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A Multidisciplinary Approach for Improving Resource Efficiency in the Indian Surimi Supply Chain

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Abstract: With the world population set to approach an estimated 9 billion by 2050, against a background of finite natural resources, we need renewable biological resources for securing healthy food and animal feed to meet the nutritional requirements of the growing population. In this paper, key findings from ReValue Eranet project financed by Norway, India, and Spain are presented. The project aims to contribute to the UN Sustainable Development Goals (SDG) target on food losses reduction, by developing innovative technologies for the surimi industry, namely reducing losses by improved cold chain management and efficient conversion of rest raw materials (RRM) and wash water into value-added protein and oil ingredients for food and feed applications. A multidisciplinary research approach was applied with expertise from supply chain management, life cycle assessment, biotechnology, energy, and process engineering to propose several solutions for improving the overall resource efficiency of the surimi supply chains in India. This paper presents a synthesis of proposed solutions from ReValue project and potential contribution towards SDGs as well as market exploitation strategies.

Keywords: surimi supply chain; resource efficiency; climate friendly refrigeration; seafood processing; cold chain management; regulatory framework

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1. Introduction

Bioeconomy and circular economy concepts have gained significant interest in recent years. Circular economy concept replaces the linear production model of "take, make and dispose" with a circular model in which the waste is kept within the system and reduced, recycled, and remanufactured [1]. Improving resource efficiency is one of the key features of bioeconomy which is defined by the European Commission as using the earth's limited resources in a sustainable manner while minimising the impacts on the environment. Improving resource utilisation efficiency is an important approach to reduce environmental impacts and increase economic performance simultaneously [2]. Furthermore, a transition towards a circular economy provides a way to improve resource efficiency of the food system.

The EU Waste Framework Directive (WFD) [3] sets the basic concepts and definitions related to waste management, including definitions of waste, recycling, and recovery. The five-step waste hierarchy established in the WFD provides an order of preference for managing and disposing of waste as depicted in Figure 1.

For the sustainability of our food systems, food waste and food loss are two critical challenges that must be solved in the coming decade [4,5]. Food loss, usually preventable, is defined by food that is discarded post-harvest due to quality issues or lack of proper infrastructure for handling and storage. Food waste, on the other hand, is discarded by the consumers themselves [6]. In 2011, the UN Food and Agriculture Organization (FAO) reported that 1.3 billion tonnes of food are lost or wasted every year, equivalent to one-third of the world's food supply produced for human consumption [7]. The importance of reducing our food loss and food waste is immense, it can reduce pressure on the environment, aid our growing world population, feed undernourished communities, and provide economic wellbeing for those working in the industry [8]. By 2030, the United Nations (UN) has ambitious goals of halving per capita global food waste while simultaneously reducing food loss from production and supply chains [9]. To attain this, continuous work on regulations and global initiatives must be achieved across all nations as the costs associated with business as usual are rising. A loss of one-third of the world's food supply amounts a loss of revenue equivalent to 680 billion USD in high-income nations and 310 billion USD in low-income nations [7]. A reduction in the post-harvest food loss, along with additional sustainable productivity onboard fishing boats and throughout the agriculture sector is crucial to face the challenge of feeding an increasing world population. This is particularly true in India, where in 2020, the global hunger index ranked it 94 out of 107 nations [10] signifying that India has a *serious* level of hunger across the country.

Figure 1. Waste hierarchy in WFD.

1.1. Seafood Sector in India

India is a self-sufficient food-producing nation with an annual loss of 40% in its food sector [11] indicating its supply chain has a great deal of improvements to be made to comply with UN 2030 standards [12]. India is a major producer and exporter of food products, and food processing is recognised as a priority sector in their new manufacturing policy [13]. The food processing industry generates a variety of valuable Rest Raw Materials (RRM) from seafood, meat, and fruits and vegetables processing that go unutilized [4]. In the case of seafood, the RRM can include viscera, skin, filleting frame, bone, and wash water, which cannot be used in the main products but can potentially be used in the preparation of valuable ingredients like marine proteins and oil, protein hydrolysates, and gelatine for food or feed applications.

India, with a coastline of over 7500 km and about 7 million hectares of inland water bodies, is a major supplier of seafood to the world [14]. During the COVID-19 pandemic, India experienced a shock in its production and export ability as restrictions were imposed on national and international trade [15], which resulted in a USD 1 billion drop in the export value of fish in 2020 [16]. However, not all seafood caught in India makes it to the frozen or even export stage. Currently, seafood not fit for sale is being underutilized, and large amounts are discarded or turned into low-value products while there is a huge potential for their utilisation into high value-added products.

One of the biggest concerns when dealing with seafood is post-harvest loss, which can be found at nearly all stages of fish supply chains throughout the world. In coastal African countries, a study found that spoilage contributed to a loss of 10 to 12 million tonnes of fish per year, equivalent to around 10% of the total fish production along the coast of Africa [17]. Many factors attribute to loss, but inadequate cooling sources leading to rapid spoilages stands out. Spoilage's biggest foe is low-income nations' insufficient access to quality cooling and preservation storage. This defeat accounts for fisher's loss of income, food insecurity growth, and forced losses for the process industry and market [18]. There are other fish supply chains around the world still able to prosper regardless of costs. One prominent fishing nation is Norway, where 33% of the world's salmon supply is produced. The industry here can bear the costs of farming fish and the price that comes with this type of aquaculture, such as diseased fish, infestation, and changes in water temperature [19]. Unlike salmon supply chains, the surimi supply chain is under pressure to evolve its practices.

