Agronomía Mesoamericana

UNIVERSIDAD DE COSTA RICA

Literature review
Volumen 34(2): Artículo 51077, 2023
e-ISSN 2215-3608, https://doi.org/10.15517/am.v34i2.51077
https://revistas.ucr.ac.cr/index.php/agromeso/index

Fish waste silage, a green process for low feedstock availability. A Review[1]

Ensilado de desechos de pescado, una actividad sustentable para bajos volúmenes de procesamiento

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[1] Reception: May 24th, 2022. Acceptance: December 2nd, 2022. This work is part of a doctoral thesis title: "Application of commercial starters of lactic acid bacteria in the fermentation of common hake (*Merluccius hubbsi)* for use in animal nutrition". This work was supported by the Secretary of Science, Art and Technology (National University of the Center of the Buenos Aires Province).

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Abstract

Introduction. Different fishing activities generate a waste volume related to the processing species (viscera, heads and bones), the discards of the companion fauna, species of low commercial value and the losses related to handling problems. Fish meal production is the most common process for recovery nutrients from these fish processing byproducts. However, those places with reduced infrastructure or where the volume of wastes produced do not justified the economic equation for conversion into fish meal or oil, the biological silage could be the technology of choice to promote a sustainable waste management. **Objective.** To compilate, organize and summarize literature related to biological fermentation of fish waste and its applications. **Development.** A bibliographic review was carried out (January 1994 - December 2020) referring to the comprehensive use of fishing residues mainly focused on the use of lactic acid bacteria in fish waste fermentation. The information was organized in different sections: fish silage, lactic acid bacteria and carbohydrate sources for biological silage. **Conclusions.** The studies analyzed in this review highlight the possibility of using a wide variety of carbohydrate sources, biological starters and fish waste fermentation conditions. The satisfactory results show the potential use of fish waste in different applications. This work could contribute to the fisheries that decide to adopt this kind technology in order to provide an innovative and viable recycling bioeconomy.

Keywords: fishery, discard, acid lactic bacteria, fermentation, byproducts.

Resumen

Introducción. Las actividades pesqueras generan un volumen de desechos relacionados con el procesamiento de especies (vísceras, cabezas y espinas), los descartes de la fauna acompañante, especies de bajo valor comercial y pérdidas relacionadas con problemas de manejo. La producción de harina de pescado es el proceso más común para recuperar los nutrientes de los subproductos del procesamiento del pescado. Sin embargo, aquellos lugares con

infraestructura reducida o donde el volumen de residuos producidos no justifique la ecuación económica para la conversión en harina o aceite de pescado, el ensilaje biológico podría ser la tecnología de elección para promover una gestión sostenible de los residuos. **Objetivo.** Recopilar, organizar y resumir la literatura relacionada con la fermentación biológica de residuos de pescado y sus aplicaciones. **Desarrollo.** Se realizó una revisión bibliográfica (enero 1994 – diciembre 2020) referida al aprovechamiento integral de los residuos de la pesca, principalmente focalizada a la utilización de las bacterias ácidos lácticas en la biofermentación de los mismos. La información se organizó en diferentes secciones: ensilado de pescado, bacterias acido lácticas, fuentes de hidratos de carbono referidas a la elaboración de ensilados biológicos de pescado. **Conclusiones.** Los estudios analizados destacan la posibilidad de utilizar una amplia variedad de fuentes de hidratos de carbono, iniciadores biológicos y condiciones de fermentación de desechos de pescado. Los resultados satisfactorios muestran el potencial uso de los desechos de pescado en diferentes aplicaciones. Este trabajo podría aportar a las pesquerías que quieran adoptar esta tecnología para el tratamiento adecuado de los residuos con la finalidad de contribuir a la bioeconomía de reciclaje.

Palabras clave: pesquería, descarte, bacterias ácido lácticas, fermentación, subproductos.

Introduction

Fishing-related activities fulfill the dual function of representing a major source of food worldwide and constitute as a livelihood for a large number of people. World fish production was estimated to be about 179 million tons in 2018 (with China, Peru, Chile and Japan being the main marine fish catcher countries), where 83 % was used for human consumption and most of the rest ended up as fishmeal and fish oil (Organización de las Naciones Unidas para la Alimentación y la Agricultura [FAO], 2020). The different fishing activities result in a waste volume related to the processing of species (filleting cuts, viscera, heads, and bones), the discards of the companion fauna, species of low commercial value or the losses related to handling problems (FAO, 2014; Toledo Pérez & Llanes Iglesias 2006).

