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Note

Qualitative detection of formaldehyde and ammonia in fish and seafood from local fish markets in Balasore, eastern India

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Abstract

The illegal use of chemical preservatives such as formaldehyde and ammonia to extend the shelflife of fish and seafood has become a growing food safety concern due to their potential adverse effects on consumer health. The current study investigated the occurrence of formaldehyde and ammonia in fish and other seafood marketed in Balasore, Odisha, eastern India. A total of 106 samples of fish and seafood were collected from four different fish markets in Balasore town and screened for the presence of these preservatives. The results showed that 75.47% of the samples were tested positive for formaldehyde and 22.64% were positive for ammonia. Contamination was detected only in fish and seafood transported from outside the region, whereas locally caught samples were free from both preservatives. These findings indicate the possible use of chemical preservatives during transportation and storage of fish and seafood brought from outside, in order to prolong freshness. Given the significant health risks associated with exposure to formaldehyde and ammonia, there is an urgent need to develop safe and effective preservation technologies that can maintain seafood quality during transportation, without compromising consumer safety.

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According to Han *et al*. (2022), globally, three million people consume 113,452 million t of seafood. Seafood form an important component of the human diet as they are a rich source of polyunsaturated fatty acids, high-quality proteins, as well as nutrients like vitamin D, selenium, iodine and potassium (Weichselbaum *et al*., 2013). Seafood is considered a healthier dietary choice compared to many other animal derived protein sources, as they are generally low in fat and contain lower levels of saturated fat (Mahmud *et al*., 2024). Seafood serves as a primary source of polyunsaturated fatty acids (PUFAs), particularly omega-3 fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Mohanty *et al*., 2016; Sprague *et al*., 2026). A study conducted as part of the National Family Health Survey (NFHS-5), found that Odisha has the highest fish-consuming population in India, with 94.75% of its population consuming fish, significantly higher than the national average of 72.10% Patiyar *et al.,* 2024. According to the Annual Activity Report published by the Directorate of Fisheries 2020, the *per capita* fish consumption in Odisha increased from 7.71 kg in 2000-01 to 16.24 kg in 2019-20, representing an increase of approximately 110% in consumption over the period. *Per capita* fish consumption in Odisha in 2022-23 was 17.73 kg, which was higher than the local fish production. Hence, Odisha imports freshwater fish to meet its high consumer demand. In 2019-20, Odisha imported 46,273 t of fish. However, during long-distance transportation, there is a risk of fish quality deterioration, which can lead to various food-borne diseases and raise concerns regarding food security and safety (Nayak *et al*., 2024; Lin *et al*., 2025).

Fish and other seafood are highly perishable and prone to rapid spoilage, thus presenting an important challenge in maintaining their freshness, texture and quality (Wang and Zheng, 2025). Various conventional preservation methods, such as chilling are commonly used to preserve fish and seafood during transportation, which is not effective for a very long period (Nateras-Ramírez *et al*., 2026). Consequently, traders have sought more cost-effective methods to prolong their shelflife., aiming to maximise profits by resorting to harmful practices like dipping fish and other seafoods in chemicals like formalin solution and sodium benzoate. Reports also show the use of ammonia to slow down the melting of ice during transportation of fish and seafood (Devaraj *et al*., 2021). Various reports have illustrated the use of formaldehyde and ammonia for extending the shelflife of fish and other seafoods during long distance transportation (Haque and Mohsin, 2009; Wahed *et al*., 2016; Olatunde and Benjakul, 2018).

Formaldehyde, an organic chemical compound, is illegally used as a preservative to extend shelflife and maintain freshness of fish and seafood. It reacts with muscle proteins, causing tissue stiffnening delaying the visible signs of spoilage (Sotelo *et al*., 1995; Bianchi *et al*., 2005). Formaldehyde is classified as a Group 1 carcinogen by both the National Toxicology Program and the International Agency for Research on Cancer (IARC) (Ding *et al*., 2022). The US Environmental Protection Agency (USEPA) has set a reference dose of 0.2 mg per kg of body weight per day, while the no-observed-adverse-effect level (NOAEL) is 1.5 mg per kg of body weight per day (Delikhoon *et al.,* 2018).

