Food and Agriculture Organization of the United Nations

Fish silage production by fermentation

A manual on how microbial fermentation can turn fish waste into a valuable feed ingredient or fertilizer

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Contents

Preface

Fish, including shellfish, are highly nutritious and in much demand all over the world. However, fish processing by-products, in particular viscera (guts), are highly perishable. If not preserved or processed within a relatively short time after harvest, they may deteriorate rapidly making them unfit for human consumption or other uses. In many cases, processing leads to the removal of significant parts of the fish, such as the viscera, head, belly flaps and backbone. Depending on the species, these parts may represent between 30 percent and 70 percent of the fish. Some parts, such as gonads, belly flaps and backbones, may be used directly for human consumption, but most of the by-products of fish processing have traditionally been wasted, leading to negative environmental impacts, or they have been used in fresh form as feed for livestock or as fertilizers.

Most wild fish stocks are either fully exploited or overexploited and an increase in the supply of fish for human consumption must therefore mainly come from aquaculture. One of the great challenges in modern fish farming is a shortage of high-quality feed resources. Fishmeal and oil produced from small pelagic fish species used to be the main ingredients in fish feed. However, the rapidly growing fish farming industry and the increasing use of small pelagic species for human consumption mean that nutritious fishmeal and oil have become minor components in most fish feed. Although some fresh by-products of fish processing are preserved by conversion into fishmeal and oil, such production is energy demanding and requires large volumes of raw materials daily. An alternative is the preservation of the by-products of fish processing and fish that is not suitable for food by silage technology. This technology is simple and can be used on any volumes. It relies on lowering the pH to approximately 4 to prevent the growth of the microorganisms that spoil fish waste.

The process of lowering the pH requires the addition of an organic acid or a fermentable substrate and a bacterial culture which produce an organic acid. During the silage process, enzymes transform fish waste into a liquid mix of high-quality hydrolysed proteins, lipids, minerals and other nutrients which are easily digested and absorbed by terrestrial and aquatic animals. Fish silage has the potential to provide a source of animal feed that could make a difference in terms of: i) environmental impact by reducing levels of waste; ii) animal health by providing nutrients and bioactive components; and iii) economic gains because waste is converted into a valuable product that can replace expensive feed ingredients. In short, silage technology can ensure that more of fisheries and aquaculture resources are utilized and that they contribute indirectly to improved human nutrition and food security.

FAO previously published a manual on the production of silage from fish waste through the direct addition of a concentrated organic acid. However, organic acids may not be readily available in all countries. Therefore, this manual focuses on fish silage production by microbial fermentation.

Fish silage is a valuable feed ingredient with unique qualities that have been shown to improve feed qualities for pork, chicken and farmed fish. Recent research has shown that the inclusion of fish silage in feed increased the appetite and growth rates of terrestrial animals. It also contributes to the production of a stronger pellet, thus reducing feed losses caused by pellets dissolving or breaking prior to consumption. The organic acid in fish silage – either added directly or produced by microbial fermentation – has been found to have antibacterial properties that enable livestock to better resist disease and stress, thereby leading to reduced mortality and the potential elimination of the use of non-therapeutic antibiotics in animal feed. The free amino acids and peptides in the silage are pre-digested proteins and the presence of limited amounts in feed may result in improved growth. Due to the unique properties of fish silage, major fish feed producers for the aquaculture sector now replace 5 percent to 15 percent of fishmeal in their feed with fish silage or silage protein hydrolysate and silage oil. The advantages of using fish silage in pork and poultry feed are also well documented. Silage may also be used as a natural fertilizer for crop production.

Setting up a small-scale unit to produce fish silage does not require sophisticated and expensive equipment, nor highly advanced training. This manual will guide you through the main principles and explain each step of the fermentation process, helping you to successfully become a fish silage producer! You will also be shown how the final product can be stored and used as an ingredient for feed, or as a fertilizer.

