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Food safety practices as determinants of self-reported foodborne illness among seafood consumers

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ABSTRACT

Improper food handling practices in the supply chain significantly contribute to foodborne illnesses. As global concerns about food safety intensify, understanding domestic practices and raising consumer awareness are essential. This study examines the association between self-reported foodborne illness and seafood handling practices among consumers in Kerala, India. A cross-sectional survey using an online questionnaire was conducted from March to December 2023, involving 2,079 seafood consumers. Of the respondents, 8.5% (n = 177) reported experiencing a seafood-borne illness. Consumers who reported illness (case group) demonstrated significantly lower adherence to safe seafood handling practices compared to those who did not (control group). Multivariate logistic regression identified demographic and behavioural predictors of illness. Key factors significantly associated with increased illness risk included younger age, occupation, income, and residence. Unsafe practices such as improper seafood purchasing, inadequate hygiene, cross-contamination, and poor temperature control were associated with a higher risk. Protective behaviours like checking freshness, thorough cooking, reheating, and prompt refrigeration reduced risk. Although raw data showed a higher proportion of illness among older adults, regression analysis revealed that increasing age was associated with a reduced likelihood of illness, underscoring the need to control for confounders. These findings highlight the need for targeted education, demographic initiatives, and oversight.

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1. Introduction

Foodborne illness is a significant global health concern, frequently resulting in acute or subacute diseases following the consumption of contaminated food or water (Almaary, 2023). The World Health Organisation (WHO) highlights the impact of these illnesses, particularly in developing nations, where foodborne illnesses contribute significantly to morbidity and mortality. Each year, more than 600 million people worldwide suffer from foodborne illness, with children under five years old accounting for 30% of the fatalities (WHO, 2015). Seafood, in particular, poses considerable health risks due to its highly perishable nature and susceptibility to contamination by pathogens and toxins throughout the supply chain. In the United States alone, seafood was linked to 4,815 illness outbreaks between 1998 and 2015, resulting in 359 hospitalisations and four deaths (Barrett et al., 2017). Similarly, the Caribbean, Japan, Korea, and the Pacific have reported multiple seafood-related food poisoning outbreaks (Chinain et al., 2021; Fleming et al., 2018). Common pathogens associated with seafood-borne illnesses include *Vibrio spp., Salmonella spp., Shigella spp., Escherichia coli,* and *Listeria monocytogenes* (Almaary, 2023; Ayyappan & Joseph, 2021). These pathogens can cause a range of symptoms, from mild gastrointestinal disturbances such as nausea, diarrhoea, and stomach pain to more severe systemic illnesses, including fever, headache, and tachycardia. These health risks underscore the importance of understanding seafood handling practices to reduce contamination, mitigate associated risks and protect consumer health.

In the United States, 52% of seafood-related outbreaks are linked to restaurant meals, and 33% to seafood prepared at home (Barrett et al., 2017). This underscores the importance of maintaining food safety across the entire supply chain from production to the consumer's table. Adopting effective food safety practices, such as thorough cleaning, appropriate cooking, adequate chilling and freezing, proper storage and preventing cross-contamination, plays a vital role in mitigating these risks (FDA, 2024b; WHO, 2015). Consumers' food handling practices at home are equally critical in minimising foodborne illnesses. Raising awareness about potential hazards including biological, chemical and physical risks in seafood, including toxins and pathogens, and the adoption of proper storage, preparation and preservation techniques are essential for inhibiting spoilage, minimising risks and maintaining seafood quality and safety (Choudhury et al., 2022; Lupo & Angot, 2020). Therefore, maintaining good handling practices throughout the supply chain and at the consumer level is essential to ensure seafood remains safe for consumption.

In India, despite regulatory efforts by agencies such as the Food Safety and Standards Authority of India (FSSAI) and the Integrated Disease Surveillance Program (IDSP), substantial research gaps persist, particularly regarding household seafood handling practices and their impact on foodborne illness incidence. This study addresses these gaps by examining the relationship between self-reported foodborne illness and seafood handling practices among seafood consumers in Kerala, India. The study compares handling practices between those who have experienced seafood-related illnesses and those who have not. By addressing this research gap, the study aims to inform targeted public health initiatives and enhance regulatory oversight to reduce illness risks and improve

consumer awareness of safe food handling. While this study specifically investigates seafood-borne illnesses due to their regional dietary significance, it does not rule out the possibility that other food sources may contribute to reported symptoms. The study's focus reflects the high prevalence of seafood in local diets, its potential association with foodborne illnesses as reported, and the seafood handling practices followed by participants.

2. Materials and Methods

2.1 Participants

Kerala is a coastal state in India with one of the highest fish consumption rates in the country, with a per capita consumption of approximately 30 kg per year – more than three times the national average of 8.89 kg – and an estimated 85% of the population consuming fish regularly (Salim, 2020; Salim et al., 2024). This exceptionally high seafood dependence underscores the dietary significance of seafood in the region and the public health importance of safe handling practices. This study surveyed seafood consumers from 14 districts of Kerala between March and December 2023. Participants were recruited through convenience sampling. Online survey forms (Microsoft Forms and Google Forms) were distributed via social media platforms, ensuring accessibility for individuals with internet access while capturing diverse demographics. A total of 3000 respondents were invited to participate in the survey, and 2484 participated. The eligibility criteria for participation included: (1) seafood consumers being 18 years or older, (2) consuming seafood at least once per week, and (3) residing in Kerala. To enhance data quality, responses were screened for completeness and consistency. After excluding incomplete and duplicate entries, a total of 2079 valid responses were included in the final analysis.