Ammonia is sometimes illegally added to ice used for fish transportation to slow down the rate of melting and prolong the cooling effect during transportation. Ammonia residues have been detected in ice used for preserving and transporting fresh fish, particularly in interstate shipments, raising concerns about food safety and consumer health. Consumption of ammonia contaminated seafood can pose significant health risks. Ingestion of high concentrations of ammonia can cause scarring of the mouth, throat, oesophagus, and stomach (ATSDR 2004). Symptoms of ammonia ingestion include pain in the mouth, throat, and chest, excessive salivation, and severe burns to the digestive tract (Singh *et al*., 1999). Prolonged exposure to high levels of ammonia can permanently damage the intestinal tissues.

The Food Safety and Standards Authority of India (FSSAI) has reported the presence of formalin and ammonia in fish and seafood samples transported through interstate supply chains. However, no systematic survey has been conducted to assess the occurrence of these chemical preservatives in fish and seafood marketed in Balasore, Odisha. Therefore, the present study was undertaken to qualitatively detect the presence of formaldehyde and ammonia in commercially available fish and other seafood collected from different fish markets in Balasore, using rapid detection kits.

Balasore is one of the major towns located in the Balasore coastal district (21° 30'12"N; 86° 55' 30"E), in northern Odisha. According to the 2021 census, Balasore had a population of 20,24,508. The *per capita* fish consumption in Balasore District was 13.49 kg (DoF, 2021).

A total of 106 fish samples were collected to detect the presence of formaldehyde and ammonia, from various markets *viz.,* Motiganj, Nuabazaar, Sunduri, and Mirzapokhari. Weight of the samples and their local names was noted. The fish samples comprised: *Coilia* sp., *Caridea* sp., *Tenualosa ilisha, Elops saurus, Macrobrachium rosenbrgi, Cirrhinus mrigala, Oreochromis niloticus, Labeo rohita, Bramidea, Dussumeiri, Labeo bata, Labeo catla, Penaeus (Litopenaeus) vennamei, Elops saurus, Anabas testudineus, Oreochromis niloticus,* Decapodiformes, *Lutjanus sanguineus, Mystus tengara, Stolephorus indicus, Pangasious bacourti*, *Ailia coilia*, *Sardinella longiceps*, *Terapon jarbua* and *Pampus argenteus*. Himedia FISH Kit (K137-1KT) also known as CIFTest, developed by ICAR-Central Institute of Fisheries Technology (ICAR-CIFT), Kochi, was used to detect formaldehyde contamination (Devaraj *et al*., 2021). The kit provides qualitative results through the development of a colour change within a maximum time span of 2 min. The development of a yellow colour on the test strip indicates that the fish sample is free of from formaldehyde contamination and is safe for human consumption and development of greenish or dark bluish colour indicates the presence of formaldehyde contamination.

Himedia FISH Kit (K136-1KT) developed by ICAR-CIFT, Kochi, was used to detect ammonia in fish samples (Devaraj *et al*., 2021). The development of yellow or greenish colour on the test strip indicates that the fish sample is free from ammonia contamination and safe for human consumption. The development of a bluish or dark bluish colour indicates the presence of ammonia contamination in the samples, rendering it unfit for consumption.

The results of the study are presented in Tables 1, 2, 3, and 4. The present investigation revealed the adulteration of fish and other seafood samples collected from different markets in Balasore, with formaldehyde and ammonia (Fig. 1). The number of samples contaminated with formaldehyde was higher than those contaminated with ammonia. Formaldehyde was detected in 80 samples, whereas ammonia was observed in 24, out of 106 samples (Fig. 2).

Samples collected from Motiganj, Nuabazaar, Sunduri and Mirzapokhari markets were found to be highly contaminated with formaldehyde, which was detected in 100% of fish samples collected from Sunduri market, 81.25% from Mirzapokhari market, 75.67% samples from Nuabazaar market and 57.78% samples from Motiganj market (Table 5).

Ammonia contamination was detected in only a few samples collected from Motiganj, Nuabazaar, Sunduri and Mirzapokhari markets. Formaldehyde was observed in 30.30% of fish samples from Motiganj market, 30% from Sunduri market, 18.91% from Nuabazaar, and 6.25% from Mirzapokhari market (Table 5).