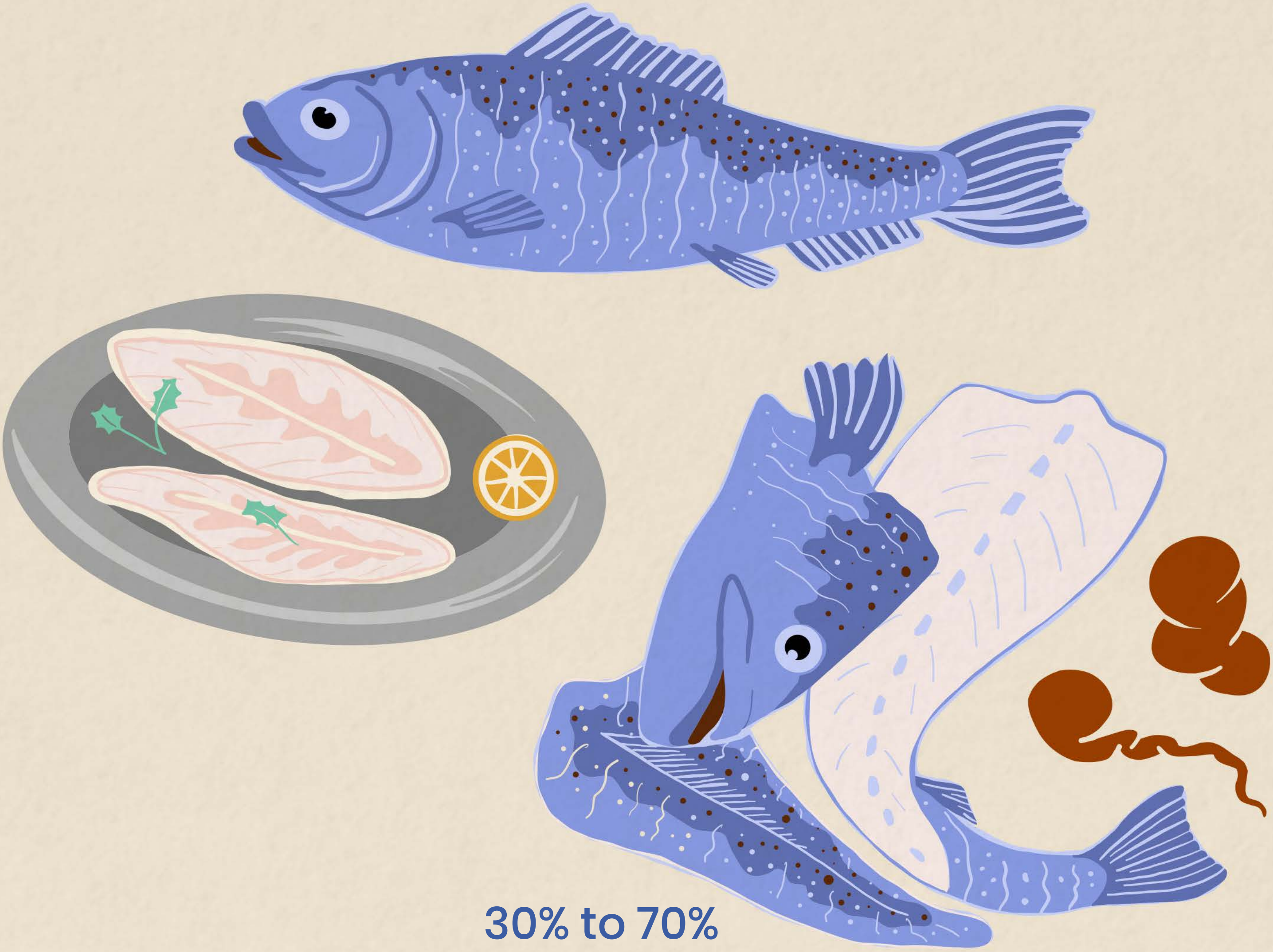
Acknowledgements

This practical guide is based on the manual Production and utilization of fish silage.[1] It aims to guide the reader through the main principles of making fish silage by fermentation, explaining each step of the process required to successfully produce fish silage.