2.2 Research Design

The study used a cross-sectional survey design, and a semi-structured, self-administered questionnaire. The questionnaire was developed by integrating established literature (Baptista et al., 2020; Langiano et al., 2011; Mol et al., 2018), and insights from field interactions, and expert consultation to ensure that it was both comprehensive and relevant to seafood consumers in Kerala. To ensure seafood's contribution to reported illnesses, the questionnaire included targeted questions about specific symptoms reported following seafood consumption. Participants were also asked to differentiate between seafood-related illnesses and other potential health conditions. Questions such as "Are you currently having any disease or systemic illness other than food poisoning or seafood-borne illness?" were included to isolate seafood-related symptoms.

Respondents who reported health-related symptoms following seafood consumption were operationally designated as the Case group, while those who did not were designated as the Control group. To minimise misclassification, reported illness causes were categorised into: (i) handling-related illnesses (spoilage, cross-contamination, or improper preparation); (ii) non-handling-related conditions (allergic reactions and histamine poisoning from oily fish), and (iii) unidentified health-related factors. All self-reported cases were retained in the primary analysis, as pathogen-level verification was outside the scope of this consumer-behaviour study. The detailed distribution of illness causes is presented in Section 3.3.

The questionnaire was divided into three sections:

(i) Demographic characteristics: Six questions covered participants' age, gender, education, occupation, family monthly income, and area of residence;

(ii) Seafood consumption habits and illness experiences: Four questions assessed the participants' role in purchasing and preparing seafood, their frequency of seafood consumption, and self-reported seafood-borne illnesses experienced in the past year, along with the reasons for illness.

(iii) Seafood handling practices: Twenty statements were aligned with the Five Keys to Safer Food guidelines from the World Health Organisation (WHO, 2006), focusing on key food safety practices such as keeping clean, separating raw and cooked foods, cooking thoroughly, storing food at safe temperatures and using safe water and raw materials. Responses were rated on a 5-point scale ranging from "Never" to "Always" (*Table 2*).

For standardisation, the survey responses were categorised and transformed based on their risk implications. Practices that inherently increased the risk of seafood-borne illness were reverse-coded so that higher scores corresponded to higher risk. For other practices, higher scores directly represented safer practices. Final scores were further classified into three categories based on their mean scores: unsafe practices (0.00–2.00), moderately safe practices (2.05–3.5), and safe practices (3.55–5.00). The questionnaire was translated into the regional language of Kerala, Malayalam, and validated using a back-translation method to ensure accuracy and comprehension. Informed consent was obtained from all participants, and data confidentiality was strictly maintained, with no incentives offered. The questionnaire's reliability was confirmed by Cronbach's alpha values ranging from 0.788 to 0.817, indicating good internal consistency across the sections. The questionnaire's validity was ensured through expert review and a pilot test conducted among 52 seafood consumers, with feedback used to refine the questionnaire for clarity and relevance.

2.3 *Statistical Analysis*

Descriptive statistics were used to summarise categorical data, including demographic characteristics, illness incidence, and seafood handling practices. An independent-samples t-test was used to compare seafood handling practices (mean scores for 20 statements, measured on a 5-point scale ranging from 0 (Never) to 5 (Always)) between participants who experienced seafood-related illnesses and those who did not. The Mann-Whitney U test was applied as a non-parametric alternative for variables that did not meet normality assumptions (McKnight & Najab, 2010) *(Table 3)*. Multivariable logistic regression was conducted to assess the association between self-reported foodborne illness (dependent variable) and demographic characteristics

and seafood-handling practices (independent variables). Collinearity among independent variables was evaluated using linear regression with tolerance values (<0.1) and the variance inflation factor (VIF>10). Odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated for each independent significant variable (*Table 4*). Statistical significance was set at $P < 0.05$, and data were analysed using the Statistical Package for the Social Sciences (SPSS Inc. Version 26.0).

3. Results

3.1 Demographic and behavioural characteristics of respondents

The age distribution of respondents showed that the largest groups were aged 27–42 years (33.0%) and 18–26 years (32.9%), with the smallest proportion (12.1%) in the 59–77 age group (*Table 1*). Females made up the majority (53.7%) of the sample, followed by males (46.3%). Education levels indicated that 33.1% held a degree, while 26.0% had a master's degree, and 24.4% had a PhD or an equivalent professional degree. Students constituted the largest occupational category (37.4%), followed by private employees (20.3%) and government servants (20.1%). Monthly family income ranged primarily between 40,001 and 60,000 INR for 27.8% of respondents. In terms of residence, 42.5% lived in suburban areas, 33.6% in urban areas, and 23.9% in rural areas. Over half of the respondents (54.7%) identified as the principal seafood purchasers for their households, and 43.9% were responsible for seafood preparation. Seafood purchase frequency varied: 42.8% bought it on alternate days, and 22.8% bought it daily.

