

## RESEARCH ARTICLE

## Prioritization of Food-Chemical Hazard Pairs of Indonesian Fishery Products Based on Export Rejection Year 2017-2019

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### Abstract

Necessary approaches are needed to reduce the impact of rejected exported Indonesian seafood due to chemical contamination. This study aims to prioritize food and chemical pairs in the rejected fishery products. The rejection data from three major export destinations: the United States, the European Union, and Japan in 2017-2019 were used. Combinations of food and chemicals were developed and screened, followed by constructing a risk matrix to prioritize the pairs based on health and economic impact. Based on the health impact, a tuna–histamine pair was considered medium risk along with other commodities pairing with heavy metals. Tuna is the most exported seafood and suffers from the most loss; hence it has the highest score for severity and likelihood of economic impact. The combination of health and economic-based prioritization suggested that tuna–histamine was the top priority for immediate mitigation. The second priority consisted of shark–mercury, swordfish–mercury, octopus–cadmium; mahi-mahi–histamine was the third priority. This prioritization can assist risk managers in determining the order of commodities be acted upon based on health and economic considerations to enhance global market access.

**Keywords:** chemicals, export control, prioritization, seafood

### Introduction

Indonesia earned more than 4.7 billion USD from almost 1.2 million tons of fishery export commodities in 2019 and is an important economic sector (Indonesian Statistics, 2020). In 2019, the commodities exported to the United States of America (US), the European Union (EU), and Japan accounted for almost 37% of the total weight but gained 60% of the total value (MMAF, 2019). However, in frequency, fisheries received more rejections than agriculture and packaged foods (Indrotristanto & Andarwulan, 2019); thus, the rejection of this commodity is a major economic burden to producers and the Indonesian government. Chemical hazards (such as heavy metal, histamine, and veterinary drug residues), microbial hazards (such as *Salmonella* spp.), and other hazards (such as filth) are eminent reasons for such rejections (Bovay, 2016; Irawati et al., 2019; Wahidin & Purnhagen, 2018).

Due to limited resources, determining the most important commodities may be helpful for policymakers to mitigate rejection (Van Asselt et al., 2018). This

prioritization approach (in the risk analysis process) assesses many aspects of public health, economic, food security, and social factors (FAO, 2017). In evaluating health impacts (i.e., risk-ranking), one considers the severity and likelihood of hazards to public health (FAO, 2020). Export values and potential losses due to recall or rejections may be involved in evaluating the economic impact.

Risk-ranking is commonly done by combining or pairing food and hazards; thus, determining those pairs is necessary (FAO, 2020). Epidemiological studies are ideal references for determining the pairs, but other types of information may still be useful, such as scientific research related to those pairs (Dewanti, 2016). Information on export rejection is valuable information as well. FAO (2020) recommends screening the pairs based on the potential for causing foodborne diseases to reduce the number of pairs that must be prioritized. In our previous study, the development of food–pathogen pairs and the screening helped prioritization and risk ranking in Indonesian seafood rejections and their associated microbial

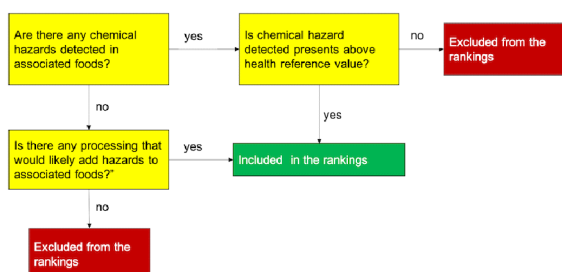
contaminants. This was shown by the fact that tuna and shrimp were the top priorities for mitigation due to *Salmonella* spp. contamination (Indrotrianto et al., 2022).

Besides ranking microbiological risk, prior research has focused on classifying the chemical risk in foods, such as fish and their products (Guillier et al., 2011), herbs and spices (Van Asselt et al., 2018), and crops (Chou et al., 2019). We designed this study to do the following: 1) listing and screening the pairs of food and chemical from rejected Indonesian fishery commodities; 2) prioritizing the pairs based on health risks; 3) evaluating the priorities after incorporating economic-based risks.