Fish waste represented half of the raw material volume of the industry and is a source of low–cost nutrients (Oetterer, 2002). The use of fishing waste in different parts of the world is allocated to animal feed and is of great interest as it represents an environmental and public benefit as well as reducing the cost of animal production. However, there were numerous reports about diverse products such as finfish or shellfish wastes for biodiesel, biogas as well as source of natural pigments and chitin (Cadavid-Rodríguez et al., 2019; Castro et al., 2018; Cira et al., 2002; dos Santos et al., 2015; Nges et al., 2012).

In countries such as Argentina, Norway, and China, waste generated from fishing activities is mainly used to produce fishmeal and oils (Ramírez, 2013). When fish were fed with animal protein, mainly fish meal, growth indicators and feed utilization were improved (Zhoug et al., 2004). Fish meal production is the most common process for recovery the nutrients from fish processing byproducts. However, the long distances to fish meal plants, the cost of transport, and law restrictions on fish meal production reduce the feedstock and raise the price of fish meal (Palkar et al., 2017). Since high costs and limited availability of fishmeal have forced companies to reduce or eliminate this component in their products, the situation promotes alternative processes where fish silage could be a promising choice (Hardy, 2010; Tacon & Metian, 2008).

Fish silage production is a technology with lower costs. Although fish silage preparation usually depends on the locally available raw materials and conditions, it recovers the nutrients contained in fishery residues and allows their use as animal feed (Ferraz de Arruda et al., 2007; Gomez et al., 2014; Inoue et al., 2013; Valério Geron et al., 2007). The use of fish processing waste could reduce the cost of producing fish feed by approximately 15 to 20 % (Li et al., 2009). Although the amount of fishmeal replacement depends on fish species specific on and its growth stage (Moon

& Gatlin, 1994; Mondal et al., 2011), 75 % fish meal could be replaced without any compromise on the growth and nutritive value of the raw material (Cheng et al., 2003).

The silage provides a double benefit: it protects the environment against the risk of contamination generated by untreated waste and reduces the costs of animal feed production (Samaddar & Kaviraj, 2014). The aim of this review was to compile, organize and summarize literature related to biological fermentation of fish waste and its applications.

Fish silage

Fish silage is an ancient preservation technique (Raa et al., 1982) that was adopted in the 1930s from a method that using sulfuric and hydrochloric acids to preserve forages (Hammoumi et al., 1998). The process involve crushing fish, which accelerates the pH reduction to 4. This result in a semi-liquid product is rich in proteins, amino acids, phosphorus, and calcium. The product has a slight malted smell and can be used as protein source in animal feed (Raa et al., 1982), particularly for fish (Goddard & Al-Yahyai, 2001; Pinto de Carvalho et al., 2006; Vidotti et al., 2002) and chickens (Bello, 1997).

Some investigations demonstrated that fish silage has the potential to be used as a nitrogen source and probiotic ingredient for poultry feeding (Hammoumi et al., 1998). In their study, the chemical and physico-chemical properties of raw sardine waste and the resulting silage were compared. The silage was found to contain an average of 11.34 % protein, 6.12 % fat, and 7.94 % ash.

Additionally, the potential of sardine waste silages as fishmeal substitute for fishmeal in the production of *Dicentrachus labrax* was assessed. Fermentation with *Lactobacillus plantarum*, supplemented with molasses and organic acid acidification at 35 °C resulted in a product with 13.2 % protein, 12 % fat, and 2.1 % ash (Davies et al., 2020). Although there were variations in the composition of silages, these values were quite similar to those obtained from the previous study and could be attributed to differences in the raw materials used.

The main cause of liquefaction of fish silages is considered to be the lower pH value and the endogenous enzymatic activities. This process can be achieved by either chemical or biological means, with the purpose of reducing the pH to inhibit the spoilage flora and extend the preparation's half-life (Dapkevicius et al., 2000; Raa et al., 1982). The rapid decrease in pH promotes favorable microbiological and enzymatic processes that help preserve the quality of fish silage (Ramírez Ramírez, 2009).

