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Impressions of the scientific training in fishery and aquaculture biotechnology in Mar del Plata, Argentina: Communication, networking, and multidisciplinary research

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Abstract

In this Letter, we report the outcomes of the first edition of the 'Marine Biotechnology and Aquaculture for Sustainable Development' training that took place in August 2022 in Mar del Plata, Argentina. We learned about the current fishery and aquaculture production in South America, with emphasis to the recent program 'Pampa Azul' released by the Argentinean authorities. Lectures of recent studies that contributed to the Argentine marine biotechnology and the prospects of fishery and aquaculture technology in the Amazon region were given to the participants. The importance of circular bioeconomy within the context of fishery and aquaculture was highlighted in detail via seminary discussions. At the end of the Letter, participants gave a glimpse into the lessons learned from the training, illustrating that interdisciplinary communication and face-to-face networking are essential attributes to expand collaborative research in the South American countries.

Keywords: PhD training, South American aquaculture, fishery industry, science communication, circular bioeconomy.

1. Introduction

Fishing and aquaculture constitute productive economic activities of great importance in the world (Kobayashi et al., 2015), and in combination with marine biotechnology can harmonize the economic growth, exploitation of natural resources and preservation of the environment (Kalogerakis et al., 2015). Marine biotechnology is also narrowly accompanied by circular bioeconomy, which optimizes the production of goods and services, and reduce or eliminate production of residues from fishing and aquaculture processing that deteriorates the quality of the environment (FAO, 2016).

According to the State of World Fisheries and Aquaculture (FAO., 2020), fisheries and aquaculture production is dominated by Asian countries with 70% of the total, followed by the Americas (12%), Europe (10%), Africa (7%), and Oceania (1%). In general, total fisheries and aquaculture production has experienced significant increases in all continents in recent decades.

Aquaculture in South America is characterized by the production of different aquatic organisms, including marine fish, continental fish, shrimp, and shellfish (Valladão et al., 2018). Chilean aquaculture is notably recognized by salmon farming, while the inland production of native fish remains insignificant (Quiñones et al., 2019). In Brazil, the most cultivated species are Nile tilapia (*Oreochromis niloticus*), black pacu (*Colossoma macropomum*), common carp (*Cyprinus carpio*), pacu (*Piaractus mesopotamicus*) and catfish (several species), with considerably growth of hybrid black pacu x pacu, cultivated in the Amazon River basin (Nobile et al., 2020). In Colombia, the current fish farming production is represented by the cultivation of Nile tilapia and rainbow trout (*Oncorhynchus mykiss*), with some extend contribution of shrimping (*Litopenaeus vannamei*) (Carrera-Quintana et al., 2022). Aquaculture in Ecuador is dominated by the production of crustaceans, notably *Litopenaeus vannamei* (Alvarado et al., 2016), with similar trend observed in Venezuela aquaculture, despite oyster *Crassostrea rhizophorae* aquaculture being developed over there (Nowland et al., 2020). In Peru, the bivalve mollusc *Argopecten purpuratus* and *Litopenaeus vannamei* are the major farmed species, with some contributions in the cultivation of rainbow trout, red tilapia and black pacu. Peru's marine resources are among the world richest and is dominated by high quantity of pelagic fish stocks, such as anchoveta *Engraulis ringens* that contribute to the Peruvian fishery industry (Durand and Seminario, 2009). Aquaculture in Uruguay is dominated by exotic Russian and Siberian sturgeons (*Acipenser gueldenstaedtii* and *Acipenser baerii*, respectively) responsible for almost all Uruguayan production, while the native black catfish (*Rhamdia quelen*) and the argentinian silverside *Odontesthes bonariensis* being also farmed in Uruguay (Carnevia, 2012; Somoza et al., 2008). In Argentina, the rainbow trout and pacu (*P. mesopotamicus*) are the most cultivated species, while the marine fishery industry processed in 2018, 336 mil tonnes of marine Argentine red shrimp (*Pleoticus muelleri*) and 417 mil tonnes of Argentine hake *Merluccius hubbsi* (Allega et al., 2020).

To support the expansion of aquaculture in South America, especially in Argentina, the Latin American Biotechnology Center (CABBIO), a regional integration program that aims to consolidate cooperation between Argentina, Brazil, and Uruguay, has financed an on-site scientific training called 'Marine Biotechnology and Aquaculture for Sustainable Development' that took place in Mar del Plata, Argentina. Seventeen early career researchers from different nationalities including Argentina, Brazil, Colombia, Mexico, Uruguay, and Venezuela gave a glimpse into their scientific work and discussed the future of aquaculture research and how they could exchange scientific information.

In this Letter to the Editor we would like to share the concluding remarks of the first edition of 'Marine Biotechnology and Aquaculture for Sustainable Development' with the wider aquaculture research community. The training allowed for the discussion of novel ideas for sustainable aquaculture, highlighting exciting ideas for the contribution of biotechnology in aquaculture research. Impacts of overfishing and aquaculture practices on the environment were also raised, seeking out suggestions for the reutilization and revalorization of fishery, and aquaculture wastes via circular bioeconomy strategies. This letter is reviewing the importance of interdisciplinary communication by encouraging the new generation of scientists to think critically about problems arising from the aquaculture research and provide solutions to expand this important sector.

2. The training week course

The meeting was organized during 8-13 August 2022 by researchers from the National University of Mar del Plata (UNMdP) located in Mar del Plata (38°0'12''S 57°33'10''W), Atlantic coast of Argentina. This city has a well-established fishing port with at least two large shipyards where industry is concentrated in fish processing. Led by Dr. Analía V. Fernandez-Gimenez, and organized by professors and senior researchers, the course allows masters, PhD, and post-doctoral researchers from all disciplines of aquaculture research to communicate their results and interact with other fellows in a laidback environment.