## Methods

### Food–Chemical Pairs Development and Screening Process

The pairs were developed using rejection data studied by Indrotrianto et al. (2022). The rejection data were from the Operational and Administrative System for Import Support of the US Food and Drug Administration, EU Rapid Alert System for Food and Feed, and the Imported Foods Inspection Services Home Page, Japan Ministry of Health, Labour, and Welfare. The following criteria included: the exporting country was Indonesia, commodities were from fisheries and their products, also the rejection occurred between 2017 and 2019. The rejection databases retrieved 415 records of rejected Indonesian fishery commodities. Food–chemical pairs were developed from those records by combining the rejected commodities and the chemical hazards causing the rejection. The frequency of rejection (*freq.*) was obtained from this dataset. The pairs were then screened based on their relevance and risk potential according to FAO (2020) (Figure 1).



Source: Modified from FAO (2020).

Figure 1. Flow chart for screening food and chemical hazards.

### Health-Based Prioritization

A 4x4 risk matrix was constructed to aid the prioritization as recommended by FAO (2017), Hanlon et al. (2015), and Van Asselt et al. (2018). This matrix consisted of three risk classes: low, medium, and high (Table 1), which was applicable for both the severity and likelihood of each pair. Four classifications were assigned for the severity and likelihood: low, medium, high, and very high. The severity was determined by toxicological values such as the Acute Reference Dose (ARfd), Acceptable Daily Intake (ADI), Tolerable Daily Intake (TDI), and carcinogenicity properties of selected chemicals (Table 2) (Van Asselt et al., 2018). A modification was made regarding the unit of ARfd for histamine, where mg was used (FAO, 2012). The information used as toxicological reference was from the Joint WHO/FAO Expert Committee on Food

Table 1. Classification of risk from severity and likelihood of selected food/chemical pairs

Severity	Likelihood			
	Low	Medium	High	Very High
Very High	Low	Medium	Medium	High
High	Low	Medium	Medium	Medium
Medium	Low	Low	Medium	Medium
Low	Low	Low	Low	Low

Source: Hanlon et al. (2015); Van Asselt et al. (2018)

Table 2. Classification for the severity of selected chemicals

Criteria	Value	Unit	Classification
ARfd	> 100	mg	
ADI/TDI	> 30	mg/kg bw/day	Low
Carcinogenicity	3 or 4	IARC Group	
ARfd	10 – 100	mg	
ADI/TDI	10 – 30	mg/kg bw/day	Medium
Carcinogenicity	2B	IARC Group	
ARfd	0.1 – 10	mg	
ADI/TDI	1 – 10	mg/kg bw/day	High
Carcinogenicity	2A	IARC Group	
ARfd	< 0.1	mg	
ADI/TDI	< 1	mg/kg bw/day	Very high
Carcinogenicity	1	IARC Group	

Note: ARfd: Acute Reference Dose; ADI/TDI: Acceptable Daily Intake/Tolerable Daily Intake; IARC: International Agency for Research on Cancer. (Source: Modified from Hanlon et al. (2015) and Van Asselt et al. (2018)).

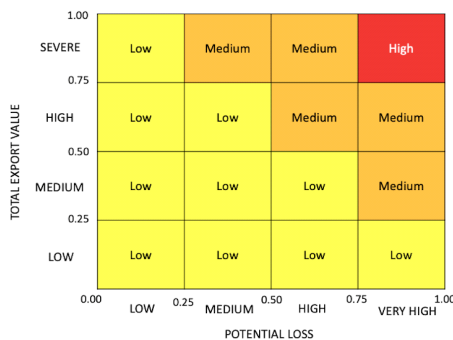
Additives (JECFA), the US Environmental Protection Agency (EPA), and the International Agency for Research on Cancer (IARC). The rejection frequency of each pair from 2017 to 2019 was used to calculate the likelihood, with none, rare, periodic, and consistent refusal events annually classified as low, medium, high, and very high, respectively (Hanlon et al., 2015).

**Incorporation of Economic-Based Prioritization**

Similar to the previous section, another 4x4 risk matrix was constructed for ranking based on the economic risk. A risk scatterplot was applied to aid risk classification as suggested by FAO (2020) and Indrotrianto et al. (2022). The matrix contained a y-axis for expressing severity and an x-axis for expressing likelihood; each axis was divided equally into four level scores: low (0 – 0.25), medium (0.25 – 0.5), high (0.5 – 0.75), and very high (0.75 – 1.00). This resulted in a matrix with 20 equal bins in the plot area divided into three risk classes: low, medium, and high (Figure 2).