The FSSAI regulations states that ice alone must be used to store fish and shellfish to extend their shelflife, and the use of any other material is illegal. However, due to the long distance between production areas and domestic markets, traders often use formaldehyde to extend the shelflife of fish and other seafood. They use formaldehyde because it is economically beneficial, as fish preserved with formaldehyde have a longer shelflife than those transported on ice, and can therefore be transported over longer distances (Yeasmin *et al*., 2010). As per a report published in 1999 by Agency for Toxic Substances and Disease Registry, consumption of a small amount of formaldehyde resulted in the death of an adult individual, thus depicting the fatal nature of the

Table 1. Formaldehyde and ammonia detection in fish and seafood samples collected from Motiganj fish market in Balasore, India
Motiganj Market

No. of samples	Trade name	Scientific name	Formaldehyde presence	Ammonia presence
2	Rohu	*Labeo rohita*	+	-
3	Indian mackerel	*Rastrelliger kanagurta*	+	+
2	Silver Pomfret	*Pampus argenteus*	+	+
1	Cohere ruli	*Coilia dussumieri*	-	-
4	Shrimp	*Caridea*	+	+
2	Thikiri shila	*Sphyraena barracuda*	-	-
1	Hilsa shad	*Tenualosa Ilisha*	+	-
1	Lady fish	*Elops saurus*	-	-
3	Barua	*Ripon borua*	-	-
2	Gangetic	*Ailia coilia*	-	-
1	Basa	*Pangasius baccourti*	+	-
2	Needle fish	*Xanenthodon cancila*	-	-
3	Crescent grunter	*Terapon jarbua*	-	-
1	Indian oil sardine	*Sardinella longiceps*	+	+
2	Indian anchovy	*Stolephorus indicus*	+	-
3	Minnow	Cyprinidae family	+	-

+ Presence of formaldehyde and ammonia; - Absence of formaldehyde and ammonia

Table 2. Formaldehyde and ammonia detection in fish and seafood samples collected from Nuabazaar fish market in Balasore, India

No. of samples	Trade name	Scientific name	Formaldehyde presence	Ammonia presence
5	River shrimp	*Macrobrachium rosenbergii*	+	-
3	Rohu	*Labeo rohita*	-	-
3	Singa chingudi	*Penaeus semisulcatus*	+	-
6	Todi fish	*Anguilla bicolor*	+	-
2	Giant freshwater prawn	*Macrobrachium rosenbergii*	+	+
1	Pomfret fish	*Pampus argenteus*	-	-
2	Ilishi	*Tenualosa ilisha*	+	-
1	Pohala	*Labeo bata*	-	-
1	Silver croaker	*Pennahia argentata*	-	-
3	Kantia fish	*Mystus tengera*	+	+
2	Catla fish	*Labeo catla*	+	+
4	Venami	*Penaeus (Litopenaeus) vannamei*	+	-
1	Lady fish	*Elops saurus*	+	-

+ Presence of formaldehyde and ammonia; - Absence of formaldehyde and ammonia

Table 3. Formaldehyde and ammonia detection in fish and seafood samples collected from Sunduri fish market in Balasore, India

No. samples	Trade name	Scientific name	Formaldehyde presence	Ammonia presence
2	Climbing perch	*Anabas testudineus*	+	-
2	Rohu	*Labeo rohita*	+	+
3	Sundarbans fish	*Oreochromis niloticus*	+	-
2	Squid	*Loligo pealeii*	+	+
3	Katkati fish	*Lutjanus sanguineus*	+	-
2	Pomfret	*Pampus argenteus*	+	-
1	Champa Para/ Queen fish	*Scomberoides commersonnianus*	+	-
3	Mystus	*Mystus tengara*	+	+
2	Khuranta	*Acanthopagrus* sp.	+	-

+ Presence of formaldehyde and ammonia; - Absence of formaldehyde and ammonia

Table 4. Formaldehyde and ammonia detection in fish and seafood samples collected from Mirzapokhari fish market in Balasore, India

No. of samples	Trade name	Scientific name	Formaldehyde presence	Ammonia presence
2	Bhakura	*Labeo catla*	+	-
1	Rohu	*Labeo rohita*	+	+
2	Pohala	*Labeo bata*	-	-
2	Pomfret	*Pampus argenteus*	+	-
1	Khuranta	*Acanthopagrus*	+	-
1	Shanki	*Lutjanus campechanus*	+	-
1	Sheela	*Sphyraena barracuda*	+	-
2	Kantia fish	*Mystus tengara*	+	-
1	Todi fish	*Anguilla bicolor*	+	-
2	Ilishi	*Tenualosa ilisha*	+	-
1	Mirikali	*Cirrhinus mrigala*	-	+