1.2. Surimi Supply Chain

Surimi derives from fish flesh proteins that are not typically sourced for human consumption. Once the proteins are transformed into a paste, they can be used to create various seafood products shipped worldwide [20]. Since the late 1970s, surimi has made its mark on globalisation in food staples such as crab sticks [21]. The surimi harvest lacks the infrastructure to support sustainable change where it is needed most. In many low- to middle-income countries, improving storage and infrastructure mechanisms are among the most valuable strategies for reducing food loss [22].

In India, there are around 15 surimi processing plants located mainly in the western coastal area, in the state of Gujarat and Maharashtra. Surimi is mainly produced from Ribbon Fish, Rani Fish, and Lizard Fish (weight of the catch ranging from 20 to 100 g). The process includes various steps such as de-heading, gutting, filleting, deboning, washing, dewatering, mixing with cryo-protectants, and freezing. The surimi supply chain is a cold chain in which temperature control after harvesting is very important to maintain the protein, quality of meat, and its gel-forming capabilities. Most of the processes in the surimi supply chain are not organised including logistics activities of fish raw material and RRM and cold chain management. The waste problems in the Indian surimi supply chain are linked to both the upstream and downstream operations [23]. This includes wastage of ice at pre-processing centres with no reuse of water and ice, wastage of fish raw material, and surimi RRM due to quality deterioration caused by inadequate cold chain management and longer lead times during transportation and handling [24,25].

1.3. Need for Multidisciplinary Research

The need for integrative, inter-disciplinary, and multidisciplinary approaches for reducing waste and improving resource efficiency in the manufacturing sectors has been discussed by several studies [26–28]. In food systems, multi- and inter-disciplinary research collaboration is essential to address and tackle all causes of loss and waste. This includes management of the supply chain for optimal post-harvest handling and storage of raw materials to reduce preventable losses and valorisation of any unavoidable RRM and co-streams into value-added products functional ingredients for food and feed applications.

There is a lack of scientific literature on multi-disciplinary research approaches to tackle the problem of loss and waste in the Indian seafood supply chains and ReValue project attempts to fill this gap. The objective of this paper is to synthesise the key findings from the ReValue project that uses a multidisciplinary research approach for improving the resource efficiency in fish value chains in India using surimi industry as the case study.

2. Methodology

A multidisciplinary research approach was applied with expertise from supply chain management, life cycle assessment, biotechnology, and energy and process engineering, to propose several solutions to improve the overall resource efficiency in the surimi supply chains in India. The surimi supply chain was mapped using value stream mapping methodology by industry visits and semi-structured interviews to understand the critical points where losses can occur and their potential causes. The study focussed on the supply chain from fishing boats to the surimi processor with an intermediary transportation stage.

Industry visits and interviews were conducted during 2018–2019 in the Mumbai area in India with surimi supply chain stakeholders. A non-vertically integrated representative supply chain of a surimi processing plant in Mumbai was selected as the case study. The surimi processing plant operates between August and June with a production capacity of 24 MT/day. The plant sources fish from 15 suppliers in the Mumbai coastal area. The RRM generated are supplied to various companies for further utilisation. The research team of ReValue spent two weeks at the fishing dock, processing side of surimi, and RRM, to gain a complete understanding of the supply chain. The process mapping and other information were collected through semi-structured interviews with the processing plant and fishers supplying fish to surimi processing plants.

An industrial refrigeration system was simulated as a part of ReValue project. The intention of this work was both to contribute with solutions that can improve fish quality compared to today's products and promote more climate-friendly refrigeration systems. The research in ReValue project was mainly divided into the following three parts:

i. Mapping of the cold chain and an industrial refrigeration system simulation.
ii. Development of valorisation options for improving resource efficiency and developing value-added products. These valorisation options were selected based on the chemical composition, quantity, and quality of RRM.
iii. Review of the regulatory frameworks for utilisation of RRM in India and Europe. Conversion of RRM from the fish supply chains is governed by a set of regulations both in India and Europe. These regulations were reviewed, and their implications on the utilisation of the rest of the raw materials were analysed.

The impacts associated with the SDGs and the effect that lack of regulatory standards can have on the environmental and economic prosperity of the industry are also presented in this paper. Finally, the market exploitation potential of derived solutions is discussed.

Main results and discussion derived from the ReValue project are presented in the next section. Impact of ReValue project associated with Sustainable Development Goals are presented in Section 4.