The chronogram of the course was consisted of theory (22h) and practical/experimental (23h) classes being 45h in total. The aims of the course/training were: *i*) comprehend the general and current state of fishing and aquaculture practices in the world, *ii*) understand the main characteristics of fishing and sustainable aquaculture with emphasis in Latin America and the Argentinean program ‘Pampa Azul’, *iii*) recognize the problem of by catch, discards and processing residues from the fishing and aquaculture activities, *iv*) perceive the generalities of blue bioeconomy considering the ethical aspects as well as the principles of the circular economy, *v*) discuss aspects of biomass biorefinery from fishery and aquaculture waste as well as by-products destined for different industries, and *vi*) conceive novel biotechnological techniques applied to aquaculture nutrition.

The course program provided theoretical and practical knowledge to strengthen the management of fishery waste as well as acquaintance on biotechnology applied to aquaculture research. The training program achieved basic and applied knowledge with a spotlight on the circular economy, which was allow, in the short term, to have the ability to actively interact in this area of continuous development in Latin America. Photographs and impressions of the event are provided in Fig. 1, while in Table 1 is presented the theory classes that were given to the participants, and the topics of the experimental classes conducted during the training is shown in Table 2.

3. The program ‘Pampa Azul’

According to a prospective study carried out between 2013 and 2015 by the Argentinean Ministry of Science, Technology and Productive Innovation, the current contribution of the maritime sector, mainly concentrated in fishing activity, is approximately 1.5% of the total gross domestic product (GDP). This value was estimated to be around 10 to 15% of GDP in 2035 if more investment in research, technological innovation and productive development is provided (UNCo, 2017). For this reason, the ‘Pampa Azul: a sustainable look at the South Atlantic’ initiative program represents a large-scale state policy to develop, in a sustainable way, the marine and coastal activities in Argentina coast, which includes aquaculture (https://www.pampazul.gob.ar/).

As a state policy, Pampa Azul seeks to create greater social awareness about the benefits provided by the Argentinean Sea, deploying a specific agenda of communication and scientific dissemination with medium to long-term multidisciplinary approaches and synergies through the inter-institutional institutions. The PROMAR Law approved by the National Congress in 2015, establishes a fund for the financing of scientific-technological research in the South Atlantic, which constitutes the main support for the implementation of Pampa Azul (Sala, 2018).

The program is supported by three main goals, which are in accordance with the United Nations Decade of Ocean Science for Development Sustainable (2021-2030), within the framework of the 2030 Agenda for Sustainable Development:

- Investing in new ships and expansion of the fleet for R&D, increase the number of campaigns, strengthen, and expand networks observation and monitoring, strengthen the National Sea Data System (SNDM) (Snowden et al., 2019);
- Building inter-institutional centres for R&D projects with an inter-institutional and federal perspective.
- Contribute to sovereignty and national security, social, and economic development with a focus on technological innovation, social inclusion, protection of marine natural assets, and integration of marine and coastal environments.

The initiative concentrates its activities in the Argentine maritime coast and spaces with a global perspective. Five priority geographic areas of research are proposed and selected based on its oceanographic characteristics, ecosystem importance and potential impact of human activities. The selected regions are: *i*) Marine Protected Area

Namuncurá-Burdwood Bank, *ii*) Fluvial-marine system of the La Plata River, *iii*) San Jorge Gulf, *iv*) Blue Hole/Continental Slope Front, and *v*) Subantarctic Islands such as Georgia and South Sandwich (Reyes, 2020). In the next topic, we will provide examples of ongoing studies align with the goals of the Pampa Azul program.

3.1. Selected recent contributions to the Argentinean Sea study

Argentina has 4700 Km of coastline on the Argentine Sea in the South-western Atlantic Ocean, making fishing a significant economic activity, being the demersal Argentine hake *Merluccius hubbsi* one of the main fishing resources. An assessment of the sustainability of the hake *M. hubbsi* artisanal fishery in San Matías Gulf, Patagonia, Argentina, emphasising the impacts on marine resources and the ecosystem was performed (González et al., 2007). As the main port landing in Argentina, *M. hubbsi* species is actively fished in the surrounding of the Mar del Plata city, and commercialized in the international market as frozen fillets (Friedman et al., 2022).

Proper food labelling is important legal, health and environmental issues, especially for fish products where fillets are indistinguishable on a morphological base (Marko et al., 2004). Fish mislabelling in Buenos Aires province, the largest sea food market in Argentina was very well-documented in a recent article (Delpiani et al., 2020). Researchers from the National University of Mar del Plata, Argentina, collected 172 fish products sold as fillets, consisting of 35 commercial fish names acquired from 24 fish retailers in 11 coastal cities of Buenos Aires (from north to south: San Clemente del Tuyú, Santa Teresita, San Bernardo, Pinamar, Villa Gesell, Mar del Plata, Miramar, Necochea, Claremecó, Monte Hermoso and Bahía Blanca), Argentina. DNA barcoding through molecular identification to assess levels of misleading or substitution of fresh fillets was used. Results indicated a total of 35 cases of mislabelling, representing a substitution rate of 21.34% of the total revealed samples, with the majority mislabelling incidents found in fillets of the sharks *Galeorhinus galeus* and *Mustelus schmitii* being sold as something else. The present investigation reinforces an urgent calling for enlarged traceability of seafood products by skilled supervisory Argentinean authorities to assess the authenticity of fish fillets.

The southern king crab (SKC) *Lithodes santolla* (Anomura: Lithodidae) has been fished in southern South America, notably Chile and Argentina, since the 1970s. Due to its high commercial value, the Argentine fishery for *L. santolla* of the Beagle Channel collapsed in 1993 mainly because of high fishing pressure over a small area near the city of Ushuaia (ca. 54°S 68°W), and lack of controls over the lifecycle of the crab (Lovrich et al., 2017). Today, ongoing efforts on the combination of indoor (hatchery) and outdoor culture (sea culture) of SKC juveniles are being tested to enhance the natural population (Sotelano et al., 2018). As the SKC population remains vulnerable, researchers from the Centro Austral de Investigaciones Científicas (CADIC-CONICET), Ushuaia, Argentina, recently investigated the baseline for successful cultivation of *L. santolla*, and evaluated the ontogenetic changes in energetic reserves, digestive enzymes, amino acid, and energy content of SKC (Sacristán et al., 2020). This research helps to understand the physiological, energetic, and nutritional requirements of *L. santolla* for maintaining this valuable species under culture conditions (Di Salvatore et al., 2021; Di Salvatore et al., 2020; Sacristán et al., 2019). This subject-matter was supported by the lecture ‘Metabolism and energy reserves mobilization of crustaceans’ provided by Prof. Dr. Hernán Javier Sacristán from the University of Buenos Aires, Argentina (Table 1).

