Jurnal Teknik Industri
Vol. 24, No. 2, August 2023, pp. 127-140
ISSN : 1978-1431 print | 2527-4112 online

Fuzzy TOPSIS for Post-Harvest Losses Drivers Evaluation in Fish Supply Chain: A Case Study

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ARTICLE INFO

Article history
Received, April 14, 2023
Revised, August 1, 2023
Accepted, August 7, 2023
Available Online, August 31, 2023

Keywords
Fish Supply Chain
Post Harvest Losses
Post-Harvest Fish Losses
Fuzzy TOPSIS
MCDM

ABSTRACT

Being highly susceptible to damage, fish result in significant post-harvest fish losses (PHFL) due to quality deterioration from inefficient harvesting and market dynamics. This study aims to identify the leading factors driving PHFL and construct a practical decision-making framework for the fisheries industry's development. Employing the fuzzy TOPSIS method, we scrutinized the critical causes of PHFL. Our literature review revealed four aspects and 13 operational processes contributing to PHFL across the supply chain. Among these processes, four drivers were the primary culprits: excessive fish capacity in shipping baskets, inadequate ice cooling during transportation to suppliers, insufficient ice cooling during supplier sorting, and the absence of appropriate tools for small retailers. To alleviate PHFL and enhance the fishery industry, priority should be given to addressing excessive fish capacity in shipping baskets, which poses a risk of physical damage during transit. Moreover, inadequate ice-cooling techniques, particularly in transportation and supplier sorting stages, raise public health and food safety concerns. Stakeholders must prioritize these critical factors for PHFL reduction.

1. Introduction

The fishing industry is crucial in the global food supply, offering sustenance and livelihoods, especially in developing nations [1-3]. This significance is particularly pronounced in Indonesia, where fish is a widely accessible source of protein compared to other alternatives [4, 5]. As the world's leading maritime nation, Indonesia annually yields 21.8 million tons of fish [6]. With escalating global demand, Indonesian fishing productivity has seen a parallel surge [7]. However, challenges persist, notably in the perishability of fish, especially in tropical climates [5, 8, 9]. The vulnerability of fresh fish to post-harvest losses (PHFL) is evident in the disproportionately small quantity that reaches consumers compared to the initial harvest [10]. Consequently, there is a growing imperative to comprehend and mitigate both production-related PHFL and consumption-induced food waste.

https://doi.org/10.22219/JTIUMM.Vol24.No2.127-140 http://ejournal.umm.ac.id/index.php/industri ti.jurnal@umm.ac.id

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Indonesia faces an alarming PHFL rate of approximately 20-30%, amounting to an annual economic loss of 63.3-82.8 trillion rupiahs [11, 12]. Projections suggest that in the next five years, Indonesia will lose 3.82-4.99 million tons of fish, equivalent to 840,000-1 million tons of vital fish protein [12]. This substantial loss is attributed to inefficiencies in the post-harvest process, wherein fish quality deteriorates from harvest to consumer delivery [5, 13, 14]. This quality decline prevails in many developing nations; fish stored for over a day becomes unfit for consumption. While often overlooked, capture, sorting, and delivery processes are critical determinants of fish quality [15]. It is imperative to recognize that each stage, from harvest to consumer, influences the final quality of the fish. Consequently, meticulous planning and monitoring of this process are crucial. It is within these stages that PHFL emerges as a significant challenge.

Post-harvest losses encompass the food losses that occur throughout the food supply chain. As such, post-harvest losses can be applied to a broad range of food commodities. One area of study that can be explored is the occurrence of post-harvest losses in the supply chain of fruits and vegetables, as demonstrated by Gardas, et al. [16] and [17]. Another example can be observed in the research undertaken by Hengsdijk and de Boer [18], which examines the post-harvest losses of cereals. This study aims to analyze the global issue of post-harvest fish losses, commonly called PHFL, which poses a significant challenge for maritime nations. PHFL is described as the decline in fish quality, quantity, or monetary value across the supply chain[15, 19]. PHFL is one of the major impediments confronting the whole fishing industry. Reducing the PHFL and increasing the proportion of fish consumed for continued human consumption is required to increase food security. PHFL can be classified as physical, economic, and nutritional losses [3, 9, 20]. Physical loss refers to the decreasing quality of fish due to improper handling and processing. When fish begin to decay, their value drops, and they must be preserved at greater expense, resulting in economic loss. Further, nutrient loss of fish mostly occurs during food processing [7, 8]. Due to a complex variety of losses, it is problematically challenging to identify the primary PHFL attributes.