3. Synthesis of Key ReValue Results

Based on process mapping in Mumbai, a representative surimi supply chain and challenges related to inadequate resource efficiency at different stages of the supply chain are shown in Figure 2. These challenges were tackled in the ReValue project where various tools are proposed to improve resource utilisation using a multidisciplinary research approach. A synthesis of the key results of ReValue project are provided in this section focussing on the following:

i. Improvement of cold chain management in the surimi supply chain
ii. Valorisation options for surimi RRM into value-added ingredients
iii. Regulatory framework for utilisation of RRM in India and Europe

3.1. Cold Chain Management

Surimi is a product highly dependent on the cold chain because it deteriorates quickly if not chilled or frozen. Previously, it was found that much of the value degradation in the Indian surimi industry was in the post-harvest phase [29]. Recent studies demonstrate that this is still the case. Various fish species are caught from motorized boats, mainly in the Arabian Sea, and brought to land-based surimi processing plants. Fish are transported in crates together with crushed ice to keep the temperature low and the catch preserved. A fishing trip usually lasts 10 days, so the ice, which is brought from land, must last for the entire trip. The fish are weighed and packed in new ice crates at the dock, sometimes also processed (manually headed and gutted), and transported to the surimi processing plant. In ReValue project, several critical factors for the maintenance of fish quality were identified, which included fragmented ownerships, fishing area identification, fishing boat and its capacity, longer boat unloading time, absence of real-time information sharing, visual inspections of fish quality at various stages, non-standard cold chain, lack of temperature measurement system, and many manual touch-points and location of operations. ReValue found that the supply chain in India suffers from longer production times and a lack of proper technology implementation. It was also found that over 20% of fish is lost due to outdated ice storage boxes onboard fishers' boats in India. This study found that the existing surimi supply chain needs to be improved to eliminate or minimise the waste for its enhancement. This is not only important for ensuring a good quality of the surimi products, but also for the RRM, which is described in Section 3.2. The surimi storage temperature and energy use need to be optimised for both product quality and profit. These findings are further elaborated in the various research papers and reports linked to ReValue [30–33].

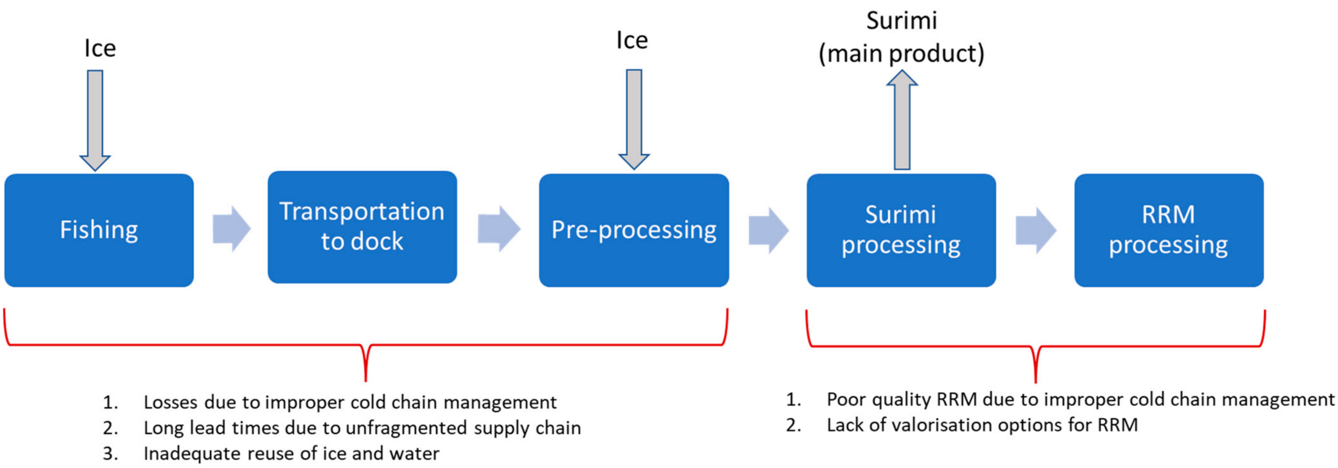

Figure 2. Surimi Supply chain in India and challenges linked to resource efficiency.

With its vast coastline and abundance of natural resources and fish, India has great potential to prosper in the seafood industry. Since 90% of India's exported seafood is in frozen form, a study suggests that the straightforward answer to improving sales is upgrading current cold chain technologies, which would require government investment [34]. However, others suggest it is not as simple to buy this technology for all fishers in India, as it is a fragmented business market [24], and the costs would be high. A refrigeration system is an important part of the cold chain. Refrigeration is used for producing ice which the fishing vessels use for chilling fish. Refrigeration is also used for chilling wash water during surimi production and freezing of the surimi blocks.

Refrigeration System Simulation

In ReValue, a simulation of vapor absorption refrigeration system for fishing boats in India was conducted, where the system would use heat from the boat engine, as presented in Figure 3. The boat would still carry ice, but the absorption system would be used to compensate for the heat ingress, preventing the ice from melting and thereby keeping the fish cold for the entire journey. It was found that the cost of this refrigeration system would be a little under $7000 USD, which could be paid back in under two years due to the profit gained from unspoiled fish.

Simulation and modelling of a cascade refrigeration system (CRS) for fish processing plants was also undertaken in ReValue. Schematic diagrams are shown in Figure 4, including both baseline ammonia system and a CRS. Industrial chilling and freezing of fish are conducted at different temperature levels, and the CRS was adjusted to suit this. The leakage of working media (refrigerant) in the refrigeration system cannot be prevented in industrial systems, so it is necessary to use refrigerants with no or very low global warming potential. Ammonia has zero global warming potential but can be dangerous if it leaks. Skilled operators and safety measures are always required for those systems. In this study, a cascade system was therefore used, which uses a combination of ammonia and CO_2 as the refrigerant. Ammonia was used in the top stage and CO_2 in the bottom stage, where the fish is chilled or frozen. There is no product quality degradation if CO_2 leaks and comes in contact with the fish. This also reduces the charge of ammonia in the system and risks of leakage, while still utilising the good thermophysical properties of ammonia. The study showed some different configurations of CRS and compared it with a conventional ammonia refrigeration system. The results showed that the ammonia charge could be reduced by up to 64% and that the system was found to be more efficient for a wide range of operating conditions. This work has been described in detail in other ReValue research papers where additional data can be found [36–38].