+ Presence of formaldehyde and ammonia; - Absence of formaldehyde and ammonia

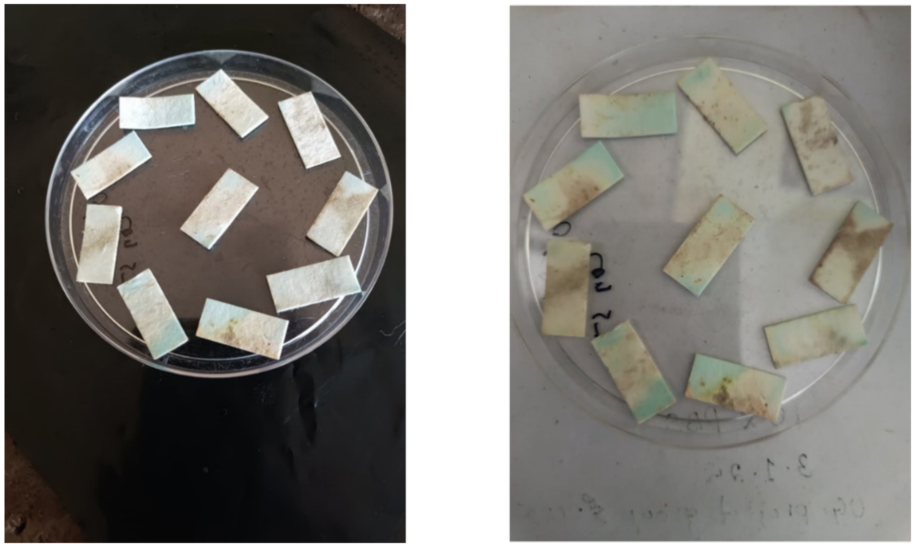

Fig. 1. Photographs showing positive results for formaldehyde and ammonia detected using Himedia FISH Kit (K137-1KT) and Himedia FISH Kit (K136-1KT), respectively

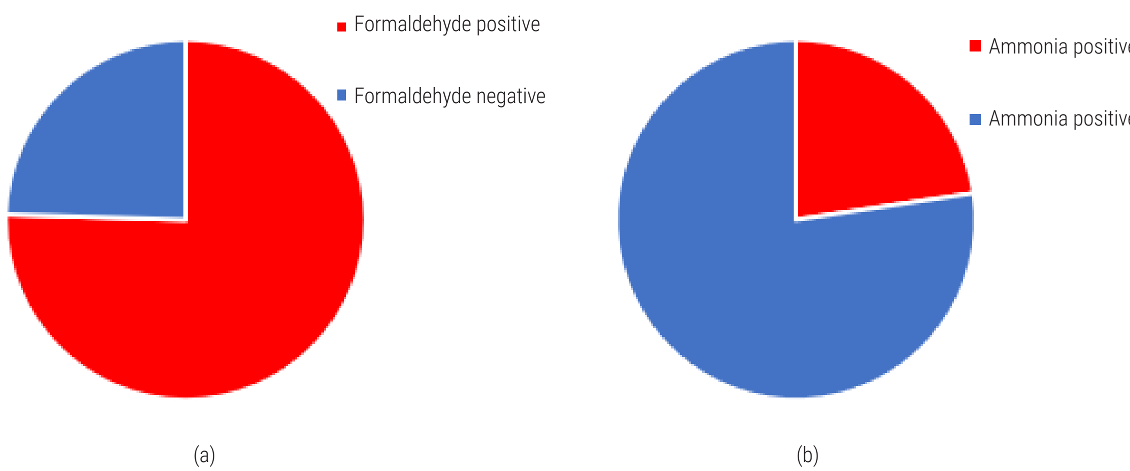

Fig. 2. Graphical representation of the number of samples contaminated with (a) formaldehyde; (b) ammonia

Table 5**.** Percentage of samples contaminated with formaldehyde and ammonia at different fish markets in Balasore

Name of the fish market	Number of samples (n)	Number of samples contaminated with formaldehyde (n)	Percentage of samples contaminated with formaldehyde (%)	Number of samples contaminated with ammonia (n)	Percentage of samples contaminated with ammonia (%)
Motiganj	33	19	57.57	10	30.30
Nuabazaar	37	28	75.67	07	18.91
Sunduri	20	20	100	06	30
Mirzapokhari	16	13	81.25	01	6.25

chemical solution. Several reports have stated that ingestion or inhalation of formaldehyde leads to detrimental effects on different parts of the body, like the nervous system, cardiovascular system, gastrointestinal system and urogenital system (Pandey *et al*., 2000; Nayak *et al*., 2024). Inhalation and ingestion of even small doses of formaldehyde can lead to bioaccumulation, which may be fatal in the long run.

