Waste minimization of fishery industry in Muara Angke, Jakarta: a comparison of chemical and biological silage processes

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Abstract. Rising environmental concerns on climate changes are causing an increasing attention on reducing wastes dumped to the landfills. As Indonesia’s marine fishery industry is in developing stage in its capacity and production systems which consequently increases generation of wastes. Approximately 25-35% of fish production will ultimately become residue or waste due to the unsophisticated technology of fish storage and processing facilities. Most of their wastes dumped in landfills which subsequently impact the environment. Waste minimization program like upcycling waste into the more useful product can be an option for not only dumping wastes dumped into the landfill but also subsequently reducing greenhouse gas emissions such as CO₂ and methane. This study evaluated the biological and chemical processes of fish silage production using various additives, including molasses as a carbon source and formic acid.

Experiments were conducted in five anaerobic reactors containing 10 kg of fish waste each; the observation period was 40 days. The results indicated that adding molasses (10%, 15%, and 20% in volume) and *Lactobacillus plantarum* to fish waste significantly influenced pH and water/ash content. On average, the silage process reduced around 38% of fish wastes dumped in a landfill.

1. Introduction

Rising environmental concerns on climate changes are causing an increasing attention on reducing wastes dumped to the landfills. As Indonesia’s marine fishery industry is in developing stage both in its capacity and production systems. National production on fisheries in 2012 reached 15.5 million tons—worth 155.3 trillion Indonesian rupiahs (about USD 12 billion). In the Jakarta Fishery Auction House in 2012, fisheries produced about 220,000 tons valued at 2.7 trillion Indonesian rupiahs (about USD 210 million) [1]. Unfortunately, an estimated 25-35% of the products ultimately became residue or fish waste, mainly because of market absorption that fell below production, unsophisticated technology associated with fish storage, and limited nearby fish processing facilities [2][3].

Marine fish waste usually consists of heads, entrails, and fins, as well as damaged fish from canny industries, fish auction houses, or markets. Most of these wastes dumped in landfills which subsequently impact the environment such as water, land, and air and emit different types of air pollutants including CO₂ and methane. Substantial greenhouse gas emissions such as CO₂ and methane can be reduced through waste minimization program like upcycling waste into the more useful product. A promising process to minimize fish waste dumped into landfill involves producing fish silage for animal feed. Fish silage is a liquid product made from the whole fish or part of a fish and the addition of acid (chemical process) or lactic-acid producing bacteria (biological process). These microbes activated through the
addition of material containing supplements high in carbohydrates. As an inoculant, *Lactobacillus plantarum* causes a rapid decrease in the pH value of silage and produces a high amount of lactic acid [4]. To stabilizing silage in liquid form, a thickener is added for easier packing, storing, and handling. Good quality silage can be used as animal feed to improve the health of livestock with increased weight and production of milk [5]. Compared to other animal feed, fish silage has many advantages, such as low investment costs, simple technology, and virtual insensitivity to weight scales in the production process. Because of the high volume of the gross product, a relatively low additional drying cost is needed [6].

This study explores the suitability of biological and chemical processes for producing fish silage using additives, including molasses as a carbon source and formic acid. Samples of fish wastes are collected from Muara Angke, Jakarta, fish waste is dumped in several locations, including in the fishery auction house and at the processing unit. No integrated fish waste treatment facilities in either location have caused stench, sanitation problems, or environmental pollution. Nowadays, approximately five tons/day of fish waste is dumped in Muara Angke, and only a small amount of waste is processed as animal feed through the traditional process of sun-drying and grinding into flour. This process is challenging because of the low quality of the product, which becomes even worse during the rainy season when the time is limited for traditional sun-drying. Many previous waste minimization initiatives have been taken into account not only in Indonesia but also in other countries to reduce wastes dump into the landfill but also protect the environment such as reducing the greenhouse gasses emissions and adds value to discarded materials such as fish waste [7].

2. Material and methods

2.1 Fish waste

The fish waste used in this research mostly consisted of heads and entrails of tuna (*Aurius thazard*), which are abundant in traditional fish markets in Muara Angke. During the experiment, fish waste was weighed, grinded, and incubated at 30°C in five anaerobic reactors referred to as A, B, C, D, and E (Table 1). The mixture in each reactor was stirred occasionally to maintain desired uniformity.

| Treatment | Unit | A Without any treatment | B 10% molasses | C 15% molasses | D 20% molasses | E 3% formic acid |
|-----------|------|-------------------------|----------------|----------------|----------------|-----------------|
| Fish waste | kg   | 10                      | 10             | 10             | 10             | 10              |
| Molasses  | kg   | -                       | 1.0            | 1.5            | 2.0            | -               |
| *Lactobacillus plantarum* | L    | -                       | 2.0            | 2.0            | 2.0            | -               |
| Formic acid | mL   | -                       | -              | -              | -              | 300             |
| Aquades   | L    | 4.0                     | 1.0            | 0.5            | -              | 3.7             |

2.2 Lactic Acid Bacteria

*Lactic acid bacteria* (hereinafter, LAB) was utilized as a starter in the fermentation process to ferment glucose into lactic acid [8][9]. During this study, *Lactobacillus plantarum* was used to produce acid rapidly, thereby preventing the growth of undesirable microbes.