Sincere thanks to Omar R. Peñarubia, FAO Fishery Officer, for reviewing the manual and offering suggestions for its improvement. FAO is also grateful to the Norwegian College of Fishery Science at UiT The Arctic University of Norway for assistance with the preparation of this manual. Thanks also to Claire Ward for editing the text and Zoe Brandizzi for the graphic design of the manual.

We are grateful for the financial assistance provided by the project "Responsible use of fisheries and aquaculture resources for sustainable development" funded by the Norwegian Agency for Development Cooperation, which allowed us to complete this manual.

[1] FAO. 2018. *Production and utilization of fish silage. A manual on how to turn fish waste into profit and a valuable feed ingredient or a fertilizer*. Rome. www.fao.org/3/i9606en/I9606EN.pdf


30% to 70%


feed


fertilizer

1. FISH SILAGE

Fish by-products

Fish processing results in a significant amount of by-products, in most cases representing between 30 percent and 70 percent of the fish. Ideally, a bigger share of the fish should be utilized as food, but in reality, huge amounts of raw material never make it to our tables. At large, industrial fish processing units, fish by-products are often processed into fishmeal and fish oil, but at small-scale processing units, investing in a fishmeal plant is not economically viable. In such cases, preservation of the fish by-products by acid silage could be a simple and inexpensive alternative. The silage process preserves the fresh fish by-products and creates a product that can be stored for longer periods and serve as an excellent feed ingredient.

What is fish silage?

Fish silage consists of minced fish by-product or minced whole fish not suitable for human consumption, plus an added preservative to stabilize the mixture. Most commonly, the preservative used is a concentrated organic acid such as formic acid. When organic acids are not readily available, an alternative is to add a fermentable carbohydrate and a lactic acid-producing bacterial starter culture to the minced fish. The bacterial culture will produce the organic acid (lactic acid) and lower the pH of the minced fish by-product.

Proteolytic enzymes, mainly from the fish guts but also from the bacterial culture, active in an acid pH range, will break down proteins into peptides and amino acids, through an autolysis process. This will leave a liquid solution rich in low molecular nutrients and, depending on the fat content of the raw material, an oil phase.

Why make fish silage?

Fish silage is a liquid solution in which proteins are pre-digested and have a nutrient composition similar to fishmeal. The process to produce fish silage is simple and does not require large investments. The product can be preserved for long periods, even years. Because the silage is in liquid form, it can easily be pumped into storage tanks or be transported by road or sea. By making silage, a waste problem can be converted into profit and contribute to the circular economy.