3.2 *Incidence and distribution of seafood-borne illness*

Of the 2079 respondents, 8.5% (n = 177) reported experiencing seafood-related illnesses. The incidence of illness varied significantly across age groups ($p < 0.001$), with the highest rate among older adults aged 59–77 years (18.7%). In contrast, rates were lower among those aged 18–26 years (7.2%), 27–42 years (6.7%), and 43–58 years (7.6%) *(Table 1)*. Males reported marginally higher illness rates than females (9.7% vs. 7.5%, $p = 0.080$). Education level was significantly associated with illness ($p = 0.009$), with the highest incidence among respondents with PhD or equivalent degrees (11.6%) and the lowest among those with a degree (6.1%). Unemployed individuals reported the highest illness rates (25.7%), while business and self-employed respondents reported the lowest (5.8%) ($p < 0.001$). Respondents with a monthly family income of 20,001–40,000 INR reported the highest incidence (12.4%), while those earning 40,001–60,000 INR reported the lowest (5.9%) ($p = 0.002$). Urban residents exhibited significantly higher illness rates than rural residents (10.9% vs. 6.6%, $p = 0.018$). Behavioural factors also influenced illness rates: principal seafood purchasers (11.6%) and principal seafood preparers (10.2%) reported higher rates ($p < 0.001$ and $p = 0.015$, respectively). Weekly purchasers (10.8%) reported higher illness rates compared to daily (8.6%) or alternate-day purchasers (6.6%) ($p = 0.013$).

3.3 Self-reported health concerns associated with seafood consumption

Among the 8.5% (n=177) of respondents who reported health-related issues after seafood consumption, the most common symptoms were vomiting (n=63, 35.6%), diarrhoea (n=36, 20.3%), allergy (n=42, 23.7%), stomach pain (n=22, 12.4%), and headache (n=14, 7.9%). The primary causes of these illnesses were classified into three categories: (i) Handling-related illnesses (47.4%, n=84): Attributed to spoiled or contaminated seafood (28.8%, n=51), improperly cleaned shellfish (7.9%, n=14), and consumption from street vendors or restaurants (10.2%, n=18), (ii) Non-handling-related illnesses (40.6%, n=72): From allergic reactions (29.9%, n=53) and histamine poisoning from oily fish (10.7%, n=19), and (iii) Other unidentified health-related factors (12.4%, n=22).

3.4 *Food handling practices among seafood consumers of Kerala*

Among the 2079 respondents, the Case group (n=177) reported experiencing seafood-related illnesses, while the Control group (n=1902) did not. The analysis revealed variations in food handling practices, with differences observed across illness groups *(Table 2)*. The average score for the food practices among respondents was 2.7 ± 0.6. The case group reported lower adherence to hygiene practices, such as washing hands with soap before handling raw seafood, with a mean score of 2.14 compared to the Control group's mean score of 2.53. Additionally, a larger proportion of the Case group failed to sanitise utensils and countertops after contact with raw seafood, with 74.0% of respondents in the Case group not performing this critical step, compared to 64.3% in the Control group. Similarly, unsafe thawing practices were more common in the Case group, where 63.3% thawed frozen seafood at room temperature, compared to just 27.2% in the Control group. The higher frequency of unsafe thawing practices in the Case group was statistically significant ($p < 0.001$), indicating an increased risk of foodborne illness. Both groups exhibited moderate scores for practices such as storing raw seafood separately from cooked foods, with the Case group scoring 3.21 and the Control group scoring 4.25 on the scale.

Additionally, the Case group reported moderate adherence to practices like ensuring raw seafood fluids did not drip onto other foods (mean = 2.69) and refreezing thawed fish (mean = 2.93). The Case group demonstrated higher adherence to safe practices, such as checking seafood freshness by smell, texture, and appearance, with a mean score of 4.71. Similarly, 77.4% of the Case group reported cooking seafood thoroughly until it was opaque and flaked easily. However, this was still significantly lower than the Control group, where 94.7% followed this practice ($p < 0.001$). The Case group reported reheating leftover seafood more frequently, with 93.2% engaging in this practice compared to 86.1% in the Control group ($p = 0.012$). Despite these safety

Table 1. Demographic characteristics and unadjusted incidence of self-reported seafood-related illness among respondents (N = 2,079)

Demographic characteristics	*Total respondents (N)*	*Proportion of ill in category (n=177)*	*p*
Age (segments)			< 0.001
18-26	683	7.2	
27-42	687	6.7	
43-58	458	7.6	
59-77	251	**18.7**	
Gender			0.080
Female	1117	7.5	
Male	962	**9.7**	
Education			0.009
Secondary school	342	9.1	
Degree	688	6.1	
Masters	541	8.3	
PhD/ equivalent	508	**11.6**	
Occupation			< 0.001
Government servant	418	6.9	
Private employee	422	7.6	
Business/ self employed	208	5.8	
Student	778	5.0	
Unemployed	253	**25.7**	
Monthly family income			0.002
<20000	327	9.2	
20001-40000	498	**12.4**	
40001-60000	578	5.9	
60001-80000	474	6.8	
80001<	202	9.4	
Area of residence			0.018
Urban	698	**10.9**	
Suburban	884	7.7	
Rural	497	6.6	
Principal seafood purchaser			<0.001
Yes	1138	**11.6**	
No	941	4.8	
Principal seafood preparer			0.015
Yes	912	**10.2**	
No	1167	7.2	
Purchase frequency			0.013
Daily	474	8.6	
Alternate days	889	6.6	
Weekly	716	**10.8**	

Proportions represent the percentage of respondents within each demographic category who reported experiencing seafood-related illness. These are unadjusted rates. See Table 4 for adjusted associations.

practices, the Control group consistently achieved higher overall safety scores. *Table 2* presents a comprehensive comparison of the seafood-handling practices followed by the Case and Control groups.

3.5 Comparison of food handling practices among the case group and the control group of seafood consumers

The analysis revealed significant differences between the two groups, with the Case group exhibiting riskier food handling behaviours than the Control group (Mann-Whitney U test, $p < 0.05$). Unsafe practices, including inadequate seafood storage, cross-contamination, and improper thawing, were more prevalent among those who reported foodborne illnesses. Significant differences were observed in checking seafood freshness, using separate cutting boards for different types of foods, storing raw seafood separately, and thawing seafood at room temperature ($p < 0.001$). However, certain practices, such as washing hands before handling seafood and using clean plates for cooked seafood, did not show statistically significant differences between the groups *(Table 3)*.