2.3 Molasses

Molasses used in this study was made by a local company —Rajawali Nusantara Indonesia— with composition presented in Table 2 as follows:
Table 2 Variations in molasses composition

| Parameter          | Value                  |
|--------------------|------------------------|
| Total sugar as invert (TSAI) (%) | 57.85–62.80           |
| Brix pol (%)       | 80.75–87.20           |
| Density            | 1.43                   |
| Lignin (%)         | 0                      |
| Texture            | Viscous, sweet         |

2.4. Lactic acid bacteria (LAB)
Lactic acid bacteria (hereinafter, LAB) was utilized as a starter in the fermentation process to ferment glucose into lactic acid [8][9]. During this study, *Lactobacillus plantarum* was used to produce acid rapidly, thereby preventing the growth of undesirable microbes.

2.5. Data and data processing
Five variations in silage characteristics were analyzed for their physical, chemical, and microbiological qualities. Data analyses and processing were conducted through descriptive and quantitative analyses. Analysis regarding the strength of the functional relationship of parameters was conducted with ANOVA to test their correlations and differences; Tukey’s test was used for the post hoc assessment.

Table 3. Details of parameters and testing procedures

| Parameter        | Procedure          | Parameter  | Procedure          |
|------------------|--------------------|------------|--------------------|
| Color            | Visual observation | TMA        | SNI 2354.8-2009    |
| Odor             | Sense of smell     | Fat content| SNI 01-2354.3-2006 |
| pH value         | SNI 06-6989.11-2004| Protein content| SNI 01-2354.4-2006 |
| Temperature      | SNI 06-6989.11-2004| TPC        | SNI 01-2332.3-2006 |
| Water content    | SNI 01-2354.2-2006 | *Salmonella*| SNI 01-2332.2-2006 |
| Ash content      | SNI 2354.1:2010    | *E. coli*  | SNI 01-2332.1-2006 |

2.6. Formic acid
Formic acid, or HCOOH or CH₂O₂, is a colorless, water-soluble liquid, as well as the simplest carboxylic acid. When reacting with alkali or alkaline, formic acid forms a salt and becomes a strong reducing agent. Bactericidal properties of the formic acid act as preservatives. During this study, 98–100% of formic acid made by Merck was added to the E reactor.

3. Results and discussion

3.1. Silage characteristics: physical, chemical, and microbiological analyses
Table 4 summarizes the results from the observation of silage produced through biological processing (reactors B, C, and D) and chemical processing (reactor E). The 40-day observation showed that silage in five reactors had gradations in color from light brown to brown; the odor gradually deteriorated and became rancid soon after; and the temperature in all five reactors varied from 24.5°C to 25.3°C. This change most likely caused by the decay of fish waste, which produces a high amount of ammonia and trimethylamine. Meanwhile, in reactors B, C, D, and E, the silage’s sour smell was detected beginning on day 1, and it became stronger for the remaining observation period (40 days).

Microorganisms contributing to the fermentation process are dominated by lactic-acid, propionate-acid, and acetic-acid forming bacteria, as well as yeast and mold [10]. In the chemical process, the addition of 3% formic acid in the E reactor helped lower the pH. Meanwhile, in the A reactor, the sample without any treatment retained a nearly neutral pH which could easily promote the growth of decomposing bacteria. These results are similar to those in Shaw’s study of the fermentation process conducted on intestines of livestock in which effects of the addition of molasses [11]. The decrease in
higher additions of molasses in reactors B, C, and D resulted in increases in ash content because the addition of LAB broke down molecules in molasses, creating more minerals in the decomposed fish waste and carbohydrates [3][12]. Previously, production of silage from sardine waste to which molasses added produced similar results in increasing ash content [13]. Ash is composed of minerals such as calcium (Ca), magnesium (Mg), and others that increase the nutritional content of silage. Reactor E had a continuous increase in water content because of the organic acid treatment. Tukey’s test showed that the ash content of silage in reactors B, C, and D differed significantly from that in reactors A and E.