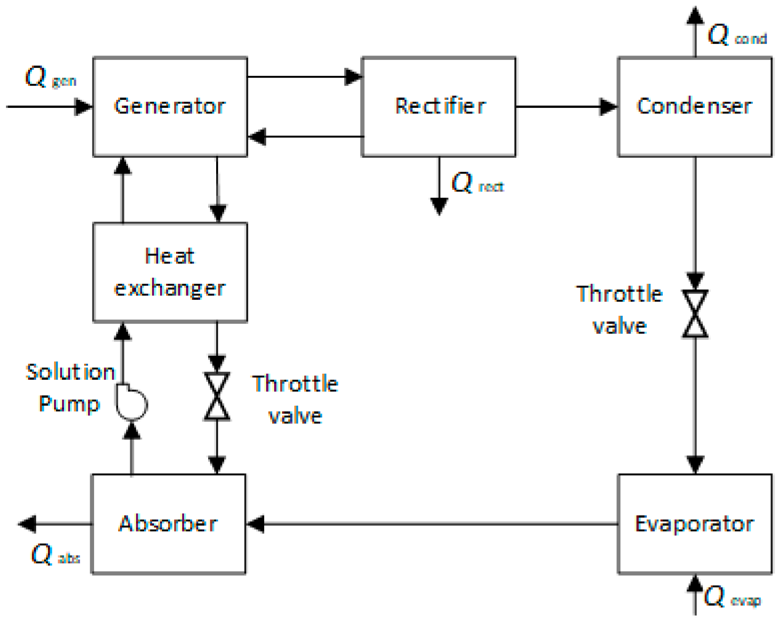

Figure 3. A schematic diagram of a vapour absorption system for a fishing boat. Figure adapted from [35].

3.2. Valorisation Options for Upscaling

A lack of proper utilisation of RRM is another shortcoming of the surimi industry. If fish intended for surimi production is filleted under good sanitary conditions, it results in fresh and human food grade quality RRM, which can be used for the production of valuable marine oil and protein ingredients. In order to obtain a more sustainable utilisation of this RRM, a techno-economically feasible process leading to high-quality products is needed. Sustainability means utilising the RRM, which can be applied for value-added products like ingredients for nutraceuticals or food as well as for livestock feeds, biogas, and fertilisers (Figure 5). ReValue project uncovered improved opportunities to address the RRM and improve the quality of fish. One of these ways includes transferring the process of removing and handling of RRM (i.e., de-heading) to the fishing vessels themselves to ensure an efficient quality control process [33]. This shift would decrease the chances of having spoiled fish ultimately equating to lost revenue. Spoiled fish can lead to a recall of an entire production batch which in turn would trigger elevated market expenses for the industry. To decrease the chance of this happening, employing traceability and temperature monitoring systems along the supply chain are important [31]. Traceability can increase the quality of surimi ventures through investments in information technology for restructuring the Indian surimi supply chain to global standards.