The existing body of literature indicates that significant losses are incurred during the post-harvest period for fish. Hence, it is essential to scrutinize the attributes responsible for giving rise to PHFL to develop more effective practices. For instance, Adelaja, et al. [13] stated that the length of time between the end of the fishing cycle and the arrival at the landing site causes a decline in fish quality. According to Gyan, et al. [2], low fish processing and gear-related issues are the primary factors contributing to post-harvest fish losses (PHFL). It is because these factors increase the likelihood of fish damage and spoilage occurring at a faster rate. Moreover, the study by Mramba and Mkude [5] indicated a positive correlation between fishers' education level and the extent of fish spoilage. The findings indicated that fishers with lower levels of education exhibited a higher risk for fish spoilage, which was attributed to their limited knowledge and inadequate implementation of proper handling practices. Furthermore, Mavuru, et al. [3] revealed that elevated temperatures accelerate the growth of bacteria, thereby expediting fish spoilage, and recognized as a significant PHFL determinant. Prior studies have discussed the attributes promoting PFHL; however, the knowledge gap remains. Previous studies have primarily concentrated on the factors that facilitate the promotion of PHFL without considering the three fundamental components of PHFL, including physical, quality, and economic losses. Furthermore, there is a dearth of methodologies that can precisely identify the key drivers of PHFL and explicate the intricate complexity of its attributes. Consequently, this study strives to fill these gaps by thoroughly investigating the primary causes of PHFL and presenting a realistic perspective on the matter.

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Due to the availability of statistical data and associated factors that may impact the result, it is feasible to identify the PHFL's drivers using qualitative methods such as the decision-making process. The decision-making process involves several steps: identifying problems, developing preferences, evaluating alternatives, and deciding the best alternatives [21]. Decision-making becomes very intuitive when there is only one criterion, and a decision-maker only needs to choose an alternative with the highest preference value. However, in the context of PHFL, the decision-making process differs owing to considering several drivers or criteria, also known as multiple criteria decision-making. In this study, one of the multiple criteria decision-making methods, the technique of preferential arrangement by similarity to the ideal solution (TOPSIS) integrated with the fuzzy theory, is conducted for the analysis. TOPSIS, which Hwang and Yoon [22] introduced based on the concept of a compromise solution combined with fuzzy theory, is utilized in this study to identify the best alternative, compromise solutions, interpret the shortest distance as ideal positive solutions, and the most negative ideal solutions. Moreover, this study utilizes fuzzy TOPSIS to determine the critical drivers of PHFL by conducting several stage, including literature review of the causes of the decline in fish values, identifying several causes pertinent to conditions in Indonesia and cross-checked them based on the opinion from the expert, designing the questionnaire to obtain the data that corresponded to the fuzzy TOPSIS approach and relevant to the PHFL in the study, and finally determining the major causes of the PHFL. In Addition, The objectives of this study encompass the construction of a decisive decision-making framework for PHFL, identifying driving attributes and providing practical guidance for industry enhancement.

This study contributes to the field by establishing a comprehensive theoretical framework for PHFL decision-making. It furnishes practical guidelines for the government and fishing industry to combat PHFL effectively. Furthermore, it presents a set of driving attributes that expand existing frameworks, shedding light on the most significant PHFL issues. The subsequent sections will delve into the scope and methodology, present the results, discuss, and ultimately conclude the study.

2. Methods

The scope of the study and the method used in this study are elaborated in this section.

2.1. The Scope of Study

PHFL was observed along the fish distribution channels, from harvest to customer reception [9, 13, 20]. As several processes along the fish distribution lines may have instigated a high PHFL, the fuzzy TOPSIS method developed by Hwang and Yoon [23] was utilized to rank the drivers of PHFL.

This study has conducted a literature study to identify the attributes of PHFL. This study is based on Ames, et al. [10] discussion of post-harvest fish losses in the tropics, including approaches to mitigate such losses. Experts were consulted to connect the findings to Indonesian contexts by discussing the PHFL issue in Indonesia. By integrating the literature review results with expert consultation, this study will be able to analyze PHFL drivers relevant to Indonesia's harvest and post-harvest process. Due to these circumstances, the final results will be capable of forming a PHFL driver list that records conditions in Indonesia.