Two interesting studies have been conducted by researchers from the National University of Mar del Plata, in the Marine Protected Area Namuncurá-Burdwood Bank

(MPAN-BB), Argentina (Covatti Ale et al., 2022; Fischer et al., 2022). This area is characterized by water masses with ample fertilization, promoting high primary production and energy transfer throughout the seafood web. In particular, feeding ecology of the longtail southern cod *Patogonotothen ramsayi* (Notothenioidei) that has the highest concentrations at Burdwood Bank and play a key ecological role in the demersal food web has been investigated (Fischer et al., 2022), while description and analysis of trophic ecology of the yellowfin notothen *Patagonotothen guntheri* with high abundance and significant ecological role in the MPAN-BB was also investigated (Covatti Ale et al., 2022). These studies highlight the relevance of investigating the diet and feed habit of the local marine species while comprehending how to protect, maintain and manage the biodiversity of the Marine Protected Area Namuncurá-Burdwood Bank (MPAN-BB), Argentina.

Microalgae play an important role in the seafood chain as they are able to synthesize a wide range of biocompounds, notably proteins, carbohydrates, lipids, and fatty acids (Oliveira et al., 2022). For this reason, researchers from the National University of Mar del Plata, Argentina, isolated seventeen microalgal strain from different brackish or freshwater ecological areas in the surroundings of Mar del Plata city and evaluated their potential as an alternative source of sugars for bioethanol production (Do Nascimento et al., 2012). Microalgal strains were preliminary identified by observation of morphological characters at the microscope and species confirmed taxonomically by sequencing a ribosomal RNA region comprising ITS1-5.8SITS2. All strains belong to the Division Chlorophyta (*Pseudokirchneriella*, *Ankistrodesmus*, *Chlorella*, *Scenedesmus*, *Desmodesmus*) and have an average carbohydrate content of 45.4%. In addition, *Desmodesmus* sp. was able to synthesize 57% of carbohydrates and after biomass saccharification and fermentation was able to produce algal biomass-to-ethanol conversion efficiency of 0.24g ethanol/algal biomass (Rizza et al., 2017).

The sea urchin *Arbacia dufresnii* (Echinodermata: Echinoidea) is abundant along the Argentinean and Chilean coasts, inhabiting coastal areas from La Plata River (35°S) in the Southwest Atlantic to Puerto Montt (42°S) in the South Pacific, including the Malvinas Islands (Brogger et al., 2013). This species has been subjected of several scientific studies, for instance, the influence of density on survival and larval development in the *A. dufresnii* was investigated by researchers from the National University of Patagonia, Chubut, Argentina (Chaar et al., 2021). In addition, the potential affinity of sea urchin natural pigments, notably 1,4-naphtoquinones polyhydroxylated such as Spinochrome A (SpinA) and Echinochrome A (EchA) as antiviral drugs and therapeutical agent against Mpro protein of SARS-CoV-2 was evaluated *in silico* (Rubilar Panasiuk et al., 2020).

All these previous studies highlighted that excellent research in fishery and marine biotechnology has been conducting by Argentinean institutions, in line with the objectives proposed by Pampa Azul program.

4. Insights into the fishery and aquaculture in the Brazilian Amazon region

Within the scope of the meeting, all participants had an immense pleasure to know more about the current fishery and aquaculture practices in the Amazon region of Brazil lectured by Prof. Dr. Tiago Viana da Costa from the Federal University of Amazonas, Brazil. The Amazon region encompasses 7,000,000.00 km^2, of which 60% of the forest in contained within Brazil, where fishing activity is the foundation of the Amazon economy. Professor Viana da Costa stated that fishing activity on the coast/estuary of the Amazon River moved around US$ 71.52 million in 2020, representing 27.5% of the fish exported by Brazil. According to a recent study conducted in the city of Coari, countryside of Amazonas state, the major fish species commercialized in 2019 were as follow: Jaraqui (*Semaprochilodus* spp.) > Tambaqui (*Colossoma macropomum*) > Pacu (*Piaractus mesopotamicus*) > Curimatã (*Prochilodus nigricans*) > Bodó (*Liposarcus pardalis*) > Pirarucu (*Arapaima gigas*) > Aruanã (*Osteoglossum bicirrhosum*) > Tucunaré (*Cichla* spp.) > Sardinha (*Triportheus elongatus*) > Acará-Açu (*Astronotus ocellatus*), among several other freshwater fish species, representing 17,000 tonnes (da Silva et al., 2020). Marine fish like dourada (*Brachyplatystoma rousseauxii*), piramutaba (*Brachyplatystoma vaillantii*), pescada-amarela (*Cynoscion acoupa*) and the shrimp (camarão-rosa, *Farfantepenaeus subtilis*) are the major marine species captured in the estuary region of the Amazon River (Bentes et al., 2016).

Aquaculture production has been also practiced in the Amazon region (Marques et al., 2020). For instance, the Amazonian black pacu (*C. macropomum*) is the preferred fish species for farming in the Amazon region due to its preference for the warmer and nutrient-rich waters that occur in the natural habitat (Valladão et al., 2018). The recurrent use of hybridization of Amazon fish species such as black pacu x pacu (*C. macropomum* x *P. mesopotamicus*) and red pacu x pacu (*P. brachypomus* x *P. mesopotamicus*) is an alternative strategy commonly used for cultivation of fish species that are sensitive to temperature variations with a mild climate (Gomes et al., 2019). Another technical aquaculture practice is the cultivation of Amazon River prawn (*Macrobrachium amazonicum*) with tambaqui, using nutrient-rich water, in integrated multi-trophic aquaculture (IMTA) systems (Dantas et al., 2020), illustrating that aquaculture biotechnology is possible in the Amazon River basin (Flickinger et al., 2020).