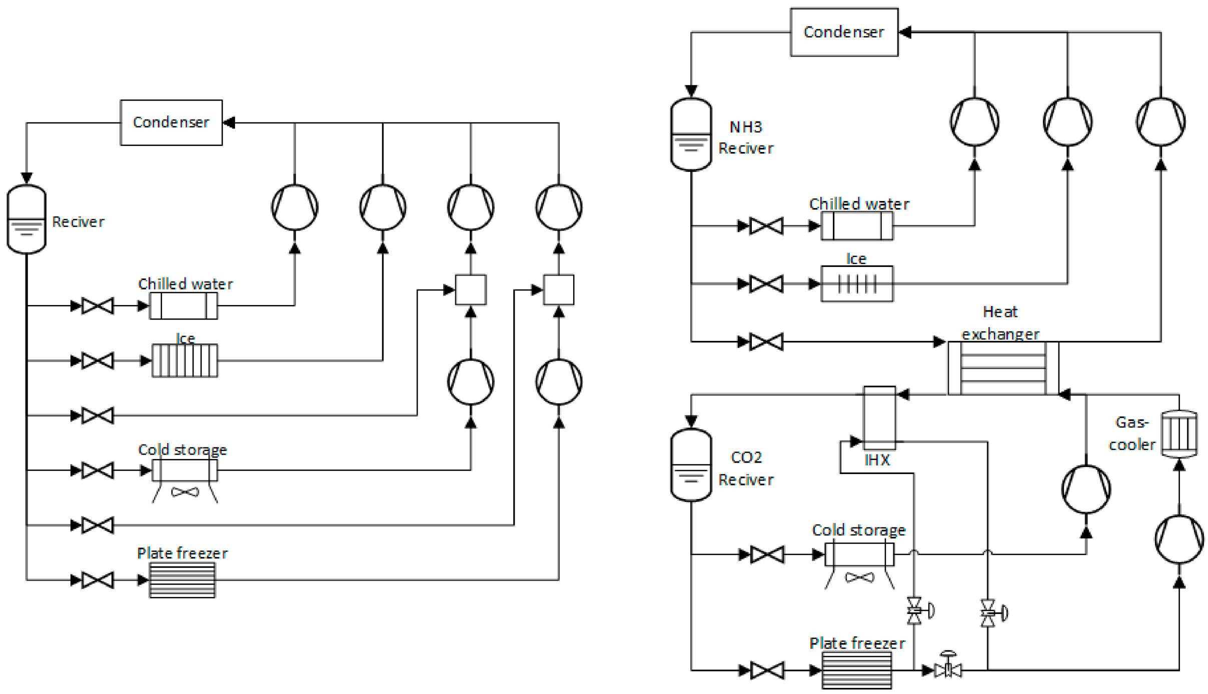

Figure 4. Schematic diagrams for baseline ammonia system (**left**) and a cascade refrigeration system (**right**), adapted from [37].

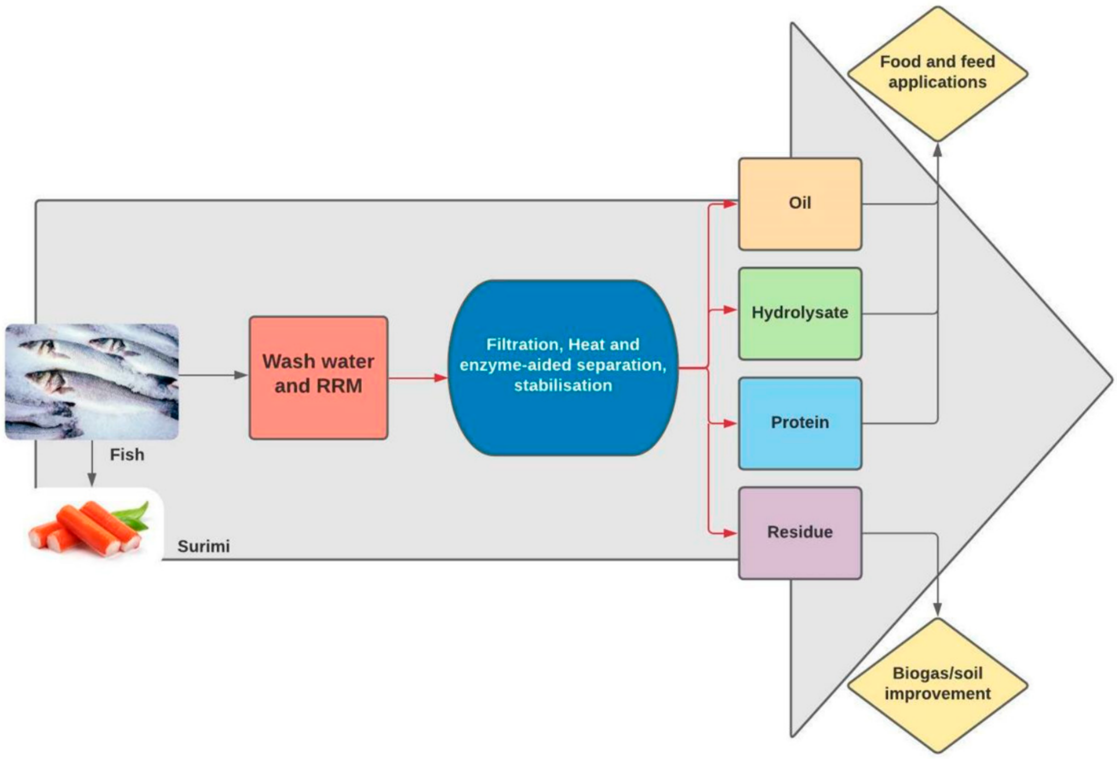

Figure 5. Possible value-added products obtained during surimi processing.

RRM from the surimi industry in India is currently used for feed/fertilizer applications or are discarded without any attempt to recover valuable components. To increase the value-addition along the supply chain by producing functional ingredients, high-quality fish and RRM are required. The ReValue project found that different RRM obtained from surimi processing plants in India have the potential to be used as valuable ingredients in different formulations both for food and feed markets. Some variation in chemical composition, as well as microbial quality, indicated that proper storage and handling methods and optimal processing technologies need to be applied to produce high-quality final products. There is no regulation available for a microbiological load of fish-related raw material used in the food industry. According to FSSAI (Food Safety and Standards Authority of India) permitted aerobic plate count in fish mince/surimi and analogues are 1×10^6, but yeast and mould should be absent. Yeast and mould count for dried fishery product can be 500 CFU/g. Samples were analysed for aerobic plate count, presence of *E. coli*, *Salmonella*, Yeast and mould, and *Lactobacillus* bacteria. No pathogenic bacteria were found in any analysed RRM, whole fish and surimi, wash water.