Chemical fish waste silage can be prepared by direct acidification with organic acid, inorganic acid, or mixture of both (Copes et al., 2006; Fagbenro & Jauncey, 1993; Gullu et al., 2015; Toledo Pérez & Llanes Iglesias, 2006). While the cost of organic acids is higher than mineral acids such as hydrochloric acid and sulfuric acid, handling inorganic acids requires trained operator and safety equipment. Organic acids like formic acid and propionic acid are less dangerous and have higher bactericidal and antifungal effects (Wicki et al., 2007).

The quality and freshness of raw materials are crucial for the production of silage since protein digestibility, fatty acids content, and vitamins levels depend on them (van 't Land et al., 2017). This is particularly important for a product that may be used in aquaculture and animal production.

Fermentation using lactic acid bacteria is preferable to chemical silage because it has beneficial effects such as antibacterial activity and prevents lipid oxidation during ripening (Raa et al., 1982). Lactic acid bacteria produce various compounds that inhibit spoilage microflora, including organic acids, diacetyl, hydrogen peroxide, and bacteriocins (Yusuf & Hamid, 2013).

The freshness of the fish waste used for silage production is generally considered important, but the raw material may sometimes have microbiological variability due to conditions at the fishing plants. To homogenize the raw material and reduce the microbiological load, Góngora et al. (2012) cooked the fish waste before chopping it.

Although the silage technology is simply, it has some disadvantages such as high water content, making it difficult to transport. Co-dried fish silage used as an aquafeed ingredient that is easy to package, store, and transport. Some aquaculture experiences have used fish silage with co-dried ingredients such as soybean, cornbean, barley flour, and wheat bran (Fagbenro & Jauncey, 1994a; Najim et al., 2014). Fagbenro & Jauncey (1995) highlighted that fermented fish silage co-dried with protein feedstuffs can provide up to 50 % of dietary protein without affecting feed efficiency, fish growth, or health.

Lactic acid bacteria (LAB)

Lactic acid bacteria (LAB) are Gram positive, non-sporulated, coccus or bacillus bacteria that can ferment carbohydrates and produce lactic acid as the main fermentation product (Hayek & Ibrahim, 2013). LAB belongs to the Phylum *Firmicutes*, class *Bacilli*, order *Lactobacillales*, and are distributed across five different families, 62 genera, and over 500 species of low guanine-cytosine content (33-51 %) bacteria. The Lactobacillaceae family includes most of GRAS species (GRAS: Generally Recognized as Safe, US-FDA) within 31 genera to date. Currently, the delineation of taxonomic ranges is based on phylogenetic analysis, average nucleotide identities (AAI), physiological characteristics, and ecological niche (Zheng et al., 2020).

The most commonly used LAB as starter cultures in the production of biological silages are *Lactobacillus* spp., *Carnobacterium* spp., *Leuconostoc mesenteroides*, *Pediococcus acidilactici* (Bhaskar et al., 2007; Faid et al., 1994; Fagbenro & Jouncey, 1995; Vazquez et al., 2008; Vazquez et al., 2011). Some of the more well-known species for their high synergism and mutualism used in commercial yogurt production are *Lactobacillus bulgaricus* and *Streptococcus thermophilus* (Fernández Herrero et al., 2013; Fernández Herrero et al., 2015; Valério Geron et al., 2007). However, some processes have been performed by native LAB strains isolated from fish (Gelman et al., 2001; Holguín et al., 2009).

Researchers have evaluated the use of *Weissella paramesenteroides*, isolated from bee bread, as a potential tool for biological fish silage through encapsulation (Libonatti et al., 2018).

Certain LAB strains are considered probiotic due to their beneficial effects on the digestive tract and immune system of consumers. Evidence supports the use of LAB in animal production (Espeche et al., 2012; Topic Popovic et al., 2017; Zhang et al., 2012), including in aquaculture, where probiotics have been shown to activate non-specific immune responses and increase the number of erythrocytes, granulocytes, macrophages, and lymphocytes in various fish species (Irianto & Austin, 2003; Kim & Austin, 2006; Nayak et al., 2007).