Formalin—a saturated aqueous solution consisting of approximately 37 to 40% formaldehyde gas (CH_2O) stabilised with a small percentage of methanol, is a powerful industrial chemical broadly utilised in plastics manufacturing, textile processing, and anatomical tissue preservation. Despite its legitimate industrial utility, its highly effective preservative traits lead to its illicit and dangerous diversion into the agro-food supply chain. Unscrupulous commercial traders exploit the chemical to artificially extend the shelflife of highly perishable commodities, including fresh fruits, vegetables, milk, meat, and seafood. While this adulteration successfully delays visible decay, it introduces a highly toxic, mutagenic, and carcinogenic substance into the human diet. The chemical mechanism behind this artificial preservation relies on a profound alteration of the food's native microbiology and biochemistry. Fresh fish carries a greater bacterial load than formalin-treated fish in storage and transport. With increased storage of fresh fish on ice for longer times, its content of non-protein nitrogen (NPN) rises. Formalin-treated fish, however, experiences a drop in NPN concentration within the same storage period, which reflects that formalin extends the shelflife of the fish.

Ammonia is used by traders to prolong the lifespan of ice by preventing it from melting. Subrahmanyan *et al.* (1963) preserved *Sardinella longiceps* for two months using ammonia and found no change in the nutritional value of the preserved fish. Many studies have mentioned that freshly caught fish, when sprayed with 0.1% ammonia, were well preserved (Mitchell, 1969). *Cirrhinus mrigala* had an extended shelflife when sprayed with ammonia vapour or when kept in an environment of ammonia vapour.

Ammonia is a highly volatile, cytotoxic byproduct of protein metabolism. It is primarily generated in the human body through the deamination of amino acids and the bacterial degradation of urea within the gastrointestinal tract. Under normal physiological conditions, the human body maintains systemic blood ammonia levels within a narrow, non-toxic range (typically 15 to 45 μmol l^{-1}). This balance is achieved through highly efficient metabolic pathways that neutralise and excrete the gas before it can accumulate. However, if these homeostatic pathways fail or if the body is exposed to concentrated exogenous sources, ammonia imparts severe tissue toxicity. The clinical presentation, ranging from widespread gastrointestinal burns and severe chest pain to profuse salivation and permanent structural scarring, stems from specific biochemical interactions between the strong alkali compound and human tissue (Singh *et al*., 1999).

Various authors have reported the presence of formaldehyde and ammonia in fish sold in different markets across India. Mehta *et al*. (2021) reported the presence of formaldehyde in fish sold in the markets of Agartala and Tripura. Similarly, Hussain *et al*. (2022), reported the formaldehyde-preserved Pangasius in local markets of Srinagar, Jammu and Kashmir. They found 78% of samples contaminated with formaldehyde above the permissible limit of 4 ppm. A recent study has found the presence of formaldehyde and ammonia for preservation in fish and seafood collected from fish markets in Chennai. Samples from N4 Beach, Chintadripet, Pattinapakkam and Kasimedu markets detected the presence of ammonia. Rapid detection kits (Himedia's HiRapid test kits) called CIFTest, developed by ICAR-CIFT, Kochi was used by Devaraj *et al*. (2021) to detect the presence of formaldehyde and ammonia in fish. Chutia *et al*. (2024) collected fish samples from markets of Nagaon, Assam and concluded that fish brought from outside, were contaminated with formaldehyde compared to locally caught fish. Das *et al*. (2018) also reported the presence of formaldehyde in *Labeo rohita*, *Catla catla*, *Wallago attu*, *Rastrelliger kanagurta*, and *Harpodon nehereus* collected from various local markets in Mumbai. Valadares *et al*. (2021) observed formaldehyde in Indian mackerel sold in markets in Goa, and formaldehyde content varied from 4.00–39.37mg kg^{-1}. Mehta *et al*. (2021) reported 54% of fish and shellfish samples were positive for presence of formaldehyde in Agartala, Tripura. Majhi *et al*. (2025) investigated the presence of formaldehyde in fish sold in local markets of Guwahati, Assam, and reported that the presence was below detection level. Nirmal *et al*. (2021) found 24.61% of fish samples from local markets in Ernakulam, Kerala, were contaminated with formaldehyde. Immaculate and Jamila (2018) detected formaldehyde content of 10.64 - 18.75 mg kg^{-1} in fish collected from different fish landing centres in Tuticorin, Tamil Nadu.