Pink Perch and Croaker are the two main species used for surimi production in India. Screening for optimal processing technology along with optimisation steps indicated that Pink Perch and Croaker RRM (head & viscera and skin & bones) which contain valuable nutritional compounds can be used for the production of nutritional protein hydrolysates with desirable functional properties as well as for the extraction of marine gelatine. All tested enzymes including alcalase, a mixture of bromelain and papain, trypsin, and endogenous enzymes yielded good quality protein hydrolysate, and the most optimal enzyme gave the highest yield as well as protein quality was determined. The conditions for enzymatic hydrolysis of Pink Perch head and viscera employing Alcalase were optimised. The potential of the application of acids for protein precipitation from the wash water was indicated. Treatment of wash water with acid led to the removal of 87% of protein from the wash water. Several extraction technologies were applied on RRM to extract gelatine indicating the potential of RRM to be used as sources for marine gelatine. Techniques for stabilization, concentration, and fractionation of protein-rich fractions from RRM were developed in ReValue project. Ingredients obtained from marine RRM can exhibit undesirable fish taste and smell, which can be originated from raw material or be a consequence of degradation and oxidation. Nowadays, microencapsulation is highly recommended in different food industries because of the benefits provided, such as thermostability enhancement, bioactive compound protection, controlled release, volatiles maintaining, odour shelter, and texture/sense improvement [39]. Microencapsulation and dehydration were found to be suitable techniques for stabilisation of the protein-rich fractions. Experimental work performed by Indian partners in ReValue with hydrolysates obtained from Pink Perch head and viscera indicated that microencapsulation can be used to make hydrolysate thermostable and mask the fish odour. The ratio between the wall material and core material as well as the microencapsulation process was selected as described by Sarabandi et al. [40]. Different wall materials were used for microencapsulation including maltodextrin, gum Arabic, sodium alginates, and carboxyl methyl cellulose which were able to mask the fishy odour and would improve the acceptability of food applications (described in detail in ReValue report by Kaushik et al., 2021 [41]).

Developed and optimised technologies were proven by up-scaling them by producing valuable and stable ingredients for consumer markets. Fish protein hydrolysates were obtained from RRM, stabilised by microencapsulation, and were incorporated into ready to cook soup, veal burgers, and chicken nuggets. Chicken meatballs have been prepared by incorporating fish gelatine, extracted from gelatine-rich fish RRM. Evaluation of functional, nutritional, and sensory properties of produced food products indicate the potential of the use of fish RRM as starting materials for extraction and production of valuable food ingredients.

To exploit various national and international markets for ingredients derived from RRM, the Indian seafood industry must adhere to the international regulatory frameworks to ensure quality control, sustainability, and freshness which were summarized in ReValue project and described in the following section.

3.3. Regulatory Framework in India and Europe

EU is the world's largest importer of agricultural and fishery products which totalled €114 billion in 2015 [42]. Due to this control, as well as the EU, being India's largest trading partner [43], accounting for €80 billion worth of trade goods in 2019 [44] the EU exhibits hard power over India in the form of regulations. India is obliged to follow as they depend on importing their seafood to the European market. Quality requirements of the global market, the increasing importance of the Codex Alimentarius Commission, and the advent of the Sanitary and Phytosanitary (SPS) Agreement under the World Trade Organization (WTO) have made it essential to implement international level food safety measures in India. India has over 25 million citizens working in the seafood industry, it is, therefore, vital to ensure compliance with regulation at both the national level at home and supranational level of the EU [45]. India's capacity to penetrate world markets and gain a higher share of world trade depends on its ability to meet increasingly rigid global food safety standards. India being a member of WTO, has adopted the sanitary and phytosanitary measures Agreement, provided by WTO, and adopted by the Codex Alimentarius Commission (CAC) of FAO and World Health Organisation (WHO). Codex Alimentarius is the key reference used for developing standards and Code of Practices and guidelines in the entire chain of custody of fish processing and marketing in India. As described in the previous sections, disposal and use of RRM not only affects the local ecosystems, but the economic prosperity of the Indian surimi market. Surimi processing generates RRM including viscera, skin, filleting frame, bone, and wash water which potentially could be used in preparation of valuable ingredients like marine proteins and fish oil, protein hydrolysate, and gelatine for food or feed application.

According to the regulations, if the RRM is produced in human-grade factories and processed under food hygiene legislation, the final product can be used for food application. The requirements for handling and processing and the final product for human consumption are very similar both in the European Economic Area (EEA) and India. In the EU if a product is intended for human consumption, the RRM handling, processing, and the final product must follow the food hygiene (e.g., No. 852/2004, No. 853/2004, No. 854/2004), No. 2073/2005—microbiological criteria and safety requirements (e.g., No. 1881/2006). In India, the regulation regarding different food product safety and security is given by FSSAI—Food Safety and Standards Authority of India. FSSAI regulation for Fish and Fish Products: section 92 (1) of the Food Safety and Standards Act, 2006 empowers the Food Authority to make regulations/standards consistent with this Act and Rules. The regulations, 2011, in regulation 2.6 relating to "Fish and Fish Products", in sub-regulation 2.6.1 provides regulations for the selection of raw materials for product development, its transportation conditions, storage, and packaging conditions. Guideline for hygiene and quality of water (IS 10500:2012) during processing is explained in FSSAI regulation for microbiological limits in fish Product Standards and fish Additives: Food Safety and Standards Authority of India has notified the Final Food Safety and Standards (Food Product Standards and Food Additives) Amendment Regulation, 2017 in the official gazette of India w.r.t microbiological requirements for fish and fishery products.