3.6 Multivariate logistic regression analysis

The multivariate logistic regression analysis identified significant relationships between specific food-handling practices, demographic factors, and self-reported foodborne illness. Age, occupation, income, and area of residence were significant predictors of self-reported foodborne illness ($p < 0.05$). Several unsafe food-handling practices increased the likelihood of illness, including failing to sanitise utensils and countertops after contact with raw seafood, not using separate cutting boards for fish, meat, and vegetables, and improper storage of raw seafood in shopping bags or containers. Additionally, keeping fish and other foods on the same shelf in the refrigerator, inadequate cooking, and thawing frozen seafood at room temperature were significantly associated with a higher risk. Other contributing factors included leaving fish on the counter before cooking, reheating leftovers until only warm, and delaying refrigeration beyond two hours ($p < 0.05$). No significant collinearity issues were detected among the independent variables, as confirmed through preliminary linear regression analysis.

Table 2. Food-handling practices among seafood consumers in Kerala based on self-reported incidence of seafood-borne illness

Food handling practices	*Respondents*	*Never*	*Rarely*	*Some times*	*Often*	*Always*	*Mean ± SD*	*p*
Use Safe Water and Raw Materials								
I check seafood freshness by examining smell, texture, and appearance when purchasing.	Case group	4.5	1.7	0.0	6.2	87.6	4.71 ± 0.925	<0.001**
	Control group	1.4	0.6	2.8	38.7	56.5	4.48 ± 0.717	
I ask the retailer to clean/ eviscerate the fish when buying	Case group	44.1	32.8	0.0	0.6	22.6	2.25 ± 1.565	<0.001**
	Control group	66.7	19.1	2.0	4.3	7.8	1.68 ± 1.208	
Keep Clean								
I wash my hands with soap before handling raw seafood	Case group	58.2	15.8	0.0	5.6	20.3	2.14 ± 1.623	0.428
	Control group	57.6	18.6	2.0	13.1	8.6	1.97 ± 1.378	
I clean kitchen surfaces immediately, not just at the end of the day	Case group	71.8	5.1	6.2	6.2	10.7	1.79 ± 1.401	<0.001**
	Control group	87.4	5.6	0.8	1.9	4.3	1.30 ± 0.924	
I don't sanitize utensils and countertops with hot, soapy water after contact with raw seafood	Case group	74.0	5.1	0.6	1.7	18.6	1.86 ± 1.577	0.009*
	Control group	64.3	6.6	0.4	2.2	26.5	2.20 ± 1.757	
Separate Raw and Cooked								
I don't use separate cutting boards for fish, meat, and vegetables	Case group	92.1	0.0	0.0	2.3	5.6	1.29 ± 1.013	<0.001**
	Control group	76.9	14.0	0.9	3.6	4.6	1.45 ± 1.015	
I use clean plates and utensils for cooked seafood, not the same ones used for raw seafood	Case group	11.3	0.0	0.0	6.2	82.5	4.49 ± 1.271	0.913
	Control group	7.0	0.2	0.0	10.8	82.0	4.61 ± 1.043	
I don't keep raw seafood separate from other foods in my shopping bag	Case group	80.2	4.0	0.0	1.1	14.7	1.66 ± 1.437	<0.001**
	Control group	57.4	10.0	0.4	5.0	27.2	2.35 ± 1.764	
I don't store raw seafood in separate containers or zip-lock bags from cooked or ready-to-eat foods	Case group	41.8	0.6	0.0	10.2	47.5	3.21 ± 1.912	<0.001**
	Control group	9.2	3.2	2.0	24.5	61.1	4.25 ± 1.234	
I ensure raw seafood fluids do not drip onto other foods in the shopping bag and refrigerator	Case group	54.2	0.0	5.1	4.0	36.7	2.69 ± 1.898	0.006*
	Control group	43.5	1.3	0.7	8.8	45.8	3.12 ± 1.913	
I keep fish and other foods on the same shelf in the fridge or freezer	Case group	52.5	0.0	0.0	4.0	43.5	2.86 ± 1.971	<0.001**
	Control group	25.3	2.5	2.4	3.7	66.1	3.89 ± 1.742	
Cook Thoroughly								
I don't cook seafood thoroughly until it is opaque and flakes easily.	Case group	4.0	1.7	4.0	13.0	77.4	4.58 ± 0.951	<0.001**
	Control group	1.0	0.1	1.4	2.8	94.7	4.90 ± 0.490	
I reheat leftover seafood until it is warm or hot before eating.	Case group	3.4	1.1	0.0	2.3	93.2	4.81 ± 0.796	0.012*
	Control group	2.1	0.6	1.4	9.8	86.1	4.77 ± 0.701	
Keep Food at Safe Temperatures								
I buy fish just before leaving the market.	Case group	72.9	6.8	2.8	11.9	5.6	1.71 ± 1.290	<0.001**
	Control group	56.8	21.0	2.6	10.9	8.7	1.94 ± 1.344	
I promptly refrigerate or freeze seafood within two hours of purchase	Case group	79.1	6.8	1.7	2.3	10.2	1.58 ± 1.282	0.052
	Control group	83.7	10.1	0.9	2.1	3.2	1.31 ± 0.861	
I thaw frozen seafood at room temperature; not using cold running water.	Case group	63.3	5.1	1.1	11.3	19.2	2.18 ± 1.676	<0.001**
	Control group	27.2	6.7	1.8	16.8	47.5	3.51 ± 1.723	
I refreeze thawed fish unless it has been cooked	Case group	50.3	0.6	0.0	4.0	45.2	2.93 ± 1.970	<0.001**
	Control group	26.4	1.1	1.7	7.3	63.5	3.80 ± 1.742	
I don't leave fish on the counter if I plan to cook it later the same day	Case group	68.9	15.3	1.7	2.8	11.3	1.72 ± 1.330	<0.001**
	Control group	80.8	14.2	1.0	1.6	2.4	1.31 ± 0.784	
I marinate seafood in the refrigerator, not at room temperature	Case group	76.8	9.0	2.3	4.0	7.9	1.57 ± 1.219	0.255
	Control group	70.3	21.9	1.8	2.3	3.8	1.48 ± 0.939	
I label the fish with the date when I put it in the freezer	Case group	79.7	7.9	1.7	3.4	7.3	1.51 ± 1.173	0.389
	Control group	82.0	8.2	1.4	3.3	5.1	1.41 ± 1.040	