In recent years, the applications of LAB have been extended beyond probiotics. Gaspar et al. (2013) particularly highlight the use of LAB as cell factories for the production of high-value complex pharmaceuticals and food ingredients, such as colors, aromas, and texturizing agents. For the specific purpose of fish fermentation, *Lactobacillus plantarum* and other species within the plantarum group have been found the better adapted bacteria (Bhaskar et al., 2007; Castro et al., 2018; Dapkevičius et al., 1998; Davies et al., 2020; Evers & Carroll, 1996; Faid et al., 1994; Fagbenro & Jouncey, 1994a; 1994b; Fagbenro & Jouncey, 1995; Góngora et al., 2012; Hammoumi et al., 1998; Vázquez et al., 2008; Vázquez et al., 2011).

Sources of carbohydrates for biological silages

Fish has a low concentration of carbohydrates, so it is necessary to add an aditional source of these substrates to increase the production of lactic acid during fermentation (Góngora et al., 2012; Ramírez Ramírez, 2009). Therefore, the selection of the carbohydrate and its appropriate level are determining factors in achieving efficient

systems for fast acidification within the economic equation of the process (Cira et al., 2002; Davies et al., 2020; Góngora et al., 2012). The availability of the substrate in the region where the silage is produced is key condition for an economically sustainable process (Parín & Zugarramurdi, 1997).

Several sources of substrates have been tasted for fish fermentation, including molasses (Table 1), sucrose, high fructose corn syrup, whey, honey, glucose, and fruits (Table 2). Molasses is one of the most widely used substrates due to its high content of soluble carbohydrates, low cost, and the ability to improve the stability and sensory characteristics of the silages (Evers & Carroll, 1996; Fagbenro & Jauncey, 1998; Zahar et al., 2002). However, other reports have highlighted the potential of carbon sources from vegetable and fruit waste (Bello, 1997; Davies et al., 2020).

Table 1. Research that uses molasses as a carbohydrate source in the production of biological fish silage.

Tabla 1. Estudios que utilizan la melaza como fuente de hidratos de carbono en la elaboración de ensilado biológico de pescado.

References	Raw material	Microorganisms	Detail
Faid et al. (1994)	*Sardinia pilchardus*	*S. cerevisiae, Candida* sp, *L. plantarum, P. acetolactic*	The combination of *S. cerevisiae* and *L. plantarum* (molasse 30 %, 26 °C-28 °C for 10 days) was selected.
Fagbenro and Jauncey (1994a)	*Oreochromis niloticus*	*L. plantarum 5 %*	Selected conditions were: heating fish substrate and 30 days fermentation at 30 °C.
Fagbenro and Jauncey (1994b)	*Oreochromis niloticus*	*L. plantarum* 5 %	The silages were performed at 30 °C-30 days, addition of natural antioxidants.
Fagbenro and Jauncey (1995)	*Oreochromis niloticus*	*L. plantarum 2 %*	Silages were done at 30 °C 7 days.
Evers and Carroll (1996)	*Shrimp or Crab*	*E. faecium, L. plantarum*	Preserved crab or shrimp waste with 25 % of molasses 7.5 % of salt, 6 days, 19.4 °C
Ahmed and Mahendrakar (1996)	*Cyprinus carpio Labeo Rohita, Catla catla, Cirrhinus mrigala*	autofermented	It was performed with 0.5% propionic acid, 2 % NaCl and 0.02 % ethoxyquin (8 days at 26±2 °C).
Hammoumi et al. (1998)	*Sardina pilchardus*	*L. plantarum* 5 %	The silage was incubated at 22 °C-20 days.
Zahar et al. (2002)	*Sardina pilchardus*	autofermented	Selected conditions were 7 days at 35 °C.
Valério Geron et al. (2007)	*Oreochromis niloticus*	*Lactobacillus (yogurt)*	It was evaluated chemical composition.
Ramírez Ramírez et. al. (2016)	*Peprilus snyderi, Sphyraena ensis, Trachynotus ovatus, Argyrosomus regius, Diplodus vulgaris, Bagre panamensis*	*Lactobacillus* sp.	Fermented condition18 % sugar cane molasses *Lactobacillus* sp. B2 (30 °C - 24 h) reach 1 x 10^9 CFU/mL.
Castro et al. (2018)	*A. punctatus*	*L. plantarum* sp. 47	Chitin extraction yielded: 6.9 % w/w by lactic fermentation (32 °C-60 h).
Shabani et al. (2019)	*Sardina pilchardus*	*B. subtilis (PTCC1156)*	Silages were done at 25 °C-15 days.
Davies et al. (2020)	Hole overfished sardines	*L. plantarum*	Silages were performed at 35 °C-7 days.