According to FAO (2017), the total values of export commodities were used as a proxy for the severity, whereas potential loss due to rejection represented the likelihood. Data for total values for export commodities were derived from the Online Integrated Quarantine System (OIQS) of the Ministry of Marine Affairs and Fisheries (MMAF), Indonesia (MMAF, 2019). This system recorded 802,532 exports and 452 reimports from 1 January 2017 through 31 December 2019. Since the database also contained commodities for non-food purposes, screening processes were carried out to determine the frequency, value, and weight data for the rejected food commodities as determined from food–chemical pairs development and screening process.

Potential losses were estimated from the screened dataset. First, the total reimport frequency ( $freq_{reim}$ )



Source: Hanlon et al. (2015) and Van Asselt et al. (2013).

Figure 2. A 4x4 matrix describes three classes of risk (low, medium, and high) from total export value as severity and potential loss as likelihood.

and total transactional value of reimport ( $val_{reim}$ ) for selected foods were obtained from the dataset. The potential loss per reimport case for selected foods ( $pot_{reim-loss}$ ) was calculated by

$$pot_{reim-loss} = \frac{val_{reim}}{freq_{reim}} \tag{1}$$

We then assumed the loss per case for rejected commodities was equal to that of the reimported commodities. Hence, the potential losses of the selected foods–chemical pairs ( $pot_{loss}$ ) were derived from the potential loss per reimport case for selected foods ( $pot_{reim-loss}$ ) and the frequency of food rejections ( $freq_r$ ) caused by selected chemicals from the dataset obtained from food–chemical pairs development and screening process with

$$pot_{loss} = pot_{reim-loss} \times freq_r \tag{2}$$

Scoring was carried out by transforming the total export value ( $val_{exp}$ ) and the potential loss ( $pot_{loss}$ ) of the selected food–chemical pairs into logarithmic values and normalized to represent severity and likelihood, respectively (FAO, 2020). Thus, the score for total export value ( $val_{exp} score$ ) and potential losses of the selected food–chemical pairs ( $pot_{loss} score$ ) were determined by

$$val_{exp} score = \frac{\log val_{exp} - \log val_{exp_{min}}}{\log val_{exp_{max}} - \log val_{exp_{min}}} \tag{3}$$

$$pot_{loss} score = \frac{\log pot_{loss} - \log pot_{loss_{min}}}{\log pot_{loss_{max}} - \log pot_{loss_{min}}} \tag{4}$$

These scores were plotted in a 4x4 risk matrix. The level of economic risk was determined by bins in the plots.

The health risk ranking and economic consequence classification were combined for an overall prioritization. The combination was conducted in a 3x3 matrix because there were three risk classes from both aspects (Table 3). The pairs were placed according to their classes of risk. If they were in the same classes, higher priority went to pairs with higher economic risks.

Table 3. Prioritization of selected food/chemical pairs based on economic and health impacts.

Economic Risk	Health Risk		
	Low	Medium	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium

Source: Kovacevic, Stojiljkovic, and Kovac, M. (2019); Ristic (2013).

## Results and Discussion

### Food–Chemical Pairs Development and Screening Process

Our previous study showed that as many as 415 exports were rejected from 2017 – 2019, including from the US (364 rejections), the EU (28 rejections), and Japan (23 rejections) (Indrotristanto et al., 2022). There were 467 cases of food and combination issues resulting from multiple issues causing one rejection, developed from the 415 export rejections. For chemical hazards, 53 rejections occurred during 2017-2019 (Table 4). Histamine and mercury were the two chemicals most commonly caused the rejection, 32 (60.4%) and 12 (37.5%) cases of rejection, respectively. Chemicals caused rejection for less than 10% of total cases including cadmium (3 cases; 5.7%), veterinary drugs (2 cases; 3.8%), carbon monoxide (2 cases; 3.8%), sodium erythorbate (1 case; 1.9%), and nitrofurantoin (1 case, 1.9%) (Indrotristanto et al., 2022).