The results of fuzzy TOPSIS calculations are then discussed in more depth to find the best solutions to reduce PHFL. This study looks for technical processes throughout the supply chain that can cause fish value losses. Through direct observation and interviews

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with fish farmers, suppliers, middlemen or retailers, small retailers, and consumers, several drivers causing PHFL were found. 13 PHFL drivers have been identified. Table 1 shows the criteria for post-harvest fish loss drivers' evaluation of each criterion used in this study.

Table 1. Criteria for post-harvest fish losses drivers' evaluation

No	**Criteria**	**Definition**
1	Physical Losses	Physical losses are due to product damage, so the fish can no longer be consumed.
2	Economic Losses	Economic losses are caused by damage or decreased fish quality, occurring gradually and progressively.
3	Nutritional Losses	Nutritional loss is a decrease in nutrient content caused by certain activities, which can occur in fresh and processed fish.

Based on the literature review, this study concentrates on three PHFL aspects: physical losses, economic losses, and nutritional losses, which may be described as follows: The physical losses are due to product damage, so the fish can no longer be consumed [3, 8, 10]. Physical Losses It can be divided into two: (a) complete physical losses (the fish is completely damaged and cannot be consumed at all) and (b) material losses (due to poor processing of fish) caused by a lack of resources, i.e., overfishing, damage during distribution, inadequate catches, poor harvesting techniques, and slow distribution and marketing processes.

In addition, the economic losses are caused by damage or a decrease in fish quality. Unlike the physical losses, which are absolute and can be calculated, economic losses occur gradually and progressively [10, 15]. In Addition, economic losses can be very subjective, so different groups of people may have different views about how valuable a product is. The value of fish with certain qualities will change from the first day of harvest to the following days. In addition, the value of fish of the same quality will also vary from place to place.

Furthermore, nutritional loss is a decrease in nutrient content caused by certain activities, which can occur in fresh and processed fish [8, 10]. The traditional processing method can significantly reduce fish nutrition. For example, the procedure for heating fish at a high temperature can damage or reduce the nutritional value of fish protein. Fish that are not fresh also experience a decrease in nutritional value because they may be infected with bacteria.

A qualitative approach uses structured tools to create numerical data. In this study, the instruments are filled in as questionnaires that experts must complete, which are then presented as quantitative tables to calculate the classification or ranking. This study will be focused more on the study case in the district of Gresik, East Java, Indonesia, as the location of data gathering information. R language is used to determine each driver's score using the fuzzy TOPSIS method to support the analysis. The reason for using the R language is due to its versatility. R Language is also famous as a simple programming language with many freely accessible packages [24].

2.2. Methodology

Fig. 1 depicts the procedures of this study's analysis. This study obtained qualitative data from various stakeholders along the supply chain of capture fisheries and ponds in Gresik Regency. Among them are fishermen, distributors, and sellers. The study begins by identifying the problem of definition, followed by a review of the relevant

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literature to establish the PHFL attributes. After obtaining the list of PHFL attributes, which incorporates three aspects and 13 criteria, the experts validate the list to ensure that the attributes are legitimate. Subsequently, the qualitative data were gathered using a questionnaire survey, which was then analyzed using the fuzzy TOPSIS method to meet the objectives [25, 26]. This method is divided into two parts: The analysis of generic fish and its supply chain for domestic consumption and the mathematical part. Both parts are essential to detect the cause and effect of PHFL on the fish supply chain.

2.2.1. Generic fish and fish product supply chain for domestic consumption

According to Vallejo, et al. [27], in the production stages, the primary producer is related to the nature of the fishery, i.e., capture and aquaculture. The supply chain begins when fishermen harvest fish. The supply chain begins when farmers lay the fish seeds during the aquaculture fishery. The intermediary is responsible for linking the producer to the processor. Agents or sub-agents are intermediaries collecting fish at the landing point. Supplier agents are intermediaries involved in some preprocessing before the fish are sold. Preprocessing activities include classification as size and quality, cleaning, and cutting. Finally, fish is sold to buyers who could be consumers or producers. All these processes reduce the value of fish after harvesting along the supply chain.