Table 2. Research that uses glucose, honey, sucrose and other carbohydrates in the production of biological fish silage.

Tabla 2. Estudios que utilizan glucosa, miel, sacarosa y otros hidratos de carbono en la elaboración de ensilados biológicos de pescado.

References	Raw material	Microorganisms	Carbon source	Detail
Bhaskar et al. (2007)	Shrimp waste	*L. plantarum*., *L. acidophilus*., *L. lactis P. acidolactici* and a mixed of the 4 strains.	Glucose 15 %	Selected conditions were 5 % *P. acidolactici* at 37 ±1 °C-72 h.
Llanes Iglesias et al. (2010)	*Oreochromis niloticus*	*L. acidophilus, Streptococcus thermophylus* 3%.	Honey	The silages were performed at room temperature for 7 days.
Kumar Rai et al. (2010)	*Rohu and Catla*	*P. acidolactici* y *E. faecium*. *Autofermentation*.	Dextrose 10 %	Silage for oil recovery from fish guts. About 85 % of oils were recovered after 3 days process at 37 °C.
Vázquez et al. (2011)	*Xiphias gladius*, *Raja clavata* and *Isurus oxyrhinchus*	*L. plantarum*, *L. buchneri, L. casei sub. casei, L. lactic sub. lactis, L. mesenteroides sub. mesenteroides* y *P. acidolactici*	Glucose (40 g L^{-1})	Biological fish silage to preserve waste from fish industry. Efficacy of several LAB as bio-silage inoculants. Selected conditions were 25 °C - 72 h.
Góngora et al. (2012)	*Merluccius hubbsi*	*Lactobacillus sp*., *Lactococcus* sp. and *Carnobacterium* sp.	Sucrose Glucose (25 -75 g L^{-1}).	*L. arizonensis* was selected for its efficiency in a wide range of temperatures (10 - 28 °C)
Nges et al. (2012)	salmon heads	-	*Heliantus tuberosus*	The study showed biodegradability of both fish sludge and fish waste, giving specific methane yields of 742 and 828 m^3 CH4/t VS added, respectively.
Góngora et al. (2018)	*Merluccius hubbsi*	*L. arizonenesis*.	Sucrose	Chemical and biological fish waste silage and its evaluation for BALB mice feeding. Silages incubation at 30 °C.
Libonatti et al. (2018)	*Cyprinus Carpio*	*W. paramesenteroides*	Sucrose 20 %	Recycled encapsulated LAB for use in the development of biological silage (30 °C-8 days).

Around half of the articles reviewed related to fish silage (23 articles) were conducted to the elaboration of biological silage as additive for animal feed, the rest were focused on other applications such as chitin, carotenoids, peptones extraction, oils recovery and methane production (Table 3).

Table 3. Applications of biological fermentation of fish waste.

Tabla 3. Aplicaciones de la fermentación biológica de residuos de pescado.

Applications	References
Ingredient for animal food	Ahmed and Mahendrakar (1996); Dapkevičius et al. (1998); Davies et al. (2020); Evers and Carroll (1996); Faid et al. (1994); Fagbenro and Jauncey (1994a); Fagbenro and Jauncey (1994b); Fagbenro and Jauncey (1995); Fagbenro and Jauncey (1998); Góngora et al. (2018); Gomez et al. (2014); Hammoumi et al. (1998); Inoue et al. (2013); Llanes Iglesias et al. (2010); Ramírez Ramírez et al. (2016); Shabani et al. (2019); Vidotti et al. (2002).
Chitin and carotenoid recovery	Bhaskar et al. (2007); Castro et al. (2018).
Oils recovery	Dapkevičius et al. (1998); Kumar Rai et al. (2010); Nges et al. (2012).
Methane production	Cadavid-Rodriguez et al. (2019); Nges et al. (2012).
Extraction of peptones to prepare an alternative culture medium to the commercial MRS medium	Vázquez et al. (2008).

Conclusions

This comprehensive review provides valuable insights into the potential of utilizing a range of carbohydrate sources, biological starters, and fish waste for fermentation processes. The findings highlight the feasibility of using fish waste for various applications, including the recovery of chemicals from fish biomass. By promoting the use of this sustainable technology, this work can help to advance the transition towards a circular bioeconomy and contribute to the scientific community's efforts to find eco-friendly solutions for waste valorization and resource recovery.

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