Chandralekha *et al*. (1992) reported the presence of formaldehyde in fish samples collected from shops in the Kandy market, Sri Lanka. Fish from local markets in Kawran Bazaar, Dhaka, Bangladesh were positive for formaldehyde, their content varying from 9.39 ± 3.39–32.57±11.23 mg kg^{-1} (Bhowmik *et al*., 2017). Formaldehyde test kits were used to test fish and other seafood from different markets of Thailand, and the samples tested positive for formaldehyde (Suwanaruang,2018). Manyanga *et al*. (2022) collected mackerel samples from supermarkets in Tanzania, and all the samples were found positive with a mean of 16.07±4.68 mg kg^{-1}, Surahman *et al*. (2019) collected 72 samples of fish from markets in Banten, Indonesia, and 42 of them tested positive. Fish samples from markets, including supermarkets in Bangladesh were found to be positive for formaldehyde (Bari *et al*., 2024; Rahman *et al*., 2016).

Recent reports have highlighted a serious food safety concern in Odisha, where imported fish samples from Andhra Pradesh were found to be contaminated with formaldehyde. Although this public health issue prompted stringent regulatory actions in neighboring states such as Assam, the local regulatory and community response in Odisha has remained profoundly inadequate. Evidence from Balasore indicates a widespread lack of consumer awareness and a systemic failure of regulatory authorities to conduct routine and rigorous quality compliance checks on seafood marketed for human consumption.

To mitigate the risks associated with the widespread adulteration of fish and seafood with formaldehyde and ammonia, a comprehensive strategy is urgently required. Regulatory authorities must establish stringent monitoring frameworks and conduct frequent unannounced inspections of fish markets and supply chains. Public awareness campaigns must be implemented to educate consumers about the health hazards associated with chemical adulteration and to encourage community participation in monitoring and reporting such practices. Further, efforts should be made to promote sustainable preservation methods during transportation and storage. This includes encouraging fishermen and traders to adopt standard icing practices and research aimed at developing slow-melting ice technologies. Bridging the gap between regulatory enforcement and technological innovation is essential to safeguard public health and ensure the integrity and sustainability of the seafood supply chain.

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References

ATSDR 2004. *Toxicological profile for ammonia*. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

Bari, L., Hossain, M. B., Talukder, N., Al Reza, M. S., Esrafil, M., Abedin, M. Z. and Abu Zubair, M. 2024. Organoleptic, physicochemical and amino acids status of formalin adulterated tilapia (*Oreochromis niloticus*) and rui (*Labeo rohita*) fish. Available at SSRN 4775397. https://doi.org/10.2139/ssrn.4775397.

Bhowmik, S., Begum, M., Hossain, M. A., Rahman, M. and Alam, A. N. 2017. Determination of formaldehyde in wet marketed fish by HPLC analysis: A negligible concern for fish and food safety in Bangladesh. *Egyptian J. Aquat. Res.*, 43(3): 245–248. https://doi.org/10.1016/j.ejar.2017.08.002.

Bianchi, F., Careri, M., Musci, M. and Mangia, A. 2007. Fish and food safety: Determination of formaldehyde in 12 fish species by SPME extraction and GC–MS analysis. *Food Chem.*, 100(3): 1049–1053. https://doi.org/10.1016/j.foodchem.2005.10.063.

Chandralekha, A. P. L., Baranage, C. and Samarajeewa, U. 1992. Formaldehyde levels in fish from the Kandy market. *J. Natl. Sci. Counc. Sri Lanka*, 20(1): 115–121.

Chutia, B. C., Borah, M. P., Bordoloi, U., Goswami, L. M., Bharadwaj, S., Borthakur, M., Sharma, P., Das, J. and Borkataki, S. 2024. Qualitative detection of formaldehyde in challani fish obtained from selected fish markets of Nagaon, Assam, India. *Discover Environ.*, 2(1): 26. .

Das, U. N., Jana, P., Dhanabalan, V. and Xavier, K. M. 2018. Detection of formaldehyde content in selected fish from three different retail markets in Mumbai. *Int. J. Curr. Microbiol. App. Sci.*, 7(11): 2316–2322. https://doi.org/10.20546/ijcmas.2018.711.261.

Delikhoon, M., Fazlzadeh, M., Sorooshian, A., Baghani, A. N., Golaki, M., Ashournejad, Q. and Barkhordari, A. 2018. Characteristics and health effects of formaldehyde and acetaldehyde in an urban area in Iran. *Environ. Pollut.*, 242: 938–951. https://doi.org/10.1016/j.envpol.2018.07.037.