Chemical hazards caused around 11.3% of the total cases of rejections by the US and EU (Indrotristanto et al., 2022). These rejections were due to violating the limit set by the authorities; for example, a maximum of two of nine samples in a batch may contain 100-200 ppm histamine in canned products (EU). Moreover, only two or less of 18 samples may have 50-500 ppm histamine in fresh or frozen fish in the US (Debeer et al., 2021). Despite their low contribution to rejections, chemical hazards are still a major concern for food safety due to their significant impact on human health. Heavy metals (mercury and cadmium) were

Table 4. Rejection frequency of Indonesian fisheries and their chemical issues in 2017–2019 from the US, the EU, and Japan

No	Pairs	Rejection Frequency (freq.)
1	Mahi-mahi–histamine	5
2	Marlin–cadmium	1
3	Marlin–mercury	5
4	Octopus–cadmium	1
5	Octopus–sodium erythorbate	1
6	Shark–mercury	1
7	Shrimp–nitrofurantoin	1
8	Shrimp–veterinary drugs	2
9	Swordfish–cadmium	1
10	Swordfish–mercury	6
11	Tuna–carbon monoxide	2
12	Tuna–histamine	27

Source: Indrotristanto et al. (2022)

the majority hazards paired with the rejected commodities (marlin, octopus, shark, and swordfish). However, the heavy metals rejection numbers were still less than histamine, which caused as many as 29 rejections between 2017 and 2019 (mainly by the US).

There were 12 food–chemical pairs among the 53 rejection cases of Indonesian exported fisheries. The chemical hazards in those pairs were cadmium, mercury, sodium erythorbate, nitrofurantoin, veterinary drug residue, carbon monoxide, and histamine. Screening processes used the approach suggested by FAO (2020) and resulted in six pairs. These pairs were mahi-mahi–histamine, marlin–mercury, octopus–cadmium, shark–mercury, swordfish–mercury, and tuna–histamine (Table 5).

A decision tree was created to screen food-chemical hazard pairs using relevant information, such as export rejection data, peer-reviewed scientific articles, and references from international organizations. Apart from the rejection data (EU, 2021; FDA, 2021; MHLW, 2021), the occurrence and the exposure of several pairs above health reference values were also well-documented in the literature, e.g., octopus–cadmium (WHO, 2011); mahi-mahi–histamine and tuna–histamine (Colombo et al., 2018); marlin–mercury, shark–mercury, and swordfish–mercury (Olmedo et al., 2013). As a result,

Table 5. Screening for food-chemicals pairs of the rejected seafood

No	Pairs	Q1	Q2	Included in The Prioritization
1	Marlin–cadmium	Yes	No	No
2	Marlin–mercury	Yes	Yes	Yes
3	Octopus–cadmium	Yes	Yes	Yes
4	Octopus–sodium erythorbate	Yes	No	No
5	Shark–mercury	Yes	Yes	Yes
6	Shrimp–nitrofurantoin	Yes	No	No
7	Shrimp–veterinary drugs	Yes	No	No
8	Swordfish–cadmium	Yes	No	No
9	Swordfish–mercury	Yes	Yes	Yes
10	Tuna–carbon monoxide	Yes	No	No
11	Tuna–histamine	Yes	Yes	Yes
12	Mahi-mahi–histamine	Yes	Yes	Yes

Note: Q1. Are there any chemical hazards detected in associated foods?; Q2. Does the detected chemical hazard present above the health reference value?; Because Q1 for all pairs are “yes,” the question regarding the effect of processing to increase the hazard (Figure 1) is irrelevant. Source: Modified from FAO (2020).

those pairs were considered in the prioritization. Six pairs were excluded from the screening process due to overall exposure levels below the health reference level for marlin–cadmium (Gonzalez et al., 2019), swordfish–cadmium (WHO, 2011), octopus–sodium erythorbate (2016), shrimp–nitrofurans, and shrimp–veterinary drug residue (Radovnikovic et al., 2013). Tuna–carbon monoxide was excluded because of regulatory issues (Djenane & Roncalés, 2018).

### Health-Based Prioritization

Toxicology evaluation based on ARfD, ADI/TDI, and carcinogenicity suggested that heavy metals were very high in severity; histamine was considered medium (Table 6). The likelihood based on rejection frequency during three years (2017–2019) suggested that tuna–histamine and swordfish–mercury had very high and high probability, respectively. Mahi-mahi–histamine, octopus–cadmium, and shark–mercury were deemed medium in likelihood (Table 7).

The severity and likelihood of health impact combination suggested that only mahi-mahi–histamine was considered low risk; other risk pairs were classified as medium (Table 8). The very high probability of occurrence for tuna–histamine made it as predictive as heavy metals.