Table 4 Silage characteristics on day 40

| Parameter          | Unit | Name of Reactor |
|--------------------|------|-----------------|
| Color              | -    | Brown           |
| Odor               | -    | Brown           |
| pH                 | -    | Brown           |
| Temperature        | °C   | Brown           |
| Water content      | %    | Brown           |
| Ash content        | %    | Brown           |
| TMA                | mgN 100g⁻¹ | Brown |
| Fat content        | %    | Brown           |
| Protein content    | %    | Brown           |
| TPC                | cfu/mL | Brown          |
| E. coli            | -    | Positive        |
| Salmonella         | -    | Positive        |

Trimethylamine (TMA) is an organic compound which often utilized as an index of marine fish damage since it formed from the decomposition of lipoprotein compounds [4]. In this study, the initial TMA level in fish waste before processing was 9.2 mg 100 g⁻¹. On day 40, it varied from 3.5 mg 100 g⁻¹ to 184.1 mg 100 g⁻¹ for silage in reactors A, B, C, D, and E.

The initial fat content of fish waste was 3.0%, during the experiment. And on day 40, the silage in reactors A, B, C, D, and E contained fat ranging from 1.0% to 2.2%. The lowest fat content (1.0%) was in reactor E on day 40, whereas the highest (2.2%) was in reactor A on day 10. The formic acid added in the silage production process helped to decompose complex fat molecules into simpler molecules so that it could proportionally decrease the fat content [11].

The protein content for the five silage samples varied from 8.0% to 10.7%, lower than the protein content of the fish waste. Similar results also observed in the biological and chemical silage production processes [9]. In this study, chemical silage production resulted in more protein than biological production. Silage in reactor A had the lowest protein content on day 40 (8.0%), whereas the highest was in reactor E on day 40 (10.7%). The decreasing protein content of silage in reactor A occurred because the neutral pH level provided a good environment for its decomposition. The protein content of silage in reactors B, C, D, and E increased in conjunction with low pH levels; hence, the protease enzyme produced by bacteria increased protein biosynthesis [14].

The TPC of silage in reactors A, B, C, D, and E decreased during the experiment. However, it is possible that contamination occurred on day 20, causing a TPC increase but then a decrease until day 40. The TPC in B, C, and D with the addition of molasses correlated with LAB. A higher LAB indicated
greater production of lactic acid, thereby decreasing the pH levels in the mixture. Similar conditions occurred in reactor E with the addition of 3% formic acid during silage production: the pH level decreased, which, in turn, reduced the number of bacteria significantly.

In food microbiology, *E. coli* known as the sanitation indicator bacterium. In this study, negative results regarding the presence of *E. coli* were reported for silage in B, C, D, and E, whereas the result was positive for silage in A. This finding is probably associated with the addition of formic acid and LAB, which inhibited the growth of *E. coli*. Test results for *Salmonella* in silage in B, C, D, and E were negative, whereas the result for silage in A was positive (Table 4). Good silage must be free of pathogenic bacteria, such as *Salmonella*. On average, the silage residue on day forty was 38% of the total weight of silage produced. Such residue becomes the ultimate fish waste for dumping in the landfill.

The Tukey’s test showed that fish waste processing with the addition of molasses (10%, 15%, and 20%) and *Lactobacillus plantarum* resulted in significant differences in pH levels and water/ash content compared to waste supplement with 3% formic acid. However, differences were not significant for temperature, TMA, TPC, and fat and protein content. On average, the silage residue on day forty was 38% of the total weight of silage produced. Such residue becomes the ultimate fish waste for dumping in the landfill.

4. Conclusions and recommendations

Most of the fish wastes dumped in landfills which subsequently impact the environment such as water, land, and air and emit different types of air pollutants including CO$_2$ and methane. Waste minimization program like upcycling waste into a more useful product can substantially reduce greenhouse gas emissions such as CO$_2$ and methane. Production of silage from fish-waste can be achieved through chemical and biological processing. During this study, silage production through biological processing involved the addition of molasses in concentrations of 10%, 15%, and 20%, along with *Lactobacillus plantarum*. The biological silage production has similar quality compared to that formed by chemical processing.

Tukey’s test indicated that biological processes using the addition of molasses produced significant differences in pH value, water content, and ash content compared to the chemical processes. However, differences were not significant in temperature, TMA, fat and protein contents, and TPC. On average, silage production can be expected to reduce around 38% of fish waste dumped in the landfill.

Further studies on the quality of silage after storage and the impact on livestock are needed. A stable product needs solid guarantees since the feedstock comes from waste fish. In the production process, economic benefits and availability of materials added must be considered. The cost of acid is about 25% of the sales price of silage [11] [14]. To reduce the price, it is possible to reclaim up to 50% of the acid when concentrating the silage. Silage production can minimize 38% of fish waste dumped in the landfill. Nevertheless, on a laboratory scale, silage production would be cost-effective only with the addition of low concentration of formic acid. In addition, further experiments should be carried out in order to study the possibility of incorporating the fermented material into animal fodder.

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