Devaraj, P., Babu, V. and Cengiz, E. I. 2021. Qualitative detection of formaldehyde and ammonia in fish and other seafoods obtained from Chennai's (India) fish markets. *Environ. Monit. Assess.*, 193: 792. https://doi.org/10.1007/s10661-021-09559-0.

Ding, N., Li, Z., Hao, Y. and Yang, X. 2022. A new amine moiety-based near-infrared fluorescence probe for detection of formaldehyde in real food samples and mice. *Food Chem.*, 384: 132426. https://doi.org/10.1016/j.foodchem.2022.132426.

Han, K., Leem, K., Choi, Y. R. and Chung, K. 2022. What drives a country's fish consumption? Market growth phase and the causal relations among fish consumption, production and income growth. *Fish. Res.*, 254: 106435. https://doi.org/10.1016/j.fishres.2022.106435.

Haque, E. and Mohsin, A. B. M. 2009. Intensity of formalin use for consumable fish preservation in Dhaka city, Bangladesh. *J. Fish. Int.*, 4(3): 51–53.

Immaculate, J. and Jamila, P. 2018. Quality characteristics including formaldehyde content in selected Seafoods of Tuticorin, southeast coast of India. *Int. Food Res. J.*, 25(1): 293–299.

Lin, D., Chen, W., Lin, Z., Liu, L., Zhang, M., Yang, H., Liu, Z. and Chen, L. 2025. Viral transmission in sea food systems: Strategies for control and emerging challenges. *Foods*, 14(6): 1071. https://doi.org/10.3390/foods14061071.

Mahmud, N., Valizadeh, S., Oyom, W. and Tahergorabi, R. 2024. Exploring functional plant-based seafood: Ingredients and health implications. *Trends Food Sci. Technol.*, 145: 104346. https://doi.org/10.1016/j.tifs.2024.104346.

Majhi, S. K., Debnath, D., Sharma, N., Nag, S. K., Sarkar, S. D., Kumar, R., Kakati, A. and Das, B. K. 2025. Formaldehyde contamination in fish samples collected from selected wholesale markets of Guwahati, Assam. *Environ. Ecol.*, 43(1): 24–28.

Manyanga, W., Makanyeza, C. and Muranda, Z. 2022. The effect of customer experience, customer satisfaction and word of mouth intention on customer loyalty: The moderating role of consumer demographics. *Cogent Bus. Manage.*, 9(1): 2082015. https://doi.org/10.1080/23311975.2022.2082015.

Mehta, N. K., Majumdar, R. K., Pal, D., Priyadarshini, M. B. and Dhar, B. 2021. Screening of fish from retail markets for the presence of formalin and its effect on the quality of fresh catla. *Indian J. Anim. Health*, 60(2): 244–252. https://doi.org/10.36062/ijah.2021.11621.

Mitchell, F. W. 1969. *Method of processing fish for food*. *U.S. Patent No. 3,442,661.* Washington, DC: USA.

Mohanty, B. P., Ganguly, S., Mahanty, A., Sankar, T. V., Anandan, R., Chakraborty, K., Paul, B. N., Sarma, D., Dayal, J. S., Mathew, E. V. S., Prabhu, T. V. A. J., Das, P., Akhtar, M. S., Vijayagopal, P. and Sridhar, N. 2016. DHA and EPA content and fatty acid profile of 39 food fishes from India. *BioMed Res. Int.*, 2016: 4027437. https://doi.org/10.1155/2016/4027437.

Nateras-Ramírez, O., Fitch-Vargas, P. R., Martínez-Macias, M. D. R., Sánchez-Cárdenas, R., Choza-Farías, S. and Fernandez-Jaramillo, A. A. 2026. Fish preservation techniques: An overview of principles, methods, and quality implications. *Processes*, 14(4): 723. https://doi.org/10.3390 / pr14040723.

Nayak, S., Nayak, P., Saha, S., Patnaik, L., Nayak, S., Pradhan, S. P., Sharma, S. N. and Muduli, N. 2024. Formaldehyde as preservative for fish and seafood: A boon or a bane. *Environ. Quality Manage.*, 34(2): e22357. https://doi.org/10.1002/tqem.22357.

Nirmal, K. V., Pillay, V. V., Ramakrishnan, U. K., Arathy, S. L. and Bhaskaran, R. 2021. Estimation of formaldehyde contamination in selected sea fish species sold in Ernakulam District of Kerala State. *Indian J. Forensic Med. Toxicol.*, 15(4): 258–265. https://doi.org/10.37506/ijfmt.v15i4.16701.