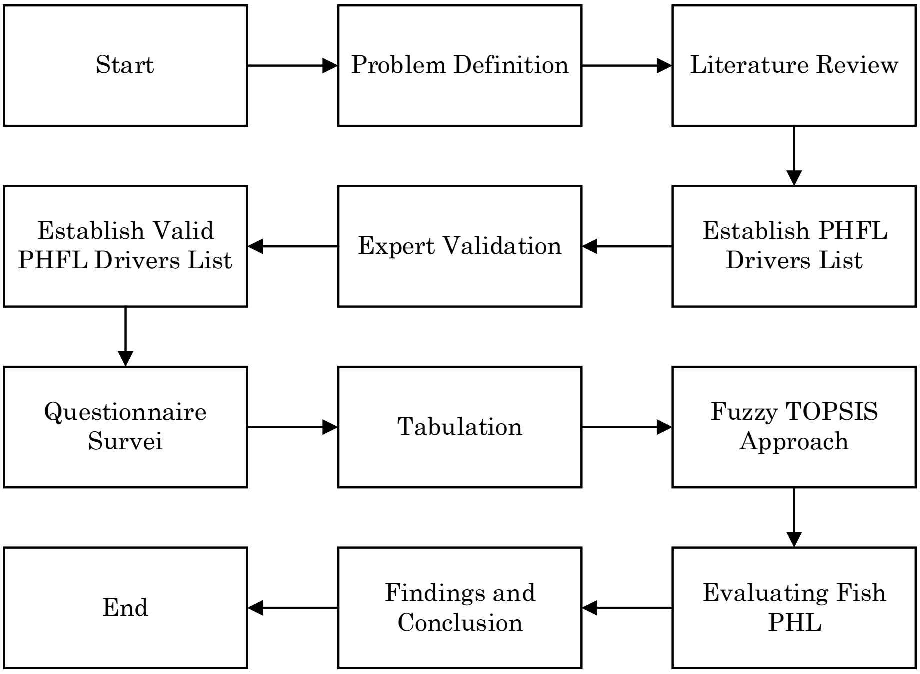

Fig. 1. Proposed analytical steps

2.2.2. Fuzzy TOPSIS (Technique for Order Preferences by Similarity to an Ideal Solution)

The theory of fuzzy became a useful decision-making modelling tool when introduced by Zadeh [28]. TOPSIS was developed by Hwang and Yoon [23]. The idea is that chosen alternatives must have the shortest Euclidean distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS), where the positive ideal solution minimizes cost criteria and maximizes benefit criteria. TOPSIS is a compensation aggregation method that compares alternatives by identifying each criterion's weight. Because the parameters or criteria are often incongruous in multi-

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criteria problems, it may create a problem in evaluation. Therefore, to avoid this problem, a fuzzy system is necessary. Using fuzzy numbers in TOPSIS for criteria analysis makes evaluation easy [29]. Chen [30] expanded TOPSIS with triangular fuzzy Numbers and introduced a vertex method to calculate the distance between two triangular Fuzzy Numbers. If $\tilde{x} = (a_1, b_1, c_1), \tilde{y} = (a_2, b_2, c_2)$ are two triangular fuzzy Number then the vertex method is employed to compute the distance between them by calculating the Equation (1).

$$d(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}[\,(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\,]} \tag{1}$$

The Fuzzy TOPSIS method can evaluate multiple alternatives against the selected criteria. According to Nădăban, et al. [31], The procedure of fuzzy TOPSIS is divided into eight steps:

Step 1. Specify a rating for criteria and alternatives

Assume there is a decision group with K members, the fuzzy rating of the k^{th} decision maker about alternative A_i w.r.t. the criterion C_j is denoted $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$, and the weight of the criterion C_j is denoted $\widetilde{w}_{j1}^{k} = \left(w_{j1}^{k}, w_{j2}^{k}, w_{j3}^{k}\right)$

Step 2. Compute the aggregated fuzzy ratings for alternatives and the aggregated fuzzy weights for criteria

The aggregated fuzzy rating $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ of i^{th} alternative w.r.t. j^{th} The criterion is derived by computing Equation (2).