Amazon fish species are generally commercialized in the local markets as entire fish (fresh or frozen), eviscerated fish with head, and fish fillets. Taking into account that huge amount of fish processing is produced daily, and most of this waste is disposed in landfills (de Oliveira Souza et al., 2019) or in some cases directly into the river, several actions have been done in order to reuse and/or recycle the fish wastes, including *i*) reutilization of tambaqui fish residues for the development of fish meal with high protein content (45%) (Silva, 2021), *ii*) reusing filleting residues from two Amazonian fish species (piramutaba and dourada) by producing acid silage with nutritional composition for animal feed (Ribeiro et al., 2020), *iii*) extraction of proteins from tambatinga fish residue, a hybrid of the crossing between the female *C. macroponum* (tambaqui) and the male *Piaractus brachypomus* (pirapitinga) (Sousa et al., 2020), *iv*) fish paté prepared from the gilthead *B. rousseauxii* (dourada) fish residues supplemented with smoked *Arapaima gigas* (pirarucu), and natural thickeners based on potato and cassava (Caldas et al., 2018), *v*) upcycling Pirarucu fish skin into leather through tanning process using two natural Amazonian plant-tannin such as *Myrcia atramentifera* (cumatê) and *Pouteria guianensis* (abiurana) in comparison to traditional chrome tanning (Nascimento, 2009).

The consumption of exotic meat has become regular in some regions, especially in communities located in Amazon region of Brazil. The Amazon region is well recognized as source of fish for food industry, and there is an increased interest in new products from other animal species, such as meat of Caimans including *Melanosuchus niger* (jacaré-açu) and *Caiman crocodilus* (jacaretinga). To evaluate the characteristics of Caiman meat, samples of *Melanosuchus niger* were collected from a protected area in Amazonas State, and their tail tender were analysed in terms of proximate composition, featuring values of 73% moisture, 28% protein, 6% lipids, and 1% ash (Kluczkovski

Junior, 2012), elevating the importance of this analysis for labelling exotic crocodile meat produced at the Amazon basin. Considering that there are no protocols for this type of meat in Brazil, a sanitary risk assessment for Caiman meat quality in Central Amazon has been carried out, enlightening the significance of proper sanitary conditions for food safety (Sotero-Martins et al., 2015). On this topic, the PhD training Samuel Hilevski from the National University of Litoral, Santa Fe, Argentina, and specialist in crocodile nutrition, complemented the discussion by providing in deep knowledge of how to determine the digestibility of diets containing plant-rich protein sources as a supplement for crocodilians species (Hilevski and Siroski, 2021).

5. Seminary discussion

In the last day of the event, participants were divided into five teams composed of four to five students with the main purpose to discuss the potential strategies for the development of aquaculture and fishing research, while maximizing the value of fishery waste and reducing its environmental impact. To expose their thoughts, each team selected one or two scientific articles published in the literature based on five different themes proposed by the organizers. The suggested themes together with supported references and main scientific contributions are shown in Table 3. Below are exhibited brief discussions of each theme divided into five topics.

5.1. Utilization of fishing residues

Fish and fishery products are one of the most commercialized foods in the world, representing a valuable source of nutrients for human diet (Thilsted et al., 2016). According to Olsen et al. (2014), 70% of fish used in industrial processing is discarded as processing leftovers, generating substantial amounts of solid wastes that includes muscle (20-15%), viscera (18-12%), spines (15-9%), heads (12-9%), skin and fins (3-1%), and scales. In Argentina, almost all of it is directly discarded on open-air dumps or water sources (Pereira and Fernandez Gimenez, 2016), although a fraction of this waste can be used to elaborate fishmeal (Matos et al., 2022). Fish waste has several characteristics like high water content, elevated level of enzymatic activity and potential for rapid autoxidation. Fishery wastes if responsibly managed can render valuable by-products with even higher value than the starting material (Lamas et al., 2015, 2017). For example, fish viscera are one of the most important wastes because they contain digestive enzymes, notably aspartic proteinases (pepsin) in the stomach. In this sense, the recovering of digestive proteinases from the marine fish processing wastes of the following fish species: Argentine hake *Merluccius hubbsi*, Brazilian flathead *Percophis brasiliensis*, Brazilian codling *Urophycis brasiliensis* and Stripped weakfish *Cynoscion guatucupa* were investigated (Friedman et al., 2022). Fish individuals were fished off the coast of the Mar del Plata (Argentina) by a commercial fleet and the viscera were immediately extracted and kept on ice until use. Optimum activity of alkaline proteinases from stomach of all species were highly stable at pH between 7.0-11.5, and temperature between 10 to 30°C during 150 min (Bonadero et al., 2022). Proteases are the most widely used group of enzymes in industrial bioprocess, representing about 40-65% of the total commercial enzyme preparations (Atta et al., 2017). For this reason, fish digestive proteinases recovered from fish-processing waste not only provide novel higher-value products, but also improve economic returns to the fishing industry (Rodriguez et al., 2019) as stated during the lectures (Table 1) given by Dr. Yamila Eliana Rodriguez and Dr. María Victoria Laitano from the National University of Mar del Plata, Argentina.

Fish oil can be also obtained as a by-product of the fish industry (Adeoti and Hawboldt, 2014). Methods to extract fish oil include cooking using solvents, extraction by supercritical fluids, enzymatic procedures and chemical (*i.e.* applying acids) or biological silages. Wet pressing is the most used method for fish oil production on an industrial scale, and is carried out in four stages: fish cooking, pressing, decantation and centrifugation (Bonilla-Méndez and Hoyos-Concha, 2018). The oil carrying on fatty acids extracted from fish waste can be thus useful for obtaining biodiesel after transesterification with the addition of short-chain alcohols and catalysts (de Medeiros et al., 2019) or to be refined by several steps, such as degumming, neutralization, bleaching, deodorization and, in some cases, winterization to achieve the quality characteristics that make it acceptable for human consumption and animal nutrition (Alfio et al., 2021).

