.90 $\pm$ 0.11				
	K22/3	3	18.98 $\pm$ 0.39				
Ginger Mackerel Fish Soup (Masak Singgang Ikan Kembung)	K23/1	3	14.13 $\pm$ 0.02	<0.001	0.023	<0.001	<0.001
	K23/2	3	100.88 $\pm$ 3.46				
	K23/3	3	25.52 $\pm$ 0.64				
Red Snapper Soup (Sup Ikan Merah)	K24/1	3	32.54 $\pm$ 0.81	<0.001	0.005	0.011	<0.001
	K24/2	3	43.36 $\pm$ 2.42				
	K24/3	3	17.98 $\pm$ 0.04				
Mixed Tom Yum (Tom Yum Campur)	K25/1	3	28.25 $\pm$ 1.26	<0.001	<0.001	0.005	<0.001
	K25/2	3	36.85 $\pm$ 0.54				
	K25/3	3	10.09 $\pm$ 0.65				

Note: # One-way ANOVA; \* Tukey's post-hoc. SG - Selangor (central region); AS - Kedah (north region); KB - Kelantan (east region). Sample codes (KXX/1, KXX/2, and KXX/3) correspond to SG, KB, and AS, respectively. For each gravy type, iodine content values represent regional mean  $\pm$  SD from three independent gravy samples per region (biological replicates,  $n=3$ ), each analyzed in analytical duplicate ( $n=2$ ) and were averaged prior to calculation of regional means. Overall  $p < 0.05$  indicates a significant difference exists among the three regions, while pairwise  $p$ -values (e.g., SG vs. AS) identify specifically which regions differ. Significant  $p$ -values  $< 0.05$  are bolded.

culinary practices, seasoning choices, and the use of iodized salt. Given the variability observed, reliance on gravy-based dishes alone may result in inconsistent iodine intake, underscoring the importance of standardised iodized salt usage in household and commercial food preparation.

This study also highlights how different cooking techniques affect iodine retention by the interaction between the cooking medium (oil or water) and the duration of heat exposure. In the present study, gravy samples cooked by frying, such as soy sauce mackerel fish gravy, tended to have a higher iodine content compared than those prepared by boiling or simmering. Although exposure to high temperatures can promote iodine loss through oxidation and reduction reactions, a study on horse mackerel found that frying resulted in less iodine loss ( $151.2 \pm 8.1 \mu\text{g}/100\text{g}$  after cooking) compared to boiling ( $145.4 \pm 9.0 \mu\text{g}/100\text{g}$ ) (Aslan Çin et al., 2024). This may be attributed to the fact that iodine salts is water soluble (Espino-Vázquez et al., 2022). Hence, this suggests that high water content in boiling or simmering methods might facilitate greater iodine leaching into the cooking liquid. Furthermore, the presence of fats and oils during oil-based cooking methods like frying, may act as a protective barrier, potentially reducing the oxidation of iodide to volatile iodine gas during heating. Consistent with this, previous studies have reported that iodine loss were at the most minimum during frying as compared to other cooking methods such as boiling and roasting (Rana & Raghuvanshi, 2013). However, prolonged cooking durations, which is common in traditional Malaysian gravies like curries, increase the total time for these reduction-oxidation reactions to occur, potentially leading to greater iodine loss regardless of the medium. This observation aligns with the findings of the present study, where gravies cooked by frying like soy sauce mackerel fish exhibited the highest iodine content while the gravies cooked by boiling like chicken Tom Yum showed the lowest.

The geographical origin of food also impacts its iodine concentration. Coastal regions, being closer to the ocean, have iodine-rich soil, leading to higher iodine levels in local crops and freshwater sources. A study by He et al. (2022) found that marine fish have significantly higher iodine content than freshwater fish, reflecting the high iodine concentration in seawater. This geographical variation directly affects the iodine content of local food ingredients and, consequently, the population's dietary intake. It was concluded that the soil in coastal regions is more enriched in iodine compared to the regions more remote from the sea (Jensen et al., 2019). Soil iodine levels can affect the plant-based ingredients used in making the gravies. Plants absorb iodine from roots or above-ground structures such as in the soils they grow (Kiferle et al., 2021). Hence, in regions with iodine-deficient soil, crops such as vegetables, spices, and herbs used in gravies will naturally have lower iodine content.

Moreover, the high iodine levels found in the east region gravies ( $134.10 \pm 6.54 \mu\text{g}/100\text{g}$ ) suggested that these traditional dishes can contribute significantly to dietary iodine requirements, potentially helps in meeting the daily requirement of iodine per day. Considering a typical gravy serving size of approximately 50–100 g per meal, gravies with iodine concentrations above  $100 \mu\text{g}/100 \text{g}$  like soy sauce mackerel may contribute substantially (45–90%) to the recommended daily iodine intake for adults in a single serving.

The diverse food preparation methods, ethnic backgrounds, and geographical locations within Malaysia contribute to significant variations in iodine intake among the population. The data on iodine content in different gravies provides valuable insights into the necessity for greater awareness of daily iodine intake. To address potential iodine deficiencies and prevent related health complications, policies emphasizing the nutritional values of food are crucial. Implementing public health strategies, such as promoting the use of iodized salt and raising awareness about iodine-rich foods, is essential to improve the overall nutritional health of the Malaysian population.

## CONCLUSION

This study demonstrates the iodine content of Malaysian gravies differs significantly across regions and ingredients, ranging from 5.63 to  $134.10 \mu\text{g}/100\text{g}$ . Compared with gravies based on chicken or beef, fish-based gravies (particularly soy sauce mackerel fish gravy) were shown to provide a substantial contribution towards the daily recommended iodine intake for adults (up to 45–90% per typical 50–100 g serving), which may subsequently help in mitigating iodine deficiency. This current study also highlights the critical need for initiatives for region specific dietary strategies. In regions with lower gravy iodine content, such as in the north region, promoting the consumption of iodine rich gravies or increase the use of iodized salt in low iodine gravies is highly encouraged to meet the recommended daily intake of  $150 \mu\text{g}/\text{day}$  for adults.

Furthermore, this study provides the first comprehensive dataset on iodine content for commonly consumed Malaysian gravies, filling a critical gap in the Malaysian Food Composition Database (MyFCD), supporting more accurate dietary assessments and public health recommendations for the Malaysian population. To comprehensively assess iodine intake, further research is suggested using objective measures. It's recommended that future studies incorporate biomarkers like urinary iodine concentration (UIC) to accurately gauge individual iodine levels. Additionally, implementing dietary questionnaires would provide deeper insights into how the consumption of specific regional gravies contributes to iodine status and overall nutritional health across the diverse populations of Malaysia. This combined approach would offer a more complete picture, enabling targeted public health interventions.

## AUTHOR CONTRIBUTIONS

Wan Ahmad Syazani Mohamed conceived the study, performed statistical analyzes, interpreted the data and drafted the manuscript. Suriana Adanan, Nur Adriana Athirah Muhammad Rhadi and Nur Syahzanani Aqilah binti Jami'an conducted the experiment and drafted the manuscript. Norhayati Mustafa Khalid and Nurul Aznyda Norizan assisted in developing experimental protocol and data collection. Ahmad Ali Zainuddin, Sulhariza Husni Zain and Kimberly Wong Yui Y'ng assisted in funding acquisition. Aswir Abd Rashed and Mohd Fairulnizal Md Noh supervised the study and provided critical feedback on the manuscript. All authors have read and approved the final manuscript.

## ETHICS APPROVAL

Not applicable.

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## CONFLICT OF INTEREST

The authors declare no conflicts of interest in this work.

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