$$a_{ij} = \min_k \left\{a_{ij}^{k}\right\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^{k}, c_{ij} = \max_k \left\{c_{ij}^{k}\right\} \tag{2}$$

The aggregated fuzzy weight $\widetilde{w}_j = \left(w_{j1}, w_{j2}, w_{j3}\right)$ for the criterion C_j is obtained by applying Equation (3).

$$w_{j1} = \min_k \left\{a_{j1}^{k}\right\}, w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{j2}^{k}, w_{j3} = \max_k \left\{w_{j3}^{k}\right\} \tag{3}$$

Step 3. Compute the normalized fuzzy decision matrix

The normalized fuzzy decision matrix is $\tilde{R} = \left[\tilde{r}_{ij}\right]$, where both benefit and cost criteria are calculated by Equation (4) and (5), respectively.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \; and \; c_j^* = \max_i \left\{c_{ij}\right\} \;\; (benefit\ criteria) \tag{4}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \; and \; c_j^- = \min_i \left\{a_{ij}\right\} \;\; (cost\ criteria) \tag{5}$$

Step 4. Compute the weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix is $\tilde{V} = \left(\tilde{v}_{ij}\right)$, where the value of $\left(\tilde{v}_{ij}\right)$ is determined by computing Equation (6).

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \tag{6}$$

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Step 5. Compute the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

The FPIS and FNIS are calculated using Equation (7) and Equation (8).

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*), where\ \tilde{v}_j^* = \max_i \{v_{ij3}\} \tag{7}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), where\ \tilde{v}_j^- = \min_i \{v_{ij1}\} \tag{8}$$

Step 6. Compute the distance from each alternative to the FPIS and the FNIS

The distance from each alternative A_i to the FPIS and the FNIS is determined by applying Equation (9).

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, v_j^-\right) \tag{9}$$

Step 7. Compute the closeness coefficient CC_i for each alternative
For each alternative A_i, We calculate the closeness coefficient CC_i using Equation (10).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \tag{10}$$

Step 8. Rank the alternatives

The alternative with the highest closeness coefficient represents the best alternative.

2.3. Data and Case Study

The fish supply chain for domestic consumption initiates with the harvest, illustrated in Fig. 2. This process involves fish farmers who harvest the fish from ponds and subsequently conduct a sorting process. Post-sorting, the fish is weighed and then delivered to a supplier. The supplier is responsible for transporting the fish to a warehouse, where another round of sorting takes place before its dispatch to the market. The criteria for sorting the fish is contingent on the specific demands of retailers. Upon arrival at the central market, the fish is packed and distributed to traders and retailers. Small-scale retailers procure fish from retailers or wholesale markets and distribute them to various regions to meet consumer demand.

Table 2 presents the weight data of ratings for various criteria represented in fuzzy numbers. Criteria such as physical and economic losses carry a relatively higher weight than nutritional losses. Based on these criteria, the evaluation results for each alternative can be found in Table 3, where ratings are expressed in fuzzy numbers. All data in this research were gathered through interviews and questionnaire distribution within the pond fishery supply chain, specifically focusing on the Gresik district, Indonesia. It is important to note that the assessment data for nutritional losses remained consistent across alternatives, as respondents faced challenges in accurately assessing this criterion.

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Table 2. Fuzzy criteria weight

Criteria	Linguistic Assessment	Fuzzy ratings
Physical Losses	Very High	(0.9, 1, 1)
Economic Losses	Very High	(0.9, 1, 1)
Nutritional Losses	Moderate High	(0.5, 0.7, 0.9)