Further example of by-product development after fish processing is turning the fish skin into leather through tanning process (Palomino et al., 2020). Fish scaly skin appearance is exotic, providing distinct leather for sophisticated and fashion products like handbags, belts, clothing, small accessories, and shoes (Duraisamy et al., 2016). Another example of by-product is the development of fish burger through mechanically deboned fish meat. The process consists of separating under high pressure through a sieve the bone from the edible meat tissue, providing a fish pulp produced by forcing pureed or ground fish (Al-Bulushi et al., 2005). The resulting fish pulp is a blend primarily consisting of tissues and can be mixed with additives (salts, sugar, spices, condiment) and transglutaminase enzyme to make fish burger, fish nuggets and fish sausage (Adrah and Tahergorabi, 2022; Marianski and Marianski, 2011). A schematic visualization of the fish processing as well as some fish by-products can be seen in Fig. 2.

5.2. Utilization of aquaculture residues

According to the latest worldwide statistics on aquaculture compiled by FAO, the total aquaculture production was around 114.5 million tonnes in live weight in 2018, consisting of 82.1 million tonnes of aquatic animals (USD 250.1 billion), followed by 32.4 million tonnes of aquatic algae (USD 13.3 billion) and 26 000 tonnes of ornamental seashells and pearls (USD 179 000) (FAO., 2020).

Aquaculture practices have grown exponentially in the last decades mainly due to the worldwide demand for protein for human consumption (Froehlich et al., 2022). However, it generates concerning consequences for the environment, including chemical and biological pollution, waters eutrophication, disease outbreaks, and competition for coastal space (Carballeira Braña et al., 2021). In addition, the increased waste products generated from aquaculture has threaten the sustainability of aquaculture practices (Dauda et al., 2019). Consequently, the reutilization of aquaculture waste materials to promote sustainable and bio-circular economy can minimize the environmental impacts of this activity (Fraga-Corral et al., 2022).

Potential reutilization of aquaculture wastes includes the following examples: *i*) revalorization of calcined mussel shells (*Perna viridis*) as partial or full substitution of construction material (concrete) that could save the production cost (Razali et al., 2017), *ii*) reutilization of waste oyster shell as filler for filter for drinking water pre-treatment (Lin et al., 2022), *iii*) processed shrimp wastes for extraction of bioactive compounds such as chitin, carotenoids and protein hydrolysates that can be used as food and feed as well as ingredient in functional food preparation (Nirmal et al., 2020), *iv*) valorization of aquaculture by-product from salmonids (rainbow trout and salmon) processing for the production of fish protein hydrolysates (FPHs) as protein ingredient of aquaculture feeds (Vázquez et al., 2019), and *v*) reusing rejects of Nile tilapia (*Oreochromis niloticus*) farming for the production of biodiesel via transesterification of Nile tilapia’s oil and enzymatic catalysis (de Oliveira et al., 2021). All these examples clearly show the alternative strategies to recycle and transforming aquaculture wastes into revalorized by-products, offering additional economic benefits. Implementation of these integrated approaches can lead to obtain certification such as Good Agricultural Practices (GLOBAL G.A.P., https://www.globalgap.org/uk_en/) through labelling programme Integrated Farm Assurance (IFA) for responsible and sustainable aquaculture production system (Osmundsen et al., 2020).

5.3. Probiotics, prebiotics and synbiotics

Intensive aquaculture practices are developing so fast around the world that infectious disease outbreak happens regularly, and chemotherapeutants treatment like antibiotics and vaccination are some strategies to control disease outbreak (Zhang et al., 2022). Microbial pathogens may develop resistance to antibiotic, while vaccination is a prophylactic tactic (Subasinghe, 2009). For this reason, some functional ingredients like prebiotics, probiotics, seaweed extracts and plant extracts have been incorporated into animal feed to enhance the immunity of aquacultural species (Hasan et al., 2019; Kiron, 2012). Synbiotic supplements, which are a combination of single or more probiotics and prebiotics have been also highly recommended in intensive sturgeon aquaculture (Hoseinifar et al., 2016).

Bacillus spp. and *Lactobacillus* spp. are two common Gram-positive bacteria applied as fed probiotics for shrimp and fish farming, preventing microbial diseases (Olmos et al., 2020). For example, *in vitro* evaluation of two probiotics *Bacillus subtilis* and *Lactobacillus plantarum* administered through *Artemia franciscana* live feed to protect European sea bass larvae (*Dicentrarchus Labrax*) against *Vibrio anguillarum* was investigated (Touraki et al., 2012). The assessment of water-soluble chitosan and mixed probiotics on the growth performance and intestinal short-chain fatty acids of *Litopenaeus vannamei* was also explored (Chen et al., 2020), highlighting the immune response and ammonia resistance capacity of Pacific white shrimp by consuming probiotic-rich compounds.

The term ‘postbiotics’ is increasingly found in the scientific literature within the functional foods field (Aguilar-Toalá et al., 2018). Very recently, a panel of renowned scientists of the International Scientific Association of Probiotics and Prebiotics (ISAPP) discussed the correct terminology of postbiotics, which is defined as a ‘preparation of inanimate microorganisms and/or their components that confers a health benefit on the host’ (Salminen et al., 2021). For this reason, application of different postbiotics including short-chain fatty acids (SCFAs), peptides, exopolysaccharides, peptidoglycan, vitamins, cell surface proteins, and teichoic acid as aquaculture disease control agents were revised and well-documented (Ang et al., 2020). For example, propionate and butyrate salts as SCFAs supplement for grass carp (*Ctenopharygodon idella*) have modulated its gut microbiota (Tian et al., 2017). Peptides like bacteriocins (divercin, bavaricin and divergicin) have been successfully isolated from healthy Patagonian trout (*Oncorhyncus mykiss*), identified by LC-MS/MS, and effectively tested as antimicrobial agent against the fish pathogen *Carnobacterium maltaromaticum* CECT 4020 (Garcés et al., 2020). Peptidoglycan (PG) derived from *Bifidobacterium thermophilum* has been appropriately tested in Pacific white shrimp, elevating its immunity and disease resistance (Song et al., 2013). Cell surface proteins or outer membrane protein (OMP) as antigen in vaccine has been efficaciously tested in channel catfish (Abdelhamed et al., 2017), while lipoteichoic acid has been molecularly identified as antibiotic agent against fish pathogenic *Enterococcus faecalis* (Rahman et al., 2017). For these reasons, molecular properties of postbiotics metabolites and their role in controlling aquaculture diseases must be considered (Sudhakaran et al., 2022).