Mean score categorisation: Unsafe handling (0.00-2.00), moderate handling practices (2.05-3.5) and safe handling (3.55-5.00)
p: p-value determined using the Mann-Whitney U test.

Table 3. Comparison of seafood handling practices between case and control groups

	Food handling practice	*Mean rank*		*Mann-Whitney u*	*Z*	*p*
		Case group	*Control group*			
1.	I check the freshness of seafood by examining its smell, texture, and appearance during purchasing.	1314.10	1014.49	119812.0	-7.348	<0.001**
2.	When I buy fish from market or stalls, I ask the retailer to eviscerate it.	1266.20	1018.95	128290.0	-6.179	<0.001**
3.	I buy fish just before leaving the market	908.90	1052.20	145122.5	-3.411	<0.001**
4.	I wash my hands with soap before handling raw seafood.	1070.57	1037.16	162916.0	-0.792	0.428
5.	I clean kitchen surfaces only at the end of day	1194.73	1025.60	140940.0	-5.955	<0.001**
6.	I clean and sanitize utensils and countertops with hot, soapy water after they come into contact with raw seafood.	945.44	1048.80	151589.0	-2.607	0.009*
7.	I keep raw seafood separate from other foods in my shopping bag.	830.42	1059.50	131232.0	-5.527	<0.001**
8.	I use a separate cutting board for fish, meat and vegetables.	907.89	1052.29	144943.5	-4.248	<0.001**
9.	I store raw seafood in separate containers or zip-top bags from cooked or ready-to-eat foods.	804.88	1061.88	126710.0	-6.209	<0.001**
10.	I ensure raw seafood juices do not drip onto other foods in the shopping bag and refrigerator.	932.89	1049.97	149368.5	-2.740	0.006*
11.	I use clean plates and utensils for cooked seafood, not the same ones used for raw seafood.	1036.86	1040.29	167771.0	-0.109	0.913
12.	I cook seafood thoroughly until it is opaque and flakes easily with a fork or other utensil	875.82	1055.28	139267.0	-8.729	<0.001**
13.	I reheat leftover seafood until it is warm or hot before eating	1110.63	1034.08	157064.0	-2.503	0.012*
14.	I leave fish on the counter if I plan to cook it later that same day.	1168.93	1028.00	145506.0	-4.273	<0.001**
15.	I marinate seafood in the refrigerator and not at room temperature.	1000.85	1043.64	161397.5	-1.137	0.255
16.	I refrigerate or freeze seafood within two hours of purchase.	1094.49	1034.93	158682.0	-1.944	0.052
17.	I don't keep fish and other foods on the same shelf in the fridge or freezer	793.50	1062.94	124696.0	-6.756	<0.001**
18.	I mark the date on the fish that I put in the freezer.	1064.99	1037.67	163904.5	-0.861	0.389
19.	I thaw frozen seafood in the refrigerator or under cold running water, not at room temperature	663.46	1075.04	101679.0	-9.322	<0.001**
20.	If thawed fish is not used completely, I refreeze it.	829.47	1059.59	131063.0	-5.675	<0.001**

Case group (n=177)
Control group (n=1902)
p <0.05*, p <0.001**

Table 4. Multivariable logistic regression analysis of factors associated with self-reported seafood-related illness

Demographic factors and seafood handling practice		***p*** [a]	**Odds ratio (95% CI)** [b]
1.	Age	0.004*	0.735 (0.597-0.905)
2.	Occupation	<0.001**	0.734 (0.640-0.841)
3.	Monthly income (family)	<0.001**	1.283 (1.103-1.492)
4.	Area of residence	0.002**	1.505 (1.165-1.945)
5.	Check freshness by sensory evaluation	<0.001**	0.616 (0.475-0.800)
6.	Don't sanitize utensils and countertops after raw seafood contact	0.015*	1.210 (1.037-1.411)
7.	Don't use separate cutting boards for fish, meat, and vegetables	0.035*	1.487 (1.029-2.150)
8.	Don't keep raw seafood separate in shopping bag	0.042*	1.200 (1.007-1.429)
9.	Don't store raw seafood in separate containers	<0.001**	1.480 (1.281-1.709)
10.	Keep fish and other foods on the same shelf in fridge	0.006*	1.294 (1.078-1.553)
11.	Don't cook seafood thoroughly	0.003*	1.729 (1.206-2.477)
12.	Reheat leftovers until warm or hot	0.023*	0.662 (0.464-0.945)
13.	Buy fish just before leaving market	<0.001**	1.576 (1.312-1.893)
14.	Promptly refrigerate or freeze seafood within two hours	<0.001**	0.555 (0.448-0.688)
15.	Thaw frozen seafood at room temperature	<0.001**	1.413 (1.200-1.664)
16.	Don't leave fish on counter (plan to cook later)	<0.001**	0.424 (0.330-0.545)

[a] P-value from a multivariable logistic regression model.
[b] Odds ratios (OR) with 95% Confidence Intervals (CI) reflect the likelihood of reporting seafood-related illness based on demographic characteristics and food handling practices. An OR > 1 indicates higher risk; OR < 1 indicates protective factors.