Table 3. Fuzzy Decision Matrix

No	Alternative	Fuzzy Ratings		
		Physical Losses	Economic Losses	Nutritional Losses
1	Lack of fish netting methods when fish are harvested	(9,10,10)	(3,5,7)	(0,0,1)
2	Lack of shovel quality to move fish from ponds to temporary shelters	(0,1,3)	(5,7,9)	(0,0,1)
3	Lack of shovelling skills when transferring fish from ponds to temporary shelters	(1,3,5)	(3,5,7)	(0,0,1)
4	Lack of temporary shelter quality after the fish is removed from the pond	(5,7,9)	(9,10,10)	(0,0,1)
5	Lack of fish sorting skills at the pond area	(5,7,9)	(7,9,10)	(0,0,1)
6	Excessive fish capacity in the basket used for shipping to suppliers	(7,9,10)	(9,10,10)	(0,0,1)
7	Lack of ice-cooling techniques when shipping to suppliers	(7,9,10)	(9,10,10)	(0,0,1)
8	Lack of basket stacking methods when shipping by vehicle	(5,7,9)	(7,9,10)	(0,0,1)
9	Lack of ice-cooling techniques when fish are sorted by supplier and transferred to the drum	(7,9,10)	(9,10,10)	(0,0,1)
10	Excessive fish capacity in the drum used for shipping to the main market	(5,7,9)	(7,9,10)	(0,0,1)
11	Lack of loading and unloading methods in the main market	(3,5,7)	(5,7,9)	(0,0,1)
12	Lack of display methods in the central market	(5,7,9)	(7,9,10)	(0,0,1)
13	Lack of use of tools when small retailers take fish	(7,9,10)	(9,10,10)	(0,0,1)

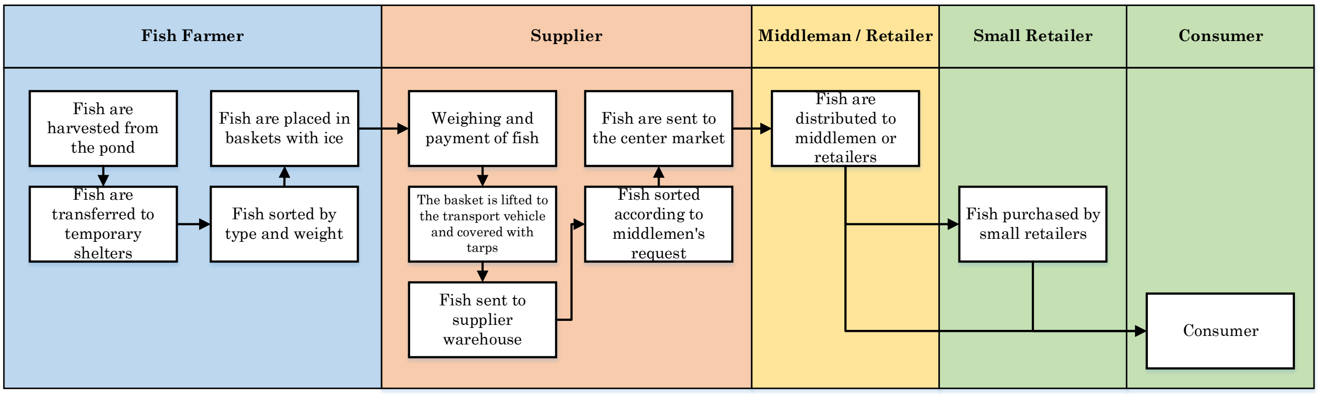

Fig. 2. Fish and fish product supply chain for domestic consumption

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3. Results and Discussion

3.1. PHFL evaluation

The analysis results obtained from the questionnaire were evaluated using the fuzzy TOPSIS technique and are displayed in Table 4. Based on these findings, it can be inferred that the technical process of transferring fish significantly decreases their value, leading to significant PHFL. The primary drivers of PHFL that require attention are identified as follows: "excessive fish capacity in the shipping baskets to suppliers," "absence of ice-cooling techniques during shipping to suppliers," "lack of ice-cooling techniques during supplier sorting and fish transfer to the drum," and "failure to use appropriate tools by small retailers during fish handling." These criteria all scored 0.668, establishing them as the four foremost drivers of PHFL. On the other hand, the criterion with the lowest rank is "lack of excavation ability during fish transfer from ponds to temporary shelters," scoring 0.399. These findings underscore the susceptibility of the fish transportation process from ponds to consumers to potential damage.

Gyan et al. [2] reported that extended transportation durations from the harbor to the market and, ultimately, to the customer may lead to fish mortality and spoilage, consequently contributing to PHFL. Additionally, inadequate facilities exacerbate this situation, as they are used out of necessity. Furthermore, an excess amount of fish in the basket can also lead to damage. Traditional cooling techniques also damage fish, as most suppliers rely solely on limited ice cubes. Small retailers in the observed locations must employ advanced cooling techniques when distributing fish to customers. Notably, this study determined that fish harvesting processes and techniques have a relatively insignificant impact on PHFL. It implies that catching fish is not necessarily correlated with LPHP, while the subsequent handling process remains relevant to PHFL.