Although probiotics and functional ingredients are used as alternatives of antibiotics in aquaculture, risk of developing antibiotic resistance or unintended impacts on the environment must be considered (Wang et al., 2019). For example, the *Lactobacillus rhamnosus*, administered as probiotic for disease protection, have caused injury to the mucosa of zebrafish (He et al., 2017), while *L. plantarum* induced damaged epithelial cells and disorganized microvilli in the gastrointestinal tract of beluga (*Huso huso*) (Salma et al., 2011). On the occasion of this topic, the senior researcher Dr. Juana Cristina del Valle from the National University of Mar del Plata, Argentina, and specialist in nutrition, gave a lecture highlighting the pros and cons of using probiotic, prebiotic, synbiotic, postbiotics, and parabiotics in aquaculture (del Valle et al., 2023).

5.4. Fish protein hydrolysates

Fish protein hydrolysates (FPH) is a breakdown product of fish proteins containing smaller peptides and amino acids (Ananey-Obiri et al., 2019). FPH is obtained by treatment of fish meat with proteolytic enzymes like trypsin, alcalase, chymotrypsin, pepsin, or other enzymes under controlled conditions of pH and temperatures (Venugopal, 2016). The functionally, bioactivity, and nutritional value of FPH offers many useful capabilities in food processing including dietetic foods such as soufflés, meringues, macaroni, or bread, and for the preparation of fish soup, fish paste, and shellfish analogues as flavouring compounds as a source of rich peptides and amino acids (Halim et al., 2016).

The choice of enzymatic hydrolysis produces a series of small polypeptides, which can modify and even improve the functional characteristics of proteins for different applications such as nutraceutical, biomedical and pharmaceutical interests (Al-Nimry et al., 2021; Gao et al., 2021). For example, Pacific whiting *Merluccius productus* muscle was used to produce hydrolysates with 10-, 15-, 20-% degree of hydrolysis (DH) using the commercial protease Alcalase® and were characterized at pH 4.0, 7.0 and 10.0 according to their solubility, emulsifying and foaming properties (Pacheco-Aguilar et al., 2008). Authors stated that the fish protein hydrolysate they produced could substitute functional compounds satisfactorily, such as sodium caseinate and bovine serum albumin, commonly utilized in food formulations.

There is a convincing argument and scientific evidence that fish protein hydrolysates can act as source of anticancer or chemopreventive molecules due to their potent bioactive peptides (Shaik and Sarbon, 2022). For instance, antioxidant and anticancer activities of enzymatic eel (*Monopterus* sp.) protein hydrolysates as influenced by different molecular weight was investigated (Halim et al., 2018), while antiproliferative activity of FPH containing a mixture of free amino acids, peptides with many sizes ranging up to 7 kDa was studied *in vitro* on human breast cancer cell lines (Picot et al., 2006). Further example also include the antioxidant activity and anticancer effect of bioactive peptides from rainbow trout (*Oncorhynchus mykiss*) skin hydrolysates (Yaghoubzadeh et al., 2020).

5.5. Alternative food proteins and functional ingredients

The global demand for protein-rich foods will continually increase as global population is projected to be around 9.7 billion in 2050 (Ehrlich and Harte, 2015). For this reason, aquaculture can help to fulfil some of this protein worldwide demand

(Gjedrem et al., 2012). Feed is a major cost in livestock production, and protein ingredients particularly elevate the aquaculture feed cost (Hixson, 2014). Historically, fishmeal has been the preferred protein ingredient in aquaculture because of its completeness source of essential amino acids (EAAs) as well as high content of protein (35-60 wt%) (Tibbetts et al., 2017). In this scenario, single cell protein (SCP) products prepared from different microbial sources, including microalgae, yeast and other fungi and bacteria, has the potential to deliver a myriad of bioactive compounds (Matos, 2017; Ritala et al., 2017). Recent advances in single cell protein use as a feed ingredient in aquaculture was summarized by Jones et al. (2020), where authors highlight the importance of microalgae as source of protein to benefit aquaculture feed performance (Karapanagiotidis et al., 2022; Matos, 2019).

Special studies on the digestibility and bioaccessibility of microalgal biomass in feed supplementation for aquatic animals have been carried out and can be found in the scientific literature (Demarco et al., 2022; Nagarajan et al., 2021). For example, apparent digestibility of nutrients, energy, essential amino acids, and fatty acids of juvenile Atlantic salmon (*Salmo salar* L.) diets containing *Chlorella vulgaris* meals were investigated (Tibbetts et al., 2017), while *in vitro* prediction of digestible protein content of marine microalgae *Nannochloropsis granulata* meals for Pacific white shrimp (*Litopenaeus vannamei*) and rainbow trout (*Oncorhynchus mykiss*) was also studied (Tibbetts et al., 2017).

The participant Dr. Ângelo Paggi Matos from the Federal University of Santa Catarina, Brazil, and specialist in food science with focus on algal biotechnology, incremented the discussion by exemplifying the chemical content in terms of protein, carbohydrates, fibers, lipids, and fatty acids composition of six microalgae biomass

Chlorella vulgaris, *Arthrospira platensis*, *Nannochloropsis gaditana*, *Nannochloropsis oculata*, *Phaeodactylum tricornutum* and *Porphyridium cruentum* (Matos et al., 2016).

6. Lessons learned from the training

Attending the scientific training in marine biotechnology and aquaculture came with a series of benefits of all participants. First, participants learned about the status of fishery around the world as well as the future of aquaculture, including new fish farming technologies. Through interactions with active researchers from different Argentinean institutions, participants also learned about the main aquaculture biotechnology research conducted around the country of Argentina, with emphasis to the newest program 'Pampa Azul' launched by the Argentinean authorities. Second, experimental and practical classes conducted during one week training provided participant's fresh laboratory skills for the elaboration of new by-products, such as fish meal and protein hydrolysates. Third, participants had the opportunity to network with master and PhD students as well as early to mid-career researchers and professors from South America, narrowing the scientific communication between us. Fourth, participants engaged as part of a team to read papers, evaluate the scientific content, and discuss new breakthrough ideas into the aquaculture circular bioeconomy, allowing for the stimulation of curiosity and in-depth debates between participants. Finally, participants were encouraged to continue networking by collaborating multidisciplinary research and exchanging ongoing PhD students to develop their research-part in another laboratory within the South America country.