The chemical hazard showing the most severe impact on human health appears to be heavy metals (Table 6). The lower reference doses and carcinogenic properties of these metals relative to histamine govern the severity of the health impacts. Several metrics can

also be used as a proxy for severity, such as case fatality rate (Eygue et al., 2020), acceptable daily intake (Van Asselt et al., 2013), nature of the illness (Guillier et al., 2011), and burden of disease (Van der Fels-Klerx et al., 2018). However, the availability of data influenced the selection of metrics. The nature of illness manifestation gives qualitative measurement, whereas not all selected chemicals possess a burden of disease values or carcinogenicity potential. For example, disability-adjusted life years were available for mercury and cadmium (Havelaar et al., 2015), but this information was not available for histamine.

Furthermore, the chemicals in this study impacted health over the long term (heavy metals) and short-term (histamine). Therefore, the combination of acute reference doses, acceptable or tolerable daily intake, and carcinogenicity were applied, similar to Van Asselt et al. (2018) and Hanlon et al. (2015). This result seemed reasonable and may be consistent with other studies. Guillier et al. (2011) and Lehane and Olley (2000) mentioned that despite symptom variations due to histamine exposure, the nature of histamine poisoning was considered generally mild. Regarding the long-term effects of mercury and cadmium exposure above the reference health value that may affect internal organs (WHO, 2007, 2011), histamine was considered relatively innocuous versus the severe effects of heavy metals.

However, the history of rejection showed that tuna–histamine was a pair with a very high likelihood of health risk (Table 7). The criteria suggested by Hanlon et al. (2015) on the history of hazards exceeding the

Table 6. The severity of selected chemicals is based on the toxicological evaluation

Chemicals	Criteria (Unit)	Value	Notes	References	Category*
Mercury	ARfD (mg)	-**			
	ADI/TDI (mg/kg bw/day)	0.2	Derived from PTWI 1.6 mg/kg bw/day in the form of methyl mercury	WHO (2007)	Very high
		0.1		US EPA (2001)	
	Carcinogenicity	2B		IPCS (1993)	Medium
Overall				Very high	
Cadmium	ARfD (mg)	-			
	ADI/TDI (mg/kg bw/day)	0.8	Derived from PTMI 25 mg/kg bw/day	WHO (2011)	Very high
		1		US EPA (1989)	High
	Carcinogenicity	1		IARC (2018)	Very high
Overall				Very high	
Histamine	ARfD (mg)	50		FAO (2012)	
	ADI/TDI (mg/kg bw/day)	-			Medium
	Carcinogenicity	-			
Overall					Medium

Note: \*categories were determined according to Table 2. \*\*not applicable

Table 7. The likelihood of selected food/chemical pairs based on track record data of rejection 2017-2019

Selected Commodities	Frequency of Rejection*			Rationale	Category**
	2017	2018	2019		
Mahi-mahi-histamine	5			Rejection occurred in only 1 year, suggesting a relatively rare event	Medium
Octopus-cadmium	1			Rejection occurred in only 1 year, suggesting a relatively rare event	Medium
Shark-mercury			1	Rejection occurred in only 1 year, suggesting a relatively rare event	Medium
Swordfish-mercury	1	4		Rejection occurred in 2 years, suggesting a relatively periodic event	High
Tuna-histamine	10	5	12	Rejection occurred in 3 years with frequencies more or equal to five per year, thus demonstrating a relatively consistent event	Very high

Note: \*Source: EU (2021); FDA (2021); MHLW (2021); \*\*Categories were determined according to Hanlon et al. (2015).

Table 8. Classification of risk from severity and likelihood of selected food/chemicals pairs

Severity	Likelihood			
	Low	Medium	High	Very High
Very High		Octopus-cadmium Shark-mercury	Swordfish-mercury	
High				
Medium		Mahi-mahi-histamine		Tuna-histamine
Low				

Note: ■ High risk; ■ Medium risk; ■ Low risk

maximum limit were relatively subjective. However, the same criteria were applied by Van Asselt et al. (2018) during the evaluation of chemical risks in herbs and spices. They used data on rejection for the last ten years by the EU and monitoring by the WHO. The occurrence of chemicals in refusal can be classified as: multiple rejections, one rejections, no rejections but residue presence, and no rejection with no residue presence. These led to very high, high, medium, and low likelihoods, respectively (Van Asselt et al., 2018). This study adopted the approach of Van Asselt et al. (2018). It used the criteria suggested by Hanlon et al. (2015) with modifications on the criteria fitted with rejection data in Indonesian seafood 2017–2019 from Japan, the US and the EU. The very high likelihood of tuna-histamine seemed to determine the result of health risk ranking. This pair was classified as a medium risk, similar to swordfish-mercury, octopus-cadmium, and shark-mercury (Table 8).