How to make fish silage

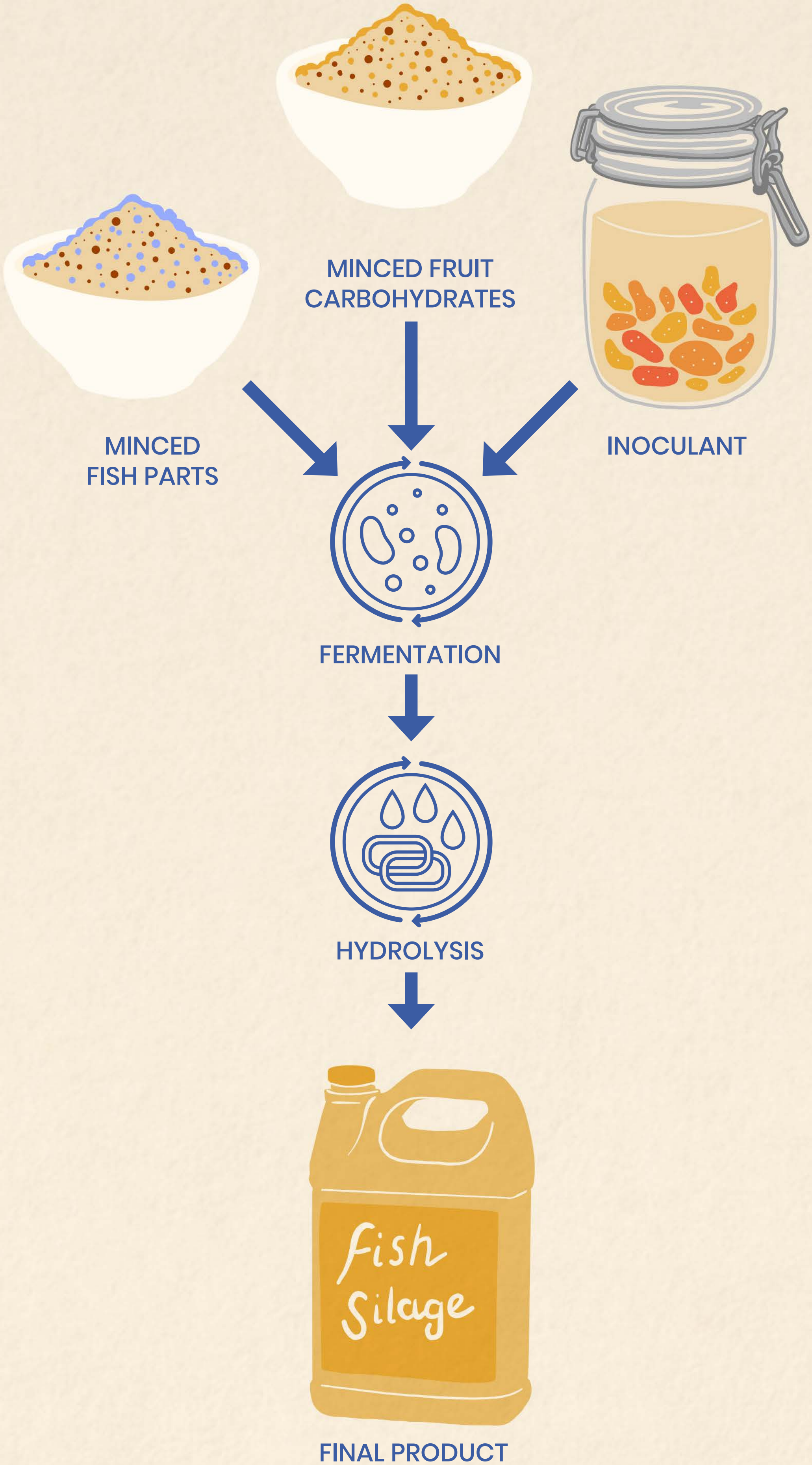
The raw material for silage production should be as fresh as possible. You will never make a good silage based on bad or deteriorating raw material! The raw material, usually minced fish by-products, can be preserved by an acid-producing bacterial culture. To ensure the efficient preservation of the product, the raw material must be minced and mixed with fruit waste, or another source of sugar, and an acid-producing bacteria (the inoculant) must be added. The final mixture should have a pH of around 4.4 (similar to the pH of yoghurt) to prevent the growth of spoiling bacteria. At this pH, enzymes from the fish guts and the lactic acid-producing bacteria will break down the fish waste through protein hydrolysis, resulting in a highly nutritious liquid product.

Raw material for silage production

Silage can be used as a preservation technique for many types of raw material. It is used for preserving several crops such as maize, sorghum, grass and other types of fodder. Producing fish silage follows the same principles, but also includes hydrolysis of the proteins because of the proteolytic enzymes present in fish guts.

Any whole fish or parts of a fish can be used for fish silage. In most cases, fish by-products generated by fish processing will be the most appropriate raw material for silage production. The viscera (guts) of the fish should preferably be included to ensure that sufficient enzymes active at an acid pH range speed up the hydrolysis of the proteins in the minced by-products.