Based on her previous experience of running scientific training of fishery and aquaculture biotechnology in Mar del Plata, Argentina, Dra. Analía V. F. Gimenez emphasizes that the constructive collaboration between young talented students and experienced researchers/professors is an essential feature for the successful implementation of the course as reflected by the survey conducted among participants with high satisfaction rate. The face-to-face interaction of the participants also creates connections between researchers, provoking collaborative research ideas. The on-site scientific training also serves to inspire participants to think critically about the importance of their research within the science of aquaculture biotechnology. Plans of how participants will use the skills will be seen in the near future where research collaborations are under progress, and new articles about fishery and aquaculture biotechnology will be published in the literature.

7. Concluding remarks

It is evident that the experienced training brings to us new insights into the ongoing fishery and aquaculture biotechnology under development in South America, with special attention to the fishery industry in Mar del Plata city, Argentina. The twenty-two hours of theory classes also provided an even more knowledge about the importance of fishery and aquaculture for sustainable development, while the twenty-three experimental/practical classes deepen the skills for the development of new by-products from fishery wastes. The topics of the seminary discussion provided an ample debate being a powerful tool of aquaculture science dissemination, which were empowered by the different background of the participants. It is clear that face-to-face interaction built a new relationship between participants, strengthening the future collaborations within aquaculture research. We hope that we have shed some light on aquaculture biotechnology bringing closer readiness knowledge for advancing this science between South American participants.

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Fig. 1. Photographs taken during the week training in Mar del Plata, Argentina. A) All participants composed of master and PhD students, early-career scientists and professors; B) Professor Dr. Analía V. Fernández-Gimenez introducing the course and lecturing about the importance of biotechnology in the context of fishery and sustainable aquaculture; C) Technical visiting at laboratory of aquaculture guided by Lic. Nahuel Zanazzi from the National Technological University of Mar del Plata; D) Participants sight-seeing the seaside port region of the Mar del Plata city; E) Dr. Patricia Romero-Murillo visualizing samples of *Brachidontes rodriguezzi* mussel at optical microscopy and evaluating the antifouling activity of enzymatic extracts; F) Group of PhD students conducting experiments.

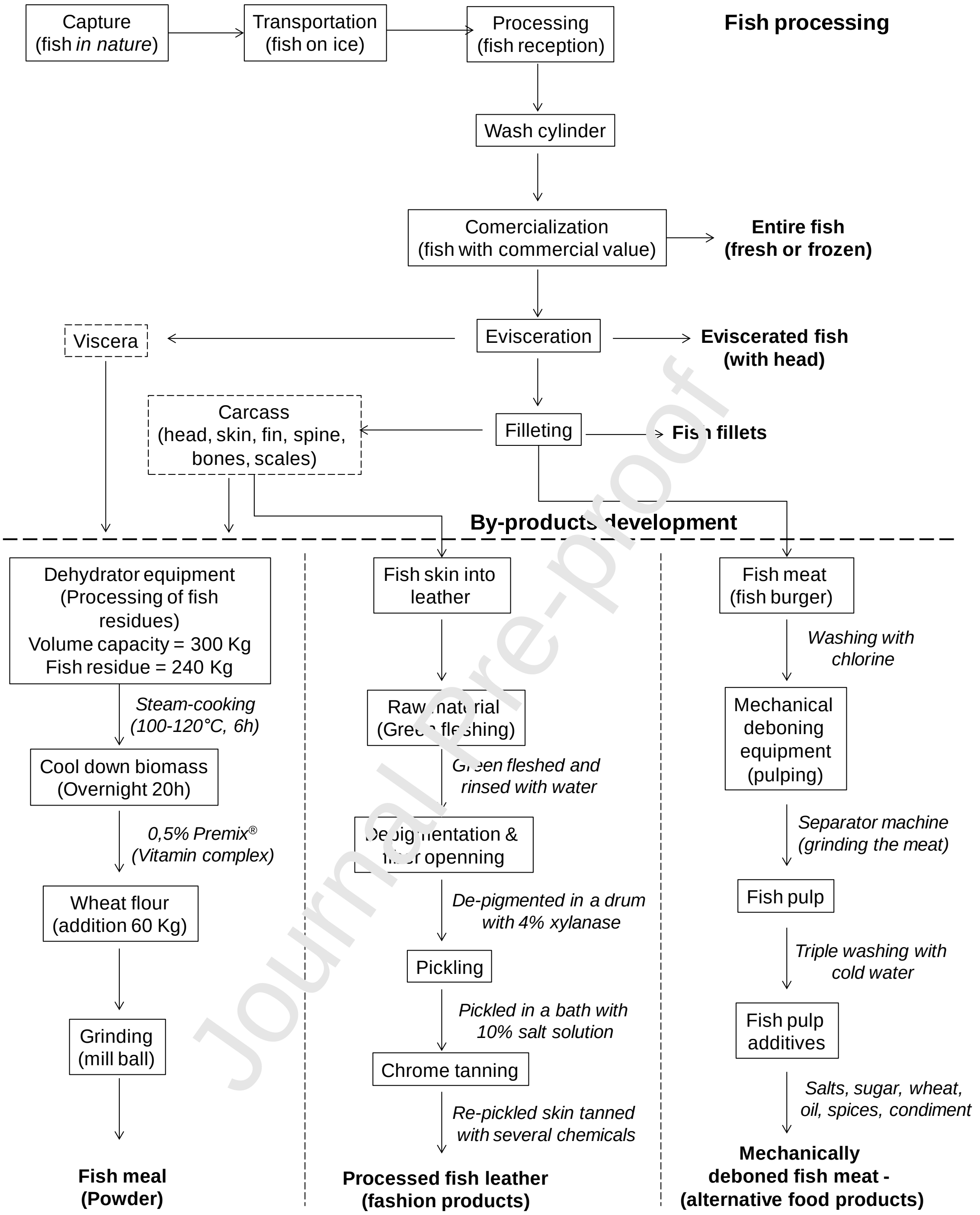

Fig. 2. Fish processing and its potentialities. Fluxogram of fish processing with different commercialized products, such as entire fish, eviscerated fish and fish fillets. Source: Flowchart adapted from Feltes et al. (2010). Schematic steps for the development of some by-products after fish processing, such as fish meal using residues from the fish processing, fish skin processed into leather useful for sophisticated products (handbags,

