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Tetrodotoxin Risk Assessment in Pufferfish at Kwandang Port

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Abstract

This study examines the food safety risk of tetrodotoxin poisoning associated with pufferfish consumption at Kwandang Fishing Port, North Gorontalo. A mixed-method approach was applied, combining field observations, interviews with fishermen, and literature-based toxicity analysis. Risk assessment was conducted using a semi-quantitative matrix integrating hazard level, exposure frequency, and community awareness. The results showed that only one species, Diodon hystrix, was identified in the landings. Although this species has lower toxicity compared to Tetraodontidae, it still contains tetrodotoxin in specific organs and poses a poisoning risk. The overall risk level was classified as moderate (score = 8), influenced by high toxicity but limited exposure. The findings indicate that local ecological knowledge contributes to risk reduction, yet inconsistencies in consumption behavior still create potential hazards. This study highlights the importance of integrating biological toxicity and socio-behavioral factors in food safety risk assessment. Strengthening public awareness and implementing risk-based monitoring strategies are essential to minimize poisoning incidents in coastal communities.

Introduction

Indonesia is an archipelago with 65% of its total area covered by waters and a coastline stretching 81,000 km, providing abundant fishery resources (Anugrah & Alfarizi, 2021; Harry et al., 2025; Heo et al., 2024). North Gorontalo's fishery resources are substantial, with the Regional Fisheries Management potential from the Sulawesi Sea to the Pacific Ocean reaching approximately 590,970 tons of pelagic fish (Baruadi et al., 2012).Kwandang Archipelago Fishing Port (PPN Kwandang) is one of the largest fish landing centers in North Gorontalo, serving as a distribution point for various fish species, including pufferfish as bycatch.

Pufferfish (Tetraodontiformes) are a fishery commodity with high economic value and are widely consumed in various regions (Kaleshkumar et al., 2022; Renjithkumar & Roshni, 2024; Nikijuluw. 2017). However, these fish are also known to contain the deadly neurotoxin tetrodotoxin (TTX). TTX is one of the most toxic naturally occurring substances known, approximately 1200 times more poisonous to humans than cyanide, with no known antidote (Lago et al., 2015). This toxin binds to sodium channels in excitable tissues in the human body, inhibiting sodium ions and effectively paralyzing those tissues. Because this toxin is heat-stable and water-soluble, boiling or frying does not inactivate it (Islam et al., 2011; Humpf & Voss, 2004; Goswami et al., 2026).

According to reports from local health agencies, a pufferfish poisoning incident occurred in North Gorontalo in January 2025, resulting in one fatality and one person receiving intensive care (Nurckholis, 2025).This incident demonstrates that the risk of pufferfish poisoning is a

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real public health problem in the region (Hempel et al., 2026; El-Aziz et al., 2026; Varini et al., 2025).

This study aimed to: (1) identify pufferfish species landed at Kwandang Archipelago Fishing Port;

(2) synthesize the distribution pattern of TTX toxin across organs of each identified species based on scientific literature; and (3) estimate the risk of poisoning that may occur in the community by mapping dominant species against their toxin distribution patterns.

Despite extensive studies on tetrodotoxin (TTX) focusing on its biochemical properties and toxicity mechanisms, limited attention has been given to its risk within real-world food systems, particularly at fish landing sites. Most existing studies emphasize laboratory-based toxin detection, while neglecting the socio-behavioral dimension of risk, including community consumption patterns and awareness.

Furthermore, the integration of hazard levels, consumption exposure, and public knowledge into a unified risk assessment framework remains underexplored, especially in developing coastal regions. In the context of food safety, this gap is critical, as the presence of toxic fish does not automatically translate into risk without considering human interaction and perception (Basurto-Cedeno & Pennington-Gray, 2026; Mendes et al., 2026; Saveanu et al., 2026).

Therefore, this study addresses this gap by applying a semi-quantitative risk matrix approach that integrates tetrodotoxin toxicity, consumption behavior, and community knowledge to provide a contextualized food safety risk assessment at Kwandang Fishing Port.

Methods

Time and Place

This research was conducted over three months from October to December 2025 at Kwandang

Archipelago Fishing Port, North Gorontalo Regency.

Tools and Materials

The tools used included a ruler for measuring samples, styrofoam as a measuring medium, a camera for documentation, and writing instruments for data recording. The primary material was pufferfish landed at the research location.