The raw material to be used as a basis for fish silage should be fresh and raw and production should preferably begin soon after the fish has been processed. High quality silage can only be made from high quality raw materials. If the raw material is of low quality, the silage will likely not be suitable for feed purposes but it can eventually be used as fertilizer.


MINCED FRUIT
CARBOHYDRATES
MINCED
FISH PARTS
INOCULANT
FERMENTATION
HYDROLYSIS
Fish
Silage
FINAL PRODUCT

2. MAIN PRINCIPLES FOR FISH SILAGE PRODUCTION

Preservation

Converting fish waste or by-products into silage, preserves the raw material and increases the bioavailability of the nutrients. This means that fish silage is an excellent way to reduce waste and, at the same time, convert it into a valuable product, both in terms of nutrition and profit. The first step in silage production is to preserve the raw material. This is done by grinding the fish and parts of the fish into small sized particles. Then, an acid is added – directly or indirectly through fermentation – to reduce the pH and ensure that the product is preserved. The fermentation process is used to produce an organic acid rather than adding it directly.

Enzymatic degradation

Producing fish silage is not only a preservation method. Fish silage becomes a mix of hydrolysed fish protein and micronutrients. Enzymes, mainly from the digestive system of the fish but also from the growing bacteria, break down the proteins into peptides and amino acids. This makes the nutrient in silage highly bioavailable and easy to digest for animals that have silage in their feed. The acidic environment of a pH of around 4.4 is ideal for the fermentation and enzymatic degradation of the fish waste. The temperature in the silage will impact the time it takes to hydrolyse the proteins. Temperatures should ideally be between 5 °C and 40 °C. Lower temperatures slow down the process and very high temperatures will inactivate the enzymes. In tropical climates, the entire process of hydrolysing the proteins will only take a few days.

Particle size

To ensure the mixture is properly preserved, the fish must be ground into particles that are small enough to ensure the acid can penetrate the minced tissues (ideally less than 1 mm). If particle size is too large, the inner part of the particle might start to rot and affect the quality of the whole batch of silage.


PROCESSING
WASTE COLLECTION
GRINDING FISH BY-PRODUCTS
GRINDING FRUIT CARBOHYDRATES
STIR THE MIXTURE
INOCULANT
FERMENTATION
STORAGE

3. PRODUCTION OF SILAGE BY FERMENTATION

Why fermentation?

Organic acids are not always readily available, but they can be produced through fermentation. Producing silage through fermentation uses bacteria to generate the acid required to complete the process and ensures the final product can be stored at ambient temperature. The following section details the steps required to produce silage by fermentation. The steps involve the production of a starter (inoculant) with the ideal bacteria for fermentation and the addition of sugar to feed the bacteria. The bacteria will convert the sugar into lactic acid which is an organic acid that can preserve the product.

Preparation of inoculant/starter

The starter, or inoculant, is a solution with a high concentration of the bacteria required to kick-start the fermentation process in the mixture of ground fish parts and carbohydrate (sugar). The bacteria exist in the environment.

Water:	500 ml
Fruit in pieces (or other source of sugar):	500 ml
Salt (NaCl):	25-50 g (1.5 to 3 tbsp)

Salt is added to improve conditions for the growth of the ideal bacteria that are present in the environment and to inhibit the growth of spoilage microorganisms.

Mix and allow to ferment at 30 °C to 35 °C for one to two days. If you can measure pH, it should be around 4.0 when ready. The mixture should have a pleasant but acidic smell.

As an alternative, you can include yoghurt in the starter.

Sources of sugar

You can use any source of sugar but a source that is not used for food purposes, such as fruit waste or molasses is recommended.

Adding carbohydrates (sugar) and inoculant

Mix the ground fish waste and the source of sugar with the inoculant. The mixture should have more than 5 percent sugar to ensure proper fermentation.

Fruit waste should have at least 10 percent sugar. This means the mixture of fish to fruit should be 50/50: one part fish waste and one part fruit waste.

If the sugar content is higher, less fruit waste will be needed.