4. Discussion

4.1 Incidence and distribution of seafood-borne illnesses

Seafood is a staple of the diet in the state of Kerala, India, and previous studies have reported foodborne pathogens, toxins, and contamination risks associated with seafood consumption in the region. For instance, Silvester et al. (2022) reported the presence of multidrug-resistant *Vibrio parahaemolyticus* in shellfish from Cochin, a major seafood export hub of Kerala, underscoring the critical need for regular monitoring and intervention to prevent such pathogens from reaching consumers. Similarly, Sunitha et al. (2017) identified *Listeria monocytogenes* and *Salmonella spp.* in raw seafood sourced from Wayanad, a district of Kerala known for its rich natural resources, thus highlighting the potential health risks associated with seafood consumption in the region. However, Menon et al. (2021) emphasised that adherence to good hygiene practices at fish catchment and processing areas could significantly reduce the risks associated with *Listeria* contamination. The study reported that the incidence of self-reported foodborne illness related to seafood consumption was 8.5%, which is lower than the outbreak-based report by Barrett et al. (2017) in the United States and incomparable to the pathogen-specific prevalence rates reported by Tanveer et al. (2024) in Asia, likely due to differences in regional variations in seafood safety practices. This inconsistency could be attributable to exposure to pathogenic factors, study populations, survey administration schedules, research methodologies, and survey techniques. Nevertheless, these findings require further validation through additional research to verify and elucidate the underlying patterns.

4.2 Consumer seafood handling practices at home

Improper food-handling practices in both domestic kitchens and commercial settings can significantly increase the risk of foodborne illness. This study surveyed seafood consumers in Kerala, India, to explore unsafe food-handling practices that may explain the association between home seafood handling practices and foodborne illness. Poor food-handling practices were common among seafood consumers who had experienced foodborne illness, with several practices categorised as unsafe (mean scores ranging from 0.00 to 2.00; *Table 2*). These critical practices require immediate attention to mitigate the risk of seafood-borne illnesses. Mol et al. (2018) reported that 57% of participants from Turkey preferred asking retailers to clean and eviscerate fish at the time of purchase, and nearly 40% always prefer to clean surfaces only at the end of the day. Ozilgen (2010) reported that more than 85% Turkish university students wash their hands with soap and water before preparing food. Baptista et al. (2020) reported that 91.68% of Brazilian respondents across age groups sanitise utensils used for handling raw seafood.

In the survey, a significant percentage of the case group (72.9%) reported avoiding the purchase of fish just before they left the market, and 71.8% of the case group consumers in the study had not cleaned kitchen surfaces immediately. Both findings are consistent with results reported in Turkey (Mol et al., 2018), where 52.8% of consumers always buy fish just before leaving the market and mostly prefer to clean surfaces only at the end of the day. Four fifths of seafood consumers (80.2%) reported that they had not separated raw seafood from other food in their shopping bags. For instance, Godwin & Coppings (2005) reported that 7% of US consumers used coolers to protect cold foods during transport, and that many refrigerators were above the recommended temperature. Hicks (2016) reported that effective temperature management of seafood during transport minimises bacterial growth and spoilage by maintaining quality. Over four-fifths of seafood consumers (92.1%) never use separate cutting boards for fish, vegetables, or meat, which aligns with Koppel et al.'s (2014) study, which found an increased risk of cross-contamination during food preparation.

Furthermore, 83.7% of the control group did not refrigerate or freeze seafood within two hours of purchase, and 61.9% refroze thawed fish. These findings are consistent with observations in Brazil (Baptista et al., 2020) and Asian countries (Koppel et al., 2014). Moreover, 76.8% of seafood consumers did not marinate raw seafood in the refrigerator, contrary to FDA guidelines (FDA, 2024a) that recommend marinating seafood in sealed containers at 5°C, further underscoring the need for improved food safety education on proper food marinating techniques in the mainland (Gong et al., 2011). The study found that nearly 63.3% of consumers thawed seafood at room temperature. This risky behaviour could be mitigated by adopting a "direct-from-frozen" approach (Neff et al., 2021). This involves cooking seafood without defrosting, which could reduce waste, enhance food safety, and increase convenience.

Additionally, only 7.3% of participants in this study reported labelling fish with the freezing date, underscoring the importance of accurate labelling to track the age of frozen seafood and ensure it is consumed safely within the safe period (Hicks, 2016). The findings of this study suggest several key areas for improvement in the food-handling practices of seafood consumers in Kerala, particularly in purchasing, handwashing, surface cleaning and sanitation, marination, and storage behaviours. The literature indicates that consumer knowledge often does not align with their self-reported or observed behaviours (Marasteanu et al., 2018; Redmond & Griffith, 2003), emphasising the need for more observational research to assess food safety practices. Addressing these knowledge and behaviour gaps through targeted education and awareness campaigns is critical to improving food safety behaviours. Consumers must be informed about the importance of adhering to proper food-handling practices at home to reduce the incidence of foodborne illness and promote continuous improvement in their food safety practices.