Data Collection Instruments

This study used primary and secondary data. Primary data were obtained through direct observation and semi-structured interviews with 15 fishermen at PPN Kwandang. Secondary data were obtained from official reports of the Ministry of Marine Affairs and Fisheries, the Regional Fisheries Service, and scientific publications related to tetrodotoxin toxicity.

Research Stages

The research stages included: (1) preparation stage involving literature study and instrument development; (2) data collection through field surveys and interviews; (3) species identification based on morphological characteristics; (4) synthesis of TTX toxicity literature; and (5) data analysis.

Data Analysis

Data analysis was conducted using qualitative descriptive and semi-quantitative approaches. Poisoning risk analysis was performed using a risk matrix combining two main parameters:

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exposure level and hazard level (Taggart & Wilke, 2025). The risk level was calculated using the formula:

R = P × I

Where:

R = Risk Level

P = Probability/Likelihood of risk occurrence

I = Impact/Consequence if the risk occurs

Exposure level was determined based on the abundance or frequency of occurrence of each species at the research location. Meanwhile, hazard level was determined based on the toxicity profile synthesis of each species obtained from scientific literature. Each parameter was classified into three categories (low=1, medium=2, high=3), which were then summed to obtain the total risk score (Putri et al., 2023).

Results and Discussion

Species Identification Results

Based on direct observation and interviews with 15 fishermen at PPN Kwandang during October 2025, only one pufferfish species was found landed: Diodon hystrix from the family Diodontidae. This species is characterized by a rounded body, long spines that can erect when the fish inflates, and a brownish-grey color pattern with dark spots. These characteristics align with the findings of(Sua et al., 2017), who stated that porcupinefish have long spines along their bodies that can stand erect when the fish inflates.

The absence of pufferfish from the Tetraodontidae family indicates local fishermen's knowledge regarding the high toxicity risk in this group. This phenomenon is consistent with the findings of (Varini et al., 2025; Zhang et al., 2024), who stated that several pufferfish species from Tetraodontidae are known to have much higher TTX levels compared to Diodontidae, thus often avoided in traditional fishing practices.

Toxicity Profile of Diodon hystrix

Based on the synthesis of scientific literature, Diodon hystrix is known to contain tetrodotoxin (TTX), especially in internal organs such as the liver, gonads, and skin. Although its TTX content is lower than some Tetraodontidae species, this fish still has the potential to cause severe poisoning and death if consumed without proper handling.

Table 1. Rendemen Value and Toxicity of Diodon hystrix Extract

Organ	Rendemen Value (%)	LC50 Value (ppm)
Heart	4.47	155.67
Skin	3.38	79.91
Meat	3.34	38.59
Liver	4.93	190.27

Source: (Deskawati et al., 2014)

Based on Table 1, the meat organ of Diodon hystrix had the lowest LC50 value at 38.59 ppm, indicating the highest toxicity compared to other organs. These data align with the statement of (Deskawati et al., 2014)that TTX toxin in pufferfish is distributed in the liver and ovaries (highest), followed by the intestines and skin, while meat and testes are non-toxic or have weak toxicity.

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Poisoning Case Data

Based on reports from local health agencies, a pufferfish poisoning incident occurred in North Gorontalo on January 26, 2025, involving two residents of Milango Village, Tomilito District. Haidin Arsyad (34) reportedly died due to TTX poisoning, while Ronal Muda (31) experienced symptoms of dizziness, vomiting, and convulsions and was still receiving medical treatment (Nurckholis, 2025). This case demonstrates that pufferfish poisoning is a real public health risk in the region.

Risk Analysis Based on Exposure and Hazard Matrix

Risk analysis was conducted using a semi-quantitative approach through the development of a risk matrix. Table 2 presents the results of the risk parameter assessment for Diodon hystrix poisoning at PPN Kwandang.

Table 2. Rendemen Value and Toxicity of Diodon hystrix Extract

No	Parameter	Category	Value	Score
1	Capture frequency	Rare	Low	1
2	Consumption frequency	Limited (fishermen)	Medium	2
3	TTX content	Toxic (literature)	High	3
4	Community knowledge	Sufficient	Medium	2
	Total Risk Score			**8**

Source: Primary data and literature synthesis, 2025

Based on the risk matrix assessment results, the total pufferfish poisoning risk score of 8 was categorized as moderate risk. Low capture frequency (score 1) indicates that pufferfish are not the main target of fishing. However, consumption frequency in the medium category (score 2) indicates that this fish is still consumed by certain groups, particularly fishermen.