### Inclusion of Economic-Based Risk for Overall Prioritization

Screening processes excluded 739,877 and 348 records from export and reimport datasets, resulting in 62,655 and 104 records, which were further analyzed (Table 9). Unfortunately, there was no reimport data of marlin from 2017–2019. This is probably because the importing countries might have destroyed the rejected marlin. Destroying recalled products was among the activities conducted by producers when their products were rejected (GMA, 2011). The total value of exports, the total reimport frequency, and the total transactional value of reimports for selected foods was derived from the screened data (Table 10).

As FAO (2017) suggested, the export value represents the severity of economic impact, whereas the likelihood is estimated by the potential losses of the



Table 9. The screening process of the exports and reimports frequency of Indonesian fishery products during 2017-2019 for the prioritization process

Processes	Export Frequency		Reimport Frequency	
	Included	Excluded	Included	Excluded
Identification from OIQS	803,532	-	452	-
Screening for ornamental, live, seed, and breed fish	496,169	307,363	383	69
Screening for selected commodities	62,655	432,514	104	279
Inclusion for prioritization	62,655	-	104	-

Source: MMAF (2019)

Table 10. The total export value, reimport frequency, and total reimport value of Indonesian seafood on 2017–2019

Selected Commodities	Total Export Value (USD) (Val <sub>exp</sub> )	Frequency of Reimport (freq <sub>reim</sub> )	Total Reimport Value (USD) (val <sub>reim</sub> )
Marlin	28,242,429	-	-
Mahi-mahi	22,533,673	4	234,216
Octopus	363,897,857	11	560,436
Shark	66,807,265	2	53,008
Swordfish	68,625,070	7	503,774
Tuna	1,344,840,896	80	4,486,460

Source: MMAF (2019)

rejected commodities. The scores for the severity of the selected food commodities (mahi-mahi, octopus, shark, swordfish, and tuna) were derived from the total export value (Table 10) using Eq. (3).

Tuna had the highest score for severity (1.0), followed by octopus (0.7), swordfish (0.3), shark (0.3), and mahi-mahi (0.0) (Figure 3). The values of the total reimport frequency and total transactional value of reimport (Table 4) were calculated to produce potential losses using Eq. (1) and Eq. (2). The scores for likelihood as determined by Eq. (4) suggested that tuna–histamine was the most likely pair causing concern (1.0) followed by swordfish–mercury (0.7), mahi-mahi–histamine (0.6), octopus–cadmium (0.2), and shark–mercury (0.0) (Figure 3). A risk matrix incorporating the total export value (severity) and potential losses (likelihood) of selected pairs could

identify pairs according to their economic risk classification. Tuna–histamine was categorized as high risk, whereas other pairs were classified as low risk (Figure 3).

The prioritization of each food–chemical pair was depicted based on their level of risk from an economic and health perspective (Table 11). Tuna–histamine was placed as the first priority. Shark–mercury, swordfish–mercury, and octopus–cadmium were ranked as the second priority. Mahi-mahi–histamine was the third priority.

The incorporation of health and economics was expected to support the multi-sectoral approach and provide better prioritization alternatives (FAO, 2017). Even though it was less accurate than other methods such as scoring methods or quantitative risk assessment, this matrix can be constructed using the limited data available; thus, this method is favorable in limited time resources (Van Asselt et al., 2018). The visible contribution of each aspect of the matrix was another advantage of using a risk matrix (Van der Fels-Klerx et al., 2018).

The contribution of economic-based prioritization was influential in putting tuna–histamine at the top priority for mitigation. Tuna is a major export commodity from Indonesia. The Indonesian MMAF noted that the total export weight for tuna is 168,434 tons (MMAF, 2018). The total export weight for tuna is expected to rise to 374,400 tons by 2030 (Tran et al., 2017). Due to its high export value, tuna is classified as high in economic prioritization (Figure 3). The potential loss per rejection case was relatively high in swordfish, around 72,000 USD more than in tuna (approximately 56,000 USD). However, the number of rejections of tuna–histamine (27 times) was far more than that of swordfish–mercury (6 times). The potential loss of tuna–histamine (around 1.5 million USD) exceeded that of swordfish–mercury (approximately 431,000 USD). Tuna–histamine was considered very