Table 4. Fuzzy TOPSIS Result

Rank	PHFL Drivers	Score
1	Excessive fish capacity in the basket used for shipping to suppliers	0.668
2	Lack of ice-cooling techniques when shipping to suppliers	0.668
3	Lack of ice-cooling techniques when fish are sorted by supplier and transferred to the drum	0.668
4	Lack of use of tools when small retailers take fish	0.668
5	Lack of temporary shelter quality after the fish is removed from the pond	0.627
6	Lack of fish sorting skills at the pond area	0.597
7	Lack of basket stacking methods when shipping by vehicle	0.597
8	Excessive fish capacity in the drum used for shipping to the central market	0.597
9	Lack of display methods in the central market	0.596
10	Lack of fish netting methods when fish are harvested	0.575
11	Lack of loading and unloading methods in the central market	0.503
12	Lack of shovel quality to move fish from ponds to temporary shelters	0.401
13	Lack of shoveling skills when transferring fish from ponds to temporary shelters	0.399

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3.2. Managerial Implication

The study provides several crucial implications for the fishing industry, offering potential strategies to enhance performance and tackle PHFL. These implications arise from crucial findings regarding the underlying drivers of PHFL. Specifically, the study identifies four primary drivers: excessive fish capacity within shipping baskets, inadequate employment of ice-cooling methods during transportation and sorting, and a lack of proper tools during fish handling by small retailers. Addressing these drivers is deemed critical in effectively reducing PHFL.

To bolster the fishing industry and mitigate PHFL, stakeholders must first confront the issue of excessive fish capacity within shipping baskets. It aligns with the findings Acharjee, et al. [19] and Naiu, et al. [32], who highlight that an overabundance of fish within a basket can lead to physical damage during transit. The observed damage is primarily attributed to the substantial pressure exerted on the fish due to overcrowding. Even with proper temperature control, the compression of fish within the basket can lead to bruising, particularly for those at the bottom. It ultimately compromises freshness and quality. Hence, it is imperative to address the problem of excessive fish capacity by implementing improved packing techniques or organizing baskets to minimize friction during transportation, especially over long distances. Standardizing basket size and capacity, tailored to specific fish types and quantities, can also prevent overcrowding during shipping.

Subsequently, it is reported that higher temperatures are increasing the fish spoilage risk [13, 19]. Hence, the lack of ice-cooling techniques, particularly during the shipping process and the supplier's sorting process, became one of the most significant PHFL issues that must be solved. This finding is also described by Mramba and Mkude [5], who point out that the risk of fish deterioration increases in tropical countries like Indonesia, especially when they lack cooling techniques. Adelaja, et al. [13] argued that the lack of handling, freezing, and packaging of fish may lead to heightened microbial activity, enzymatic reactions, and lipid oxidation in the flesh of the fish. These processes contribute to physical deterioration during the period between harvesting and consumption. In tropical climatic countries like Indonesia, fish spoils fast within 12 hours of being harvested. This spoilage deteriorates the fish quality and causes lower market prices. Therefore, to improve the fish industry and food security and reduce the PHFL, low temperatures must be maintained throughout the whole supply chain, including unloading, auctioning, transportation, and distribution, until the product is delivered to consumers or final purchasers. Using ice to cool fresh fish is a very efficient technique for preventing spoiling [4, 8]. Ice is an appropriate cooling solution since it is safe, has an exceptionally excellent cooling capacity for a particular volume or weight, is relatively inexpensive, and may rapidly chill fish. To keep the low temperature for all fish equally, it should be ensured that the ice used covers the whole surface of all the fish; thus, the use of crushed ice is ideal since it is capable of making contact with the fish's body evenly, thereby rapidly reducing its temperature. By freezing the fish to around 0°C, its freshness or shelf life can be extended until 12 to 18 days, depending on the kind of fish and how it was handled from when it was harvested.