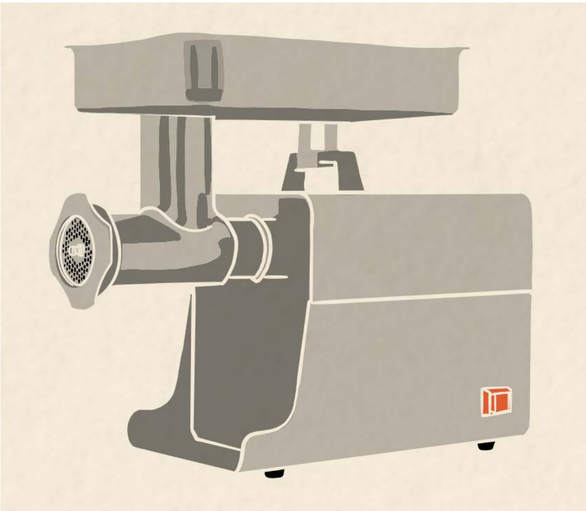
Molasses from sugar production contains between 50 percent and 75 percent sugar. If molasses is used as a source of sugar, 10 percent to 15 percent molasses should be added to the ground fish mixture.

4. EQUIPMENT

The equipment used for silage production is not very sophisticated, but regular checks, cleaning and maintenance is required to ensure good quality silage and a cost-efficient process. The equipment used can range from small, low-cost manual units to bigger and automated plants.

Grinder

The first step in the production process is to grind the product. If volumes are small, this can be done with a manual meat grinder. For bigger volumes, an electric grinder will be necessary. It is important for the grinder to produce particles that are small enough to enable the preservative (acid) to enter the heart of the particle. Ideally, maximum particle size should be less than 1 mm.



Pump

Pumps can be used to move silage from one place to another, for example from a production tank to a storage tank. Pumps can also be used to circulate the product to ensure all fish particles are exposed to the acid and enzymes that transform the fish into silage. In many cases a grinder pump is used so that the job of grinding and pumping is completed in one operation. Grinder pumps are typically used to treat sewage, but they can be used for silage purposes. However, to ensure the pump can resist long-term exposure to low pH levels, more expensive grinder pumps may be required and these are available.

Mixing tank

In batch production, which is the most realistic for small-scale producers, the grinding of the fish and the sugar containing component can be done in the mixing tank. When the enzymes have done their job in breaking down the fish into a liquid and the bacteria have produced enough acid, a stable soup of hydrolysed proteins exist if the pH is stable at around 4.4. In tropical climates, this process will take only a week or two. In colder climates the process is longer. The mixing tank should be made of an acid-resistant material such as plastic, fibreglass or stainless steel.

Daily mixing is required until the enzymatic process is complete and pH is stable. This can be done with a pump, or even by stirring the tank with, for example, a wooden paddle.

The pH must be controlled and eventually corrected daily by adding more fruit waste/sugar, until it is stable. pH control can be done with a pH-meter, or by using litmus paper. This is a more cost-effective option for checking the pH and is a good option.

Storage tank

Although the product in the storage tank is supposed to be stable, the pH should be checked regularly, for example, every week. The content of the storage tank should also be circulated regularly to avoid a rotting process taking place in pockets of the tank. The material used for the storage tank should be resistant to corrosion and could be plastic, fibreglass or stainless steel. Galvanized materials should not be used because this could lead to the release of toxins into the silage.

Batch production

For a small-scale fish silage unit, batch production is most realistic. The raw material, acid and eventually an antioxidant are added to a tank in which all ingredients are minced or mixed in one process. Fresh raw material can be added to the tank until it is three-quarters full. When the pH in the mixture is stabilized after a couple of weeks, it can be pumped into a storage tank, if required.

5. QUALITY

Quality control

The first step in ensuring a good quality silage is to check the quality of the raw material; it should be as fresh as possible. The raw material must be minced, then mixed with the fruit waste and the starter as soon as possible. Control the pH so that it moves down to around 4.4 during the first one to two days of the process. After the pH is stable at around 4.4 in the storage tanks, it should be checked regularly, for example every week, and eventually corrected by adding more fruit waste.