Olatunde, O. O. and Benjakul, S. 2018. Natural preservatives for extending the shelf-life of seafood: A revisit. *Compr. Rev. Food Sci. Food Safe,*, 17(6): 1595–1612. https://doi.org/10.1111/1541-4337.12390.

Pandey, C. K., Agarwal, A., Baronia, A. and Singh, N. 2000. Toxicity of ingested formalin and its management. *Human Exp. Toxicol.*, 19(6): 360–366. https://doi.org/10.1177/096032710001900608.

Padiyar, P. A., Dubey, S. K., Bayan, B., Mohan, C. V., Belton, B., Jena, J. and Murthy, C. K. (2024). *Fish consumption in India: Patterns and trends. WorldFish,* Penang, Malaysia.

Rahman, S., Majumder, M. A. A., Ahasan, R., Ahmed, S. M., Das, P. and Rahman, N. 2016. The extent and magnitude of formalin adulteration in fish sold in domestic markets of Bangladesh: A literature review. *Int. J. Consum. Stud.*, 40(2): 152–159. https://doi.org/10.1111/ijcs.12239.

Singh, S., Malhotra, P., Jain, S. and Varma, S. 1999. Gastro-esophageal burns following domestic liquid ammonia ingestion: Report of two cases. *J. Assoc. Physicians India*, 47(6): 647–648.

Sotelo, C. G., Gallardo, J. M., Piñeiro, C. and Pérez-Martín, R. 1995. Trimethylamine oxide and derived compounds' changes during frozen storage of hake (*Merluccius merluccius*). *Food Chem.*, 53(1): 61–65. https://doi.org/10.1016/0308-8146(95)93927-J.

Sprague, M., Betancor, M. B., Rolland, A. and Tocher, D. R. 2026. Evaluating the adequacy of current dietary guidelines for seafood as a source of long-chain omega-3 fatty acids. *Sci. Rep.*, 16: 5122. https://doi.org/10.1038/s41598-026-09854-w.

Subrahmanyan, V., Lahiry, N. L., Moorjani, M. N., Nair, R. B. and Krishnaswamy, M. A. 1963. Ammonia: Possible use for preserving fish. *Science*, 142(3589): 233–234. https://doi.org/10.1126 /science.142.3589.233.

Surahman, Z. M., Hanningtyas, I., Aristi, D., Cahyaningrum, F. and Laelasari, E. 2019. Factors related to the presence of formaldehyde in the salted fish trade in Ciputat, Indonesia. *Malaysian J. Med. Health Sci.*, 15(3): 43–48.

Swenberg, J. A., Moeller, B. C., Lu, K., Rager, J. E., Fry, R. C. and Starr, T. B. 2013. Formaldehyde carcinogenicity research: 30 years and counting for mode of action, epidemiology, and cancer risk assessment. *Toxicol. Pathol.*, 41(2): 181–189. https://doi.org/10.1177/0192623312466459.

Valadares, J., Majik, M. S. and Tilve, S. G. 2021. Comparison of the formaldehyde content in Indian mackerel (*Rastrelliger kanagurta*) fish using high performance liquid chromatography and UV-VIS spectrophotometry. *J. Aquat. Food Prod. Technol.*, 30(8): 980–987. https://doi.org/10.1080 /10498850.2021.1963870.

Wahed, P., Razzaq, M. A., Dharmapuri, S. and Corrales, M. 2016. Determination of formaldehyde in food and feed by an in-house validated HPLC method. *Food Chem.*, 202: 476–483. https://doi.org/10.1016/j. foodchem.2016.01.136.

Wang, X. and Zheng, Z. 2025. Mechanistic insights into fish spoilage and integrated preservation technologies. *Appl. Sci.*, 15(14): 7639. https:// doi.org/10.3390/app15147639.

Weichselbaum, E., Coe, S., Buttriss, J. and Stanner, S. 2013. Fish in the diet: A review. *Nutr. Bull.*, 38(2): 128–177. https://doi.org/10.1111/nbu.12021.

Yeasmin, T., Reza, M. S., Khan, M. N. A., Shikha, F. H. and Kamal, M. 2010. Present status of marketing of formalin treated fishes in domestic markets at Mymensingh district in Bangladesh. *Int. J. Biol. Res.*, 1(4): 21–24.