4.3 Demographic factors, food handling practices and seafood-borne illness

The study found that demographic factors and food handling practices significantly influenced the incidence of seafood-borne illness. Descriptive statistics in *Table 1* indicated that older adults (59–77 years) reported the highest proportion of seafood-related illness (18.7%), while younger adults

aged 27-42 years reported the lowest proportion (6.7%). However, multivariable logistic regression analysis *(Table 4)* revealed that, after adjusting for food-handling practices and other demographic variables, increasing age was associated with a significantly reduced likelihood of reporting foodborne illness (OR = 0.735; 95% CI: 0.597–0.905; p = 0.004).

This contradiction between proportions and adjusted risk suggests that other confounding factors, such as unsafe food-handling behaviours and socioeconomic factors, may independently influence illness rates regardless of age. Although older adults reported higher absolute rates of illness, their adjusted odds of illness were lower after accounting for these behavioural and demographic factors. This finding may reflect safer food-handling behaviours among older adults, as suggested by their higher behavioural scores in areas such as hand hygiene and seafood storage. However, the data do not allow us to draw definitive conclusions about causality, and additional qualitative or longitudinal research would be needed to confirm these mechanisms. One possible explanation is that older adults, despite being biologically more vulnerable to foodborne pathogens due to diminished immune function, may compensate through more cautious and consistent food safety practices developed over a lifetime (Anderson et al., 2011; Buzby, 2002).

On the other hand, younger adults, while biologically more resilient, may engage more frequently in unsafe food handling behaviours, which increases their risk despite their lower absolute reported illness rates (Byrd-Bredbenner et al., 2007, 2008). These observations reinforce the importance of multivariable analysis in epidemiological research, as simple descriptive comparisons may obscure underlying risk patterns. From a public health perspective, these results emphasise the need for targeted food safety education initiatives that specifically address unsafe food-handling practices among younger populations to reduce the risk of seafood-borne illness.

Furthermore, occupation significantly affected foodborne illness incidence ($p < 0.001$), with specific job sectors exhibiting greater risk. Occupations involving long hours or limited access to food safety education may lead to riskier food-handling practices, contributing to higher illness rates. In the study, respondents with higher monthly family income and those residing in urban areas had a 1.2- and 1.5-fold increased risk of seafood-borne illness, respectively. Higher income levels are often associated with less time spent on food preparation, leading to greater reliance on quick, convenient cooking methods that may not always prioritise food safety. Socioeconomic status (SES) and changing demographic patterns, such as an increase in women in the workforce, often lead younger individuals to prepare their own meals, which can increase the risk of foodborne illness. While higher incomes generally improve access to quality food and food safety education, they also contribute to lifestyle changes that may not always support safe food handling. In many low- and middle-income countries, food safety concerns often limit the consumption of nutrient-rich foods, even though affordability and access issues persist (Conway et al., 2023; Liguori et al., 2022). Urban settings pose additional food safety challenges due to high population density and complex food-handling environments. Research from China has shown that foodborne illnesses linked to *Vibrio parahaemolyticus* are more common in urban areas, where inadequate temperature control and poor hygiene practices further increase the risk (Bian et al., 2022; Piglowski, 2023).

According to the World Health Organisation's "Five Keys to Safer Food" program, critical food safety practices such as cleaning, separating, cooking, chilling, and using safe water or raw materials (WHO, 2006) are essential for reducing the risk of foodborne illnesses. In the study, consumers who evaluated seafood freshness based on sensory characteristics, such as appearance, texture, and odour, were less likely to report foodborne illnesses. The Codex Alimentarius guidelines for effective sensory evaluation recommend that fresh seafood should have clear, bright eyes, firm flesh, bright red or pink gills and shiny scales, and no odour or a mild ocean odour, while discolouration of the flesh, dullness of the appearance, a foul odour or brown or faded gills indicate a loss of freshness. Hence, consumers who enhance their ability to assess seafood freshness can significantly improve public health outcomes (Viana et al., 2022).

On the other hand, consumers who purchase fish just before leaving the market face a 1.5 times increased risk of illness, highlighting the importance of effective temperature management during transport. Promptly refrigerating or freezing seafood within 2 hours of purchase is crucial for preventing pathogen growth ($p < 0.001$), demonstrating a protective effect against foodborne illness. In contrast, not leaving the fish on the kitchen counter with the plan to cook later also decreases illness risk ($p < 0.001$), indicating a protective effect against seafood-borne illness. Improper temperature control practices, such as thawing seafood at room temperature, increase the risk of foodborne illness by 1.4 times. Temperature abuse during the purchase and handling of seafood, such as prolonged exposure to ambient temperatures and poor timing of purchase, accelerates bacterial growth. However, using proper thawing methods, such as refrigeration or cold water, significantly reduces the risk of seafood-borne illness compared with thawing at room temperature, which promotes pathogen growth. The U.S. FDA (2024b) recommends thawing seafood in a refrigerator or using cold water to prevent rapid bacterial spread. Additionally, refreezing thawed seafood unless it has been cooked should be avoided, as it can compromise both safety and quality.