Potential problems

Silage production is a relatively simple process if procedures and quality controls are strictly followed. However, variations in the raw material might lead to some challenges. If the raw material is of bad quality, it can impact the quality of the whole batch of silage. A large number of bones can neutralize the acid to some extent, raising the pH to levels that could lead to a rotting process. Bones that do not dissolve will sink to the bottom of the silage tank. If the bones settle in the tank, they should be removed regularly to ensure the quality of silage in the tank.

6. STORAGE OF SILAGE

Shelf life

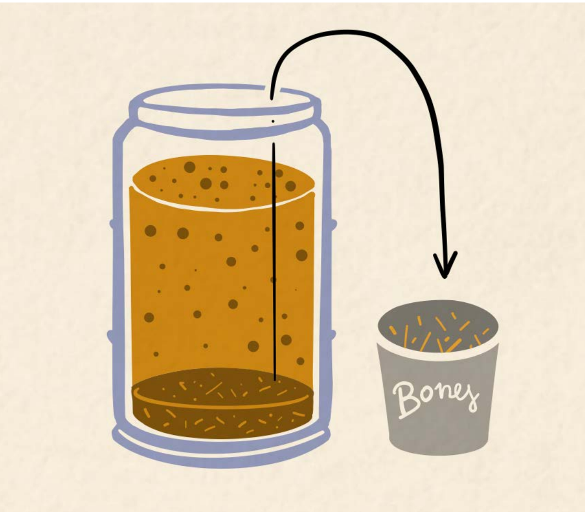
If procedures are followed, fish silage can be stored for long periods without any significant reduction in its nutritional quality and safety. Regular stirring of the silage and pH control are essential and correction may be needed. Studies have shown that levels of some amino acids (e.g. tryptophan) might be slightly reduced in the silage during storage.

Quality assurance

Regular control, maintenance and cleaning of equipment is important to ensure the safety of workers and the good quality of the product. Regular stirring and pH control and/or correction of the product are essential.

Separation of oil

Especially in warmer climates, the fat/oil will float on top of the silage. If no antioxidant is added, this oil will easily go through an oxidation process, impacting on the quality of the silage. Oil should be separated from the rest of the silage. This is most easily done through decantation: leave the silage without mixing for a while and allow the oil to separate from the aqueous phase, then it can be easily separated and removed to another tank. If an antioxidant is used, it should be added when acid is added to the mix to ensure a good quality oil. This oil is a good feed ingredient, particularly in aquaculture feed.