Both in EU and India for unprocessed fishery products must not exceed: TVB-N 25–35 mg of nitrogen/100 g flesh, histamine levels 100 mg/kg–200 mg/kg, *L. monocytogenes* < 100 CFU/g or absence in 25 g. There are no special regulations for fish protein hydrolysates or powders, but they should follow hygiene regulation 853/2004. Therefore, taking into consideration requirements for fish products, and dry powders, microbiological quality for the final dry fish protein powder products (per gr) must be: Total count $< 10^5$ CFU/g, *E. coli* < 10 CFU/g, *Salmonella* absent in 25 g, Moulds and Yeast $< 10^3$ CFU/g. Very similar microbiological quality requirements for dry fish products are also given by FSSAI in India (Fish and Fisheries Products)/FSSAI-2013, Eleventh Amendment Regulations, 2017): aerobic plate count $< 1 \times 10^5$ CFU/g, yeast & mold count < 100–500 CFU/g, *E. coli* count < 20 CFU/g.

In EEA, if the RRM or by-products are going to be used for feed application, the raw material should follow the description of category 3 after Regulation (EC) 1069/2009. Handling and processing of by-products should follow the regulation 1774/2002 and hygiene for feed described No. 183/2005. In India, there are no special regulations for the by-products not intended for human consumption, however, the requirements for the processing of fish meal are regulated by the Bureau of India Standards (BIS).

These regulations indicate that the RRM can be utilized and processed into ingredients both for food and feed application. The RRM should follow the food hygiene requirements all the way to processing if the final product/ingredient is intended for the food market. EU has clear regulations for use of by-products for feed application. In India regulations for fish meals are given, however other technological solutions such as enzymatic hydrolysis can be also applied for utilisation of RRM for feed applications, and regulations for industrialisation of these technologies are needed.

4. SDGs and Impacts

The reduction of food loss and food waste can propel us towards a zero-hunger world which is one of the UN Sustainable Development Goals (SDGs). Within this study, there are two SDGs that stand out among the others, SDG 2 (End Hunger) and SDG 12 (Ensure sustainable consumption and production patterns). As earlier realised, post-harvest loss is a major challenge when handling seafood, the less food loss that occurs within the value chain the more food available for consumption. As spoilage is a problem, especially in low-income nations that lack access to cooling storage, less food will be made available. As part of SDG2, zero hunger, better refrigeration technology can be applied and made more widely available to nations who lack food preservation equipment. Over 820 million people do not have guaranteed access to food every day [14]. This is a result of inadequate food supplies across the world. This loss and waste of food have catapulted to an issue among researchers, governments, and the public sector, making it even more imperative for governments to agree to create lasting policy in line with the SDGs. Ending hunger means creating a healthier world where all individuals receive enough nutrients to thrive in their daily lives. However, this needs to be done sustainably and efficiently, or else the food produced can cause harm from foodborne illnesses, creating even deeper problems. Within SDG 12, one of its indicators calls for reducing food losses along the production and supply chains. Without an outright reduction of food loss and waste, harsher environmental detriments, as well as economic damage, will be seen as described below.

4.1. Environmental Impacts

There is a magnitude of steps that can go wrong and cause significant environmental harm when it comes to fish supply chains. Organic waste is mainly contributed to food processing industries, such as when RRM is not correctly processed. Unlike chemical waste, where you can see the spillage effects head-on, organic waste usually escapes unnoticed until its impacts have reached uncontrollable proportions [46]. This 2013 study examined one of the biggest seafood processing zones in India, Cochin Corporation, to find that large quantities of seafood solid waste is left unutilised and mismanaged by the private sector. Without regulations for proper seafood disposal, the area was left as an environmental and health hazard. The waste not only affects typically poorer areas, but also the surrounding ecosystems and waterways by reducing biomass and destroying natural food webs [47,48]. It will be vital to implement SDG 12 in ensuring the surimi production and supply chain performs to sustainable standards. If protocols for RRM disposal are not followed, it would, in turn, affect the total revenues and health of a country.

One of the outcomes of ReValue project is the analysis of the environmental impact of frozen surimi production in the current supply chain where the pre-processing and surimi production operations are not integrated. This was compared to two scenarios that propose supply chain integration. The study found that frozen surimi production generates 4.67 kg CO_2 eq/kg without supply chain integration and 4.43 kg CO_2 eq/kg with the integration of pre-processing and surimi production operations (described in detail in ReValue paper by Sultan et al., 2021 [49]). An overall reduction in the carbon footprint of surimi production will be achieved if the utilisation of RRM is improved.

4.2. Economic and Health Impacts

Aside from the growing environmental concerns regarding management problems within the seafood industry, the global demands continue to increase, making mismanagement cost 50 billion USD annually [50]. Additionally, food waste alone in the aquacultural sector reaches over 1 trillion USD annually [51]. Moreover, efficient utilisation of by-products also directly impacts the economy. One review analysed how underutilisation of RRM leads to loss of revenue and increased cost of disposal [52]. Since the fishing industry in India is fragmented, having the government set a standardised form of how to store fish after catch could help bring the cost of waste down. There are also greater causations leading to a loss of profit that can continuously happen as climate change and deforestation moves wildlife closer to us. Before 2020, India was on track to grow its seafood sector by making well over US $7 billion a year on exports. Unfortunately, instead of growing the sector, it declined by 7% this past year due to matters outside India's control—a pandemic [53].