Furthermore, the primary cause of PHFL is the lack of small retailers to utilize the proper equipment while taking fish after landing. It is well known that fish may incur physical damage from the moment they are caught until they are landed, which quickens the spoilage process [14, 32]. Supporting the finding, Mavuru, et al. [3] and Acharjee, et al. [19] have emphasized that inadequate equipment and suboptimal handling techniques contribute to the physical loss of fish. Small fish such as anchovy, mackerel, and sardine are easily damaged and crushed during the unloading process; thus, merchants should avoid using equipment that might cause physical harm, such as shovels, harpoons, knives, and others. It must be unloaded using the proper lifting equipment to prevent large fish from being slammed and physically damaged. Therefore, to reduce PHFL, better and more appropriate tool use is required during the fish unloading process. The fish should then be placed in a clean container with ice to avoid the oxidation and microbial activity that causes quick spoiling. In Addition, to address the lack of proper equipment utilization, extensive training and instructional programs are needed to target small retailers, emphasizing the advantages and appropriate utilization of tools for fish handling. The provision of workshops, demonstrations, and instructional resources can serve as an effective means to enhance the knowledge and awareness of retailers. Along with that, the government can provide incentives or financial assistance to small retailers who invest in and utilize proper equipment for fish handling. This approach is intended to promote the adoption of improved and safe equipment, thereby mitigating PHFL.

Therefore, this study highlighted the most significant causes of PHFL that must be solved, such as excessive fish capacity in the basket used for shipping to suppliers, lack of ice-cooling techniques when shipping to suppliers, and lack of ice-cooling techniques when fish are sorted by supplier and transferred to the drum, lack of use of tools when small retailers take fish. These drivers must be managed to develop the fishing business and lower the PHFL. These drivers resulted from the professionals' Gresik, East Java, Indonesia survey. In Addition, these drivers are applicable and useful for other countries having similar characteristics, laws, and progress. Consequently, these drivers are vital for supporting relevant practitioners in addressing the problem of PHFL.

4. Conclusion

The objective of this study is to find the critical factors of PHFL. For this purpose, this study uses the fuzzy TOPSIS approach to find the most critical causes of PHFL in the scope of the study. Based on the qualitative data, this study constructs a decisive decision-making framework for PHFL. The physical, economic, and nutritional losses have been determined to be aspects driving the PHFL. In Addition to these three factors, the literature review identifies thirteen operational processes contributing to PHFL throughout the supply chain. The data for the analysis were collected through interviews and questionnaires with relevant stakeholders in the aquaculture supply chain in Gresik, East Java. The results of this study reveal that there are four drivers identified as the highest cause of fish losses, such as excessive fish capacity in the basket used for shipping to suppliers, lack of ice cooling techniques when shipping to suppliers, lack of ice-cooling techniques when suppliers sort fish out and transfer fish to the drum; and lack of use of tools when small retailers take fish. The finding provides a list of PHFL drivers and a score for each driver, which may assist the practitioner in enhancing the fishing industry and decreasing PHFL, enhancing the nation's food security. This study's result indicates that fish damage will likely occur during transportation. Through additional interviews, it was also discovered that insufficient facilities are still in operation and that excessive fish accumulation continues exacerbating fish damage. Suppliers always use ice cubes to chill fish during transportation, making the fish susceptible to contamination from dissolving ice. Furthermore, many minor retailers do not use refrigerators when distributing fish. It demonstrates that the techniques and materials used to chill fish during distribution should be a primary concern for the supply chain.

This study has certain limitations. Since the proposed drivers in this study were gathered from the existing literature, the framework's comprehensiveness may be restricted. Future studies are needed to broaden and enhance the proposed drivers to

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enrich the PHFL literature. Related to the scope of the study, this study is analyzing a case study in the district of Gresik, Indonesia. From the findings, fish cooling techniques are essential. However, many fishermen still use traditional techniques, so the cooling technique is not advanced. This area mostly uses traditional methods for fish preservation. In future studies, the discussion may benefit from focusing on efficient fish-cooling techniques and fish-cooling materials to reduce the PHFL by considering the uncertainty during the delivery. It is also essential to consider the effect of it on the environment.

Declarations

Author contribution: We declare that both authors contributed equally to this paper and approved the final paper.
Funding statement: No funding was received for this work.
Conflict of interest: The authors declare no conflict of interest.
Additional information: No additional information is available for this paper.

Acknowledgments

This study is supported and funded by Universitas Internasional Semen Indonesia through a competitive research grant scheme. Thank you to the previous researchers whose results are used in this study.

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