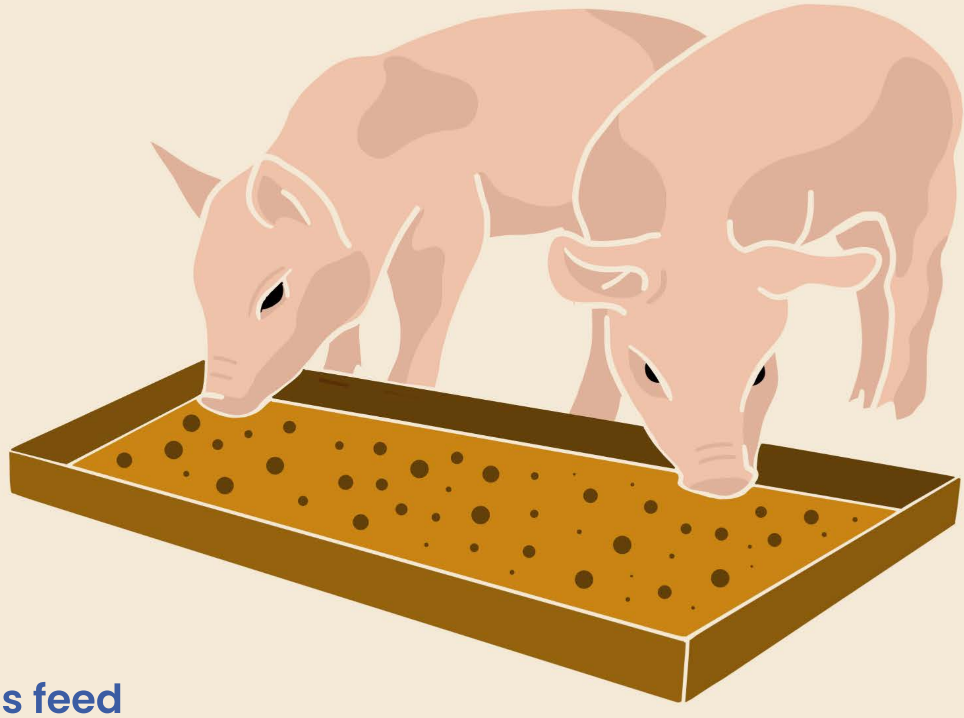


Separation of bones

High numbers of bones or crustacean shells in the raw material will usually lead to increased consumption of acid to reach the recommended pH level. Therefore, in some cases bones are separated from the silage, both to reduce costs and to avoid any problems caused by pockets of high pH in the silage. In other cases, where bones are not removed, they settle at the bottom of the storage tank if the circulation of the product is limited. These bones should be removed from the tank on a regular basis, but precautions should be taken by workers who enter storage tanks for the purpose of clean them. Residual gases could lead to reduced levels of oxygen in the tanks and create dangerous situations for workers if ventilation in the tank is poor.

7. UTILIZATION OF SILAGE

Fish silage is a nutrient dense product ideal for feed purposes, or for eventual use as a fertilizer. In practice, the nutrient composition is the same as the raw material used for silage production and comparable to the nutrient composition of fishmeal on a dry matter basis. Fat-free fish silage will therefore typically have a moisture level of close to 80 percent, a protein level of around 15 percent and an ash level of less than 4 percent. If a drier product is required, the silage may be evaporated. Fish silage has similar nutritional properties to fishmeal, but it is more easily digested by animals because of its hydrolysed proteins. In addition, the organic acid in the silage, which acts as a preservative, has antibacterial properties which are very beneficial for the gut microbiota of the silage-fed animal.



Directly as feed

Due to a relatively low acidity (high pH in the acid range), fish silage can be fed directly without any prior mix or treatment. Fish silage has been successfully included in the daily diet of pigs, resulting in higher growth rates, improved health and reduced mortality.

Mixed with other feed ingredients

Fish silage can also be mixed with other feed ingredients such as grains. Following the inclusion of silage, the mix can be fed directly to livestock as a wet feed. The feed will not require further processing, but it will retain all the nutritional and health benefits of including fish silage.

Use in pellet production and extruded feeds

It is recommended that fish silage partially replaces fishmeal or other protein sources in feeds. Due to its hydrolysed proteins, the silage has a high level of free amino acids and peptides, which have been shown to improve growth performance. Use of fish silage for extruded feeds is well documented with good results. The silage can replace part of the fishmeal (typically 5 percent to 15 percent) and will partially replace the water added to the mixture before extrusion. The inclusion of silage has also been shown to produce pellets that are stronger and more resistant to physical degradation. A stronger pellet reduces waste because it minimizes losses to dust during transport and feeding.

Fertilizer

If it does not meet the quality requirements for animal feed, silage might be used as a fertilizer. Fish silage is a good source of nitrogen (from the protein), phosphorus, potassium, calcium, magnesium (particularly from the bone structure) and most trace elements required by plants.

The application of fish silage as a fertilizer can be done as part of the irrigation process by directly adding between 5 percent to 10 percent liquid silage to irrigation water. The nutrient composition of the silage may vary depending on the raw material used. For instance, if the number of bones is high, levels of phosphorous and magnesium will be higher.

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