belts, clothing, small accessories and shoes), and deboned fish meat that can be utilized to produce fish burgers, fish fingers, fish balls and nuggets. Sources: (Bainy et al., 2015; Duraisamy et al., 2016; Matos, et al., 2022; Matos and Matos, 2018).

Table 1. Theory classes that were given to the participants during the training.

Day	Class title	Lecturer
First	Course introduction. Status of fishery and aquaculture around the world. Circular bio-economy and sustainable aquaculture. Fishery residues and its processing.	A.V. Fernández-Gimenez
Second	Functional ingredients and alternative protein sources in aquaculture. Probiotics, prebiotics, synbiotics, postbiotics, and parabiotics. Exogenous enzymes as feed additives for animal nutrition in aquaculture.	A.V. Fernández-Gimenez J.C. del Valle Y.E. Rodriguez
Third	Metabolism and energy reserves mobilization of crustaceans. Biorefinery of fishery and aquaculture wastes. Anti-fouling paint.	H.J. Sacristán M.V. Laitano
Fourth	Status of Brazilian Amazon fishery. Fish exploitation, capture technology, products commercialization (salty, fillets, eviscerated). Revalorization of fish wastes.	T.V. Costa
Fifth	Commercialization of ornamental fishes and target species. Fish protection and policies in the Brazilian Amazon river basin.	T.V. Costa
Sixth	Seminary discussions.	Round-table of all participants.

Table 2. Topics of discussion during practical and experimental classes.

Topic	Highlights	Supported references
Technical visit at aquaculture laboratory facilities of the National Technological University of Mar del Plata	Elaboration of fish meal diet for Nile tilapia. Utilization of vegetables residues for improvement of ω-3 in fillet of Nile tilapia. Use of residues from fish industry as source of functional ingredients to aquaculture nutrition	(Barragán et al., 2017; Matos, et al., 2022; Ramos et al., 2021; Waldmann et al., 2021)
Enzymatic activity of proteases from fish and crustaceans	Determine and compare the alkaline and acidic protease activity from the homogenates of *Pleoticus muelleri* and *Oreochromis niloticus*	(Cardenas-Lopez and Haard, 2005; Gimenez et al., 2001)
Inhibitory effect of vegetable flour over fish and crustacean proteases	Evaluate the degree of inhibitory effect of different vegetable flour over the enzymatic extracts of *P. muelleri* and *O. noliticus*	(Garciacarreno et al., 1993)
Fish fillets from *Merluccius hubbsi*	Elaborate fillet from *Merluccius hubbsi* fish. Estimate and calculate fish fillet yields.	(González et al., 2007; Matos and Matos, 2018)
Protein hydrolysate from fish and crustaceans	Elaborate and evaluate the degree of hydrolysis of protein hydrolysates from *P. muelleri* and *M. hubbsi*	(Anal et al., 2013; Camargo et al., 2021)
Antifouling activity of	Determine the antifouling activity	(Nalini et al., 2019;

protein extracts	of enzymatic extracts of *P. muelleri* on living individuals of *B. rodriguezii* mussels	Pérez et al., 2019)
Immobilization of bioactive compounds in alginate particles	Elaborate micro-particles of alginate by ionic gelation method. Determine the size and encapsulation yield of micro-particles by using software program	(Hariyadi et al., 2014; Rodriguez et al., 2018)

Table 3. Thematic discussion of the teams based on aquaculture and fishing research.

Team	Theme	References selected	Highlights
Group 1	Utilization of fishing residues	(de Medeiros et al., 2019)	Physicochemical characterization and obtainment of oil with long-chain fatty acid profile using fishing waste.
Group 2	Utilization of aquaculture residues	(Razali et al., 2017)	Revalorization of calcined mussel shells (*Perna viridis*) as partial cement replacement using four different percentages (10-, 20-, 30-, 40-%) by volume of concrete formulation.
Group 3	Probiotics, prebiotics and	(Ang et al., 2020; Chen et	Improvement of immunity and ammonia resistance of shrimp *Litopenaeus*

	synbiotics	al., 2020)	*vannamei* fed with water-soluble chitosan and mixed probiotics. Postbiotics as infectious disease control agent in aquaculture.
Group 4	Fish protein hydrolysates	(Pacheco-Aguilar et al., 2008; Picot et al., 2006)	Pacific whiting (*Merluccius productus*) muscle was used to produce hydrolysates with 10-, 15-, 20-% degree of hydrolysis using commercial protease. Fish protein hydrolysates have shown antiproliferative activity on human breast cancer cells.
Group 5	Alternative food proteins and functional ingredients	(Jones et al., 2020; Matos et al., 2016)	Single cell protein (SCP) use as feed ingredient in aquaculture. Chemical characterization of six microalgae as potential source of proteins, lipids and fatty acids. *A. platensis* and *C. vulgaris* rich in proteins (40-60%), *P. tricornutum* and *N. oculata* rich in lipids and ω-3 PUFAs.

Author statement

All authors whose name are listed in this manuscript have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission to Aquaculture for peer review.

Statement of informed consent, human/animal rights

No conflicts, informed consent, or human or animal rights are applicable in this study.

Declaration of competing interest

None.

Declaration of competing interest

None.

Highlights

- Lessons learned from the scientific training in aquaculture and fishery research
- Lectures about the Argentinean Sea studies
- The importance of circular bioeconomy in aquaculture within South American countries
- Aquaculture science communication via seminary discussions