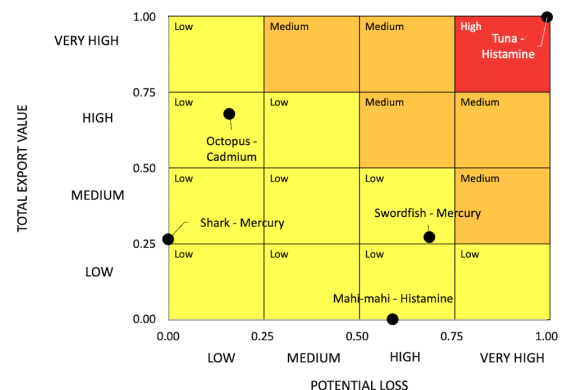


Figure 3. The risk matrix shows the economic impact of the selected food-chemical pairs.

Table 11. Prioritization of selected food/chemical pairs based on economic and health impacts

Economic Risk	Health Risk		
	Low	Medium	High
High		Tuna-histamine (#1)	
Medium			
Low	Mahi-mahi-histamine (#5)	Octopus-cadmium (#2-4) Shark-mercury (#2-4) Swordfish-mercury (#2-4)	

Note: ■ Higher priority; ■ Medium priority; ■ Lower priority  
# priority number

high in economic impact with severity (Figure 3). The combination of medium risk from risk ranking and high risk from economic consequences resulted in tuna-histamine being among the top priority for developing mitigation strategies (Table 10). Risk matrices clearly showed that even though the pair was considered to have a medium risk for health impact, the high risk from an economic standpoint made the pair a top priority for mitigation.

Histamine is also considered a middle-to-high priority for intervention as recommended by risk-ranking studies elsewhere. Histamine was categorized as medium rank causing several outbreaks in Australia (Sumner & Ross, 2002). A recent risk-ranking study, Risk-Ranking Model for Food Tracing, was performed by the FDA to aid in prioritizing food for traceability lists to protect public health (FDA, 2020c). The ranking used several criteria such as outbreak frequency, illness occurrence, severity, probability of contamination, hazard increase potential, the likelihood of hazard reduction during processing, consumption, and cost of treatment (FDA, 2020a). The ranking resulted in histamine in sea finfish as having one of the highest rankings due to the high score for outbreak frequency, consumption, the likelihood of contamination, and cost of treatment (FDA, 2020b).

Tuna is also an Indonesian fish commodity in the highest position for food-pathogen prioritization. Indrotristanto et al. (2022) performed prioritization using total export value and total loss representing economic as well as several proxies (such as disease burden, hospitalization number, and deaths rate) representing health impacts. They suggested that tuna-*Salmonella* spp. was the top priority for mitigation in food-pathogen pairs and shrimp-*Salmonella* spp. (Indrotristanto et al., 2022). Mitigation for tuna may be a strategic policy because it may tackle chemical

and microbiological contamination problems. Unlike heavy metals that are more related to environmental conditions, histamine may be formed by enzymatic reactions with microorganisms. Therefore, hygiene and sanitation, together with rapid processing at low temperatures, are needed to decrease the formation of such chemicals (CAC, 2009; Mercogliano & Santonicola, 2019) and reduce the risk of pathogens.

There were also several limitations of this study that may be improved for future works. The available export rejection data used for health and economic risk ranking were from the US, the EU, and Japan. Furthermore, these countries were major destinations for Indonesian fishery exports. Thus, this study used the rejection data from those countries to represent fishery export rejection data. However, the inclusion of export rejection data from other countries would improve the risk ranking. Nevertheless, the priority list produced from this study may be beneficial for risk managers in developing mitigation to reduce the number of fishery export rejections.

## Conclusion

Prioritization based on health and economic impact can be used to identify the most important rejected seafood-chemical pairs, which can be followed by establishing the mitigation measures. The top priority was the tuna-histamine pair, followed by the shark-mercury, swordfish-mercury, and octopus-cadmium. Mahi-mahi-histamine was suggested to be a lower priority for mitigation. The risk ranking using the matrix method is acceptable for prioritization with several advantages, including limited time resources and visual outputs. Using the available rejection data, the results of this study may assist the Indonesian government in developing a mitigation policy for fishery export rejections.

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## Supplementary Material

Supplementary materials are available online at the Journal's website.

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