The TTX content parameter received the highest score (score 3) and was the dominant factor in the risk assessment. The scientific literature consistently states that TTX is a potent neurotoxin capable of causing paralysis and death in very low doses, and is heat-stable, so it cannot be neutralized through conventional cooking methods (Varini et al., 2025;Nißl et al., 2025).

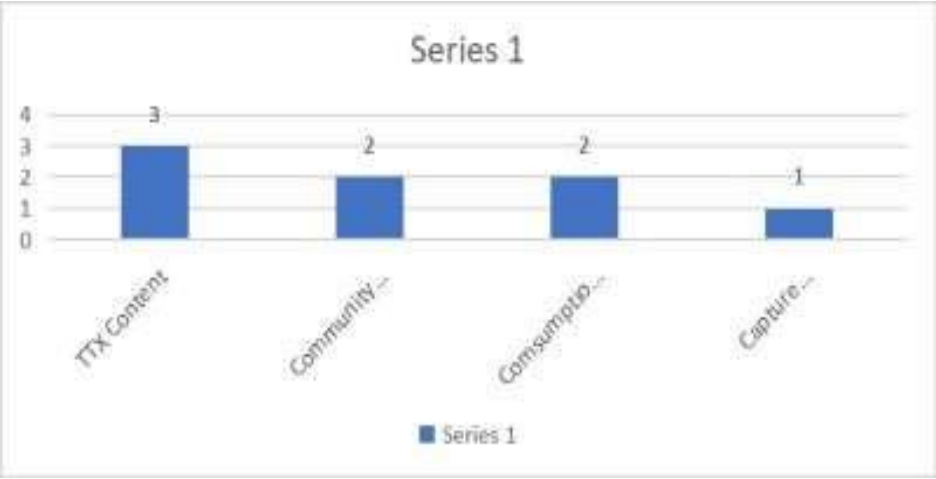

Figure 1. Contribution of each parameter to the total risk score

The results showed that only Diodon hystrix was landed and consumed at PPN Kwandang. This finding indicates that local fishermen possess empirical knowledge in distinguishing

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pufferfish species that are relatively safe for consumption. This selective practice reflects a form of local wisdom that indirectly reduces the potential for TTX exposure to coastal communities. Similar phenomena have been reported in various fishing communities in the Indo-Pacific region (Ulman et al., 2024).

The toxicity of pufferfish is influenced by several environmental and biological factors (Choudhary et al., 2026; Alnady & Al-kareemm, 2026; Xue et al., 2025). First, the origin of the toxin is exogenous, where pufferfish do not produce TTX themselves but accumulate it through the food chain. Research has proven that bacteria, especially Vibrio harveyi, living on the skin and kidneys of pufferfish are the main source of TTX production (Campbell et al., 2021). Second, differences in habitat or water salinity also play an important role. Histological studies show that the number of mucous cells in the esophagus of pufferfish from marine waters (706 cells/mm²) is much higher than from brackish waters (293 cells/mm²) as a form of adaptation to the environment (A Malpezzi et al., 2020). Third, geographic and seasonal factors also determine variations in TTX levels (Azmar et al., 2014).

The poisoning incident in North Gorontalo reflects a global pattern where poisoning generally occurs due to the consumption of internal organs and a lack of practical toxicological understanding at the community level (Varini et al., 2025; Nißl et al., 2025; VAJERU et al., 2026). To date, no rapid TTX detection method is widely available for use at the community level, so the most effective prevention strategy is a risk-based approach through education, distribution monitoring, and clear species identification (Ulman et al., 2024; Puspita & Karim, 2026).

Conclusion

This study demonstrates that Diodon hystrix is the only pufferfish species landed at Kwandang Fishing Port and still poses a potential risk of tetrodotoxin poisoning despite its relatively lower toxicity compared to other species. The moderate risk level identified reflects the interaction between high toxin hazard and limited exposure frequency. Although local knowledge contributes to reducing risk, inconsistent consumption practices remain a concern within the food safety system. Therefore, strengthening community awareness and implementing risk-based management strategies are essential to minimize potential poisoning incidents in coastal areas.

Suggestion

For future researchers, direct toxicity testing on Diodon hystrix samples from Kwandang waters is recommended to determine the actual levels and variations of tetrodotoxin (TTX). Furthermore, further research can be directed at more in-depth ethnographic studies to understand why fishermen and the community continue to consume toxic fish despite knowing the risks. The development of a simple and applicable rapid TTX detection tool at the community level is also a strategic step that needs to be taken to support poisoning prevention efforts more effectively in the future.

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