Cross-contamination during seafood handling is a critical concern for preventing foodborne illnesses. It often occurs when pathogens from raw seafood, such as *Vibrio spp., Salmonella spp.,* and *Listeria monocytogenes*, are transferred to other foods through direct contact or contaminated utensils, cutting boards, and surfaces. Not sanitising utensils and countertops after handling raw seafood significantly increases the risk of seafood-borne illness by 1.2 times. Public health guidelines emphasise sanitising utensils and countertops with hot, soapy water

or a dishwasher to thoroughly clean cutting boards, knives, and other tools after contact with raw seafood (FDA, 2022). Additionally, the improper use of separate cutting boards for seafood, vegetables, poultry, and meat elevates the risk by 1.4 times, which aligns with previous research identifying inadequately cleaned kitchen tools as major contributors to foodborne illnesses (De Jong et al., 2008). Inadequate cleaning and sanitising practices contribute to contamination cycles, increasing the risk of foodborne illness. Adherence to recommended practices, including proper hygiene, cleaning, and sanitation, is essential for reducing foodborne illnesses associated with seafood (CDC, 2024; WHO, 2006). Consumers who fail to keep raw seafood separate in their shopping bag (1.2 times) and fail to store it in separate containers (1.4 times) are more likely to experience foodborne illness. Similarly, keeping raw seafood on the same shelf as other foods in the refrigerator increases the risk by 1.2 times. Placing raw fish on the lower shelf of the refrigerator can help prevent contamination of ready-to-eat or cooked foods by seafood juices that may drip onto them. In many households, this risk is significant when various foods are stored together. Hence, proper storage practices and regular cleaning of high-contact areas in the refrigerator, such as the door handle and bottom shelf areas, are crucial for preventing contamination and reducing the growth and spread of harmful pathogens. Neglecting these high-contact areas can increase the risk of contamination and compromise food safety (Agi et al., 2021; Cunningham et al., 2022).

The study noted that not cooking seafood thoroughly until it is opaque and flakes easily with a fork or other utensil increases the risk by 1.7 times. Cooking seafood to an internal temperature above 74°C and thoroughly reheating leftovers are effective in eliminating pathogens. Research indicates that *Vibrio species* are eliminated at 55°C, *Salmonella species* at 75°C, and *Listeria species* at 85°C, emphasising the need for appropriately tailored cooking temperatures for different seafood species (Chintagari, 2022). Proper cooking methods, such as preheating the pan and controlling cooking temperatures, are key to ensuring food safety. Additionally, perishable seafood should be consumed within 24 hours if stored for more than 2 hours after cooking. Leftover seafood must be promptly refrigerated and kept below 5°C to ensure safety. In Kerala, while consumers have a strong perception of the nutritional benefits of fish, they exhibit lower awareness of specific health benefits and express concerns about fish quality, particularly regarding transportation and the lack of freshness certification systems (Rejula et al., 2021; Sajeev & Joshy, 2024). Although most consumers have a moderate perception of fish safety, significant differences in perceptions of safety issues highlight the need for targeted government interventions in supply chain management and quality assurance to address both real and perceived risks.

Limitations

This study has several limitations. First, it relies on self-reported data, which may be subject to recall bias and inaccuracies in reporting. Second, the analysis focuses on seafood-borne illnesses without differentiating among specific seafood types (e.g., finfish, shellfish, molluscs, crustaceans) or conducting pathogen-specific analyses (e.g., *Salmonella*, *Vibrio*, *norovirus*), limiting the granularity of the risk assessment. Third, as the study was conducted in Kerala, a coastal state in India, its findings may not be generalizable to inland regions or other states with different seafood consumption patterns. Fourth, the cross-sectional study design prevents establishing causal relationships between seafood handling practices and illness, and the absence of microbiological testing restricts validation of contamination sources. Fifth, small sample sizes in certain demographic subgroups may reduce the robustness and statistical power of subgroup-specific findings. Sixth, convenience sampling through online platforms likely over-represented respondents with higher educational qualifications, including Master's degree holders (26.0%) and PhD or equivalent professionals (24.4%), relative to the general population of Kerala seafood consumers. This educational skew may mean the sample underestimates the prevalence of risky food-handling practices among less educated consumers, and the findings may be more reflective of behaviours in educated urban populations. Future studies should employ probability-based sampling strategies, such as stratified or cluster sampling, to obtain more representative samples across education, income, and geographic subgroups.

Additionally, while the study focuses on handling-related causes of seafood-borne illness, it also acknowledges other non-microbial causes, such as allergic reactions and histamine poisoning, particularly from oily fish consumption. These cases were not integrated into the core analysis but are recognised as important areas for future investigation. Greater differentiation between microbial contamination and non-microbial biological responses would enhance risk communication and public health education. Future research should address these gaps by including pathogen detection, seafood type differentiation, larger and more diverse samples, and longitudinal or experimental designs to strengthen causal inference and broaden generalizability.

5. Conclusion

Improper seafood handling practices, including temperature control, kitchen hygiene, cross-contamination, and storage, significantly increase the risk of seafood-borne illness. Additionally, unsafe purchasing behaviours were important contributors to self-reported illness. Conversely, protective practices such as checking freshness, thorough cooking, prompt refrigeration, and reheating leftovers until hot were associated with reduced risk. Demographic factors, including age, occupation, income, and residence, also influenced illness risk, highlighting the need for tailored interventions. Although older adults reported higher illness proportions in raw data, regression analysis showed they were less likely to report illness when accounting for other variables—underscoring the importance of multivariate approaches in public health research. The findings highlight the need for targeted consumer education on safe seafood handling, hygiene, and cross-contamination prevention.

To ensure seafood safety and reduce illness, public health initiatives must be demographic-specific, supported by regulatory oversight, clear food safety communication, and robust supply chain monitoring in Kerala.

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