It is vital in today's world to ensure safety of our food. An estimated 600 million people globally were sickened by foodborne illnesses in 2019, and 420,000 people died, primarily in Africa and Southeast Asia [54]. In the United States, where food safety protections generally are applied, rather than the lacking as witnessed in many developing nations, a foodborne illness still annually affects one in six people [55]. One study found that for fish and shellfish, most illnesses are caused by bacteria stemming from *Vibrio parahaemolyticus* in at least 75 percent of bacterial disease cases [56]. There are also several other key sources of bacteria and diseases when it comes to seafood. Appropriate storage with protection from weather and pests cannot only reduce food loss and waste but keep food safe. Storage, including refrigeration and freezing, is a top-priority approach to reducing food loss and waste and foodborne illness in low- and middle-income countries [57]. Though proper food storage can be viewed as too expensive for some less developed countries, without it they risk a US $110 billion annual loss due to unsafe food [54]. The entire supply chain of our world's fishing industries was affected by COVID-19. The COVID-19 pandemic caused loss of jobs; in the future, governments need to address the supply chain hardships about future possible pandemics. In the future, governments need to address the supply chain hardships brought about by the pandemic, while also moving towards the protection of our ecosystems and natural resources to ensure we do not face the same problems again from spoiled and dangerous food [58].

ReValue project results can further contribute to an increase in distributed economic activity and job creation in both downstream and upstream of the supply chain as the demand for surimi and new products increase. Reduction in waste along the supply chain and lower energy consumption in the cold chain will also decrease societal loss and the RRM derived food supplements will help to fight malnutrition.

4.3. Market Exploitation

A series of innovations will enable ReValue to optimise the surimi value chain including improved temperature management, reduction of the waste generated by processing, conversion of RRM and wash water into high value-added ingredients for food and feed, and a business strategy for commercial exploitation of the project outcomes in India and Europe.

A high market and economic impact can be achieved through strengthening the competitiveness of the industry in target market sectors by:

(1) promoting the use of ReValue materials, components, and systems in high value-added applications while keeping costs competitive,
(2) strengthening and differentiating the EU and Indian Industry,

(3) increasing workers' skills.

Global fish production has grown steadily in the last five decades, increasing at an average annual rate of 3.2%. The worldwide fish processing industry leads to the production of a large amount of RRM which is generally discarded (~7.3 million tons/year) resulting in an increasing amount of RRM available for example to produce gelatine and derivatives for food and feed applications in ReValue. India is the largest country in the Indian Ocean and has a long coastline with over 200 varieties of commercially important fishes and shellfishes [51]. One of India's exports assets is its surimi market. Europe uses about 70,000 tons of surimi for producing over 210,000,000 tonnes of surimi-based products. The main consumer in Europe is France (market accounts for about 60,000 tonnes of surimi-based products) followed by Spain (consuming about 40,000 tonnes), Ukraine (14,000 tonnes), the UK (12,000 tonnes), and Italy (8000 tonnes) [59]. In the last decade, surimi penetration in the European market was slow, in 2016 it increased in the order of 20,000 metric tons (about 3%). In 2018 the EU market produced nearly 170,000 tonnes of surimi product, from its top producers in Spain, France, and Lithuania, signalling a true rise in demand [59]. In this scenario, ReValue has the potential to achieve a huge market impact, drastically increasing the surimi industry profitability. The average value of fish used for surimi will increase significantly if the RRM can be utilised into feed ingredients, and the value will be higher for food applications. In particular, ReValue solutions contribute to quality enhancement through improvement in process and cold chain and introduction of functional ingredients derived from RRM that can be used as nutritional supplements. Further exploitation should focus on the marketing of surimi-derived products, increasing consumer awareness for wider acceptance of surimi and derived products from India in the European market.

5. Conclusions and Future Work

The bio-economy business model is directed to sustainable production via the conversion of natural biomass and by-products into a range of food, health, and other industrial products. Reduction of losses and valorisation of RRM in the fish value chains is a global societal challenge and, at the same time, a great competitive opportunity. The impact of the surimi industry on global food waste production, responsible for more than 3.5% of the global fish losses, is due to its low efficiency processing that generates a huge amount of RRM and wash water.

The most pressing issues facing the surimi supply chains in India were identified in the ReValue project and addressed in this paper. It was found that the main problems stem from fragmented supply chain networks, especially the lack of cold chain infrastructure onboard fishing vessels and throughout the post-harvest process. Currently, the volume of value-added products derived from fish RRM is very low, primarily because alternative uses of RRM require demonstration of feasibility and profitability, where retaining the quality of RRM is a key issue.

A multidisciplinary research approach, as applied in the ReValue project, is essential for solving the main challenges within the seafood supply chains and other similar sectors. The results show that combining expertise within supply chain management, life cycle assessment, biotechnology, and energy and process engineering can enable this sector in developing a wide range of tools to reduce avoidable loss and utilise the unavoidable loss and waste into high value-added ingredients. The main solutions developed in ReValue project focus on improving the surimi cold chain, developing climate-friendly refrigeration systems, and conversion of RRM into value-added ingredients.

The study also dove into the impacts implicated in the SDGs, and the effect lack of standards can have on the environmental and economic prosperity of the industry. Though the EU is currently India's biggest importer, without proper management of the RRM the seafood industry can suffer. Health was also a forefront issue in the discussion as the recent pandemic caused India's seafood industry to decrease its profits by 7 percent in 2020.

Looking forward, it will be imperial for governments to create lasting policy involving the world's seafood sector while minimizing the fragmentations within the supply chain.

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