

Optimizing the Co-Composting of Fish By-Products With Biochar-Enriched Agricultural Residues: Process Dynamics and Nutrient Transformation

Ngo BaoKhoa

baokhoa0905@gmail.com

VNU-HCM High School for the Gifted <https://orcid.org/0009-0007-0409-1391>

Do Tran Khanh Ngoc

VNU-HCM High School for the Gifted <https://orcid.org/0009-0001-8742-6834>

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Abstract

At many small-scale local markets, fish by-products are often disposed of using inefficient and unscientific methods such as unsanitary landfilling, open burning, or improper composting. These practices release NH_3 and H_2S , which negatively affect community life, as well as CH_4 , a greenhouse gas that contributes to climate change. Therefore, various methods have been developed to utilize fish by-products, such as processing them into collagen, thermal processing to produce fish oil, or fish meal. This study aims to evaluate the effectiveness of using a microbial consortium consisting of *Trichoderma* sp. fungi, *Bacillus* sp. bacteria, and *Streptomyces* sp. actinomycetes to compost fish by-products into organic fertilizer. The composting process was carried out with a substrate composed of coconut coir, rice husk ash, and biochar, mixed with fish by-products at a 1:1 ratio. The monitored parameters included temperature, odor, moisture, porosity, pH, C/N ratio, and nutrient composition, analyzed using Kjeldahl, MBM, and FAES methods. The expected outcome is that a 50% substrate and 50% fish by-product mixture will produce compost with an optimal C/N ratio and aeration for plant growth. The significance of this study lies in identifying the most suitable substrate-to-by-product ratio in combination with specialized microbial groups to compost fish by-products into organic fertilizer. From this, a standardized formula can be developed to create convenient composting kits, contributing to sustainable agriculture.

Introduction

Compost is the product of the biological decomposition of organic matter under controlled thermophilic conditions, designed to eliminate pathogens, weed seeds, and produce organic fertilizer that meets soil application standards (Haug, 1993). Compost plays an important role in sustainable agriculture, helping to improve soil structure, increase fertility, and maintain beneficial microbial communities, while reducing dependence on chemical fertilizers that can cause long-term soil degradation. At the same time, compost contributes to reducing the amount of organic waste that must be landfilled, especially in the context of Vietnam generating about 60,000 tons of household waste per day.

The composting process can be enhanced by microorganisms such as *Trichoderma* sp., *Bacillus* sp., and *Streptomyces* sp. These strains not only decompose organic matter and generate heat to kill pathogens, but also act as biological antagonists against harmful microorganisms. Substrates such as coconut coir, rice husk ash, and biochar help create an aerated environment, retain moisture, and support microbial activity.

Literature Review

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Hypothesis

It is hypothesized that Treatment 4 (NT4), characterized by a balanced 1:1 ratio of fish by-products to biochar-enriched agricultural residues, will exhibit the highest composting efficiency and yield a superior quality organic fertilizer compared to other treatments. This prediction is based on the biological principle that a balanced proportion of nitrogen-rich fish waste and carbon-rich structural substrates provides the optimal physical and chemical environment for thermophilic microbial activity.

The biological rationale for this hypothesis is centered on the optimization of the microbial environment. A 1:1 ratio is expected to provide sufficient carbon to offset the rapid nitrogen release from fish viscera, thereby maintaining a favorable carbon-to-nitrogen balance for microbial metabolism. Physically, the inclusion of the agricultural substrate is expected to regulate moisture levels; it prevents the mixture from becoming overly saturated and compact, which would otherwise lead to anaerobic conditions and foul odors. By ensuring adequate porosity and aeration, this specific mixture should facilitate a more robust thermophilic phase, allowing the inoculated microbial consortium to decompose organic matter more effectively than treatments with higher concentrations of fish waste.

Methods

The experimental procedure involved the collection of fish by-products (heads, bones, viscera) from An Dong, Cay Sot and An Suong markets over a five-day period. Samples were preserved under cold storage conditions and subsequently transported to the Experimental Farm of Nong Lam University, Ho Chi Minh City, where they were homogenized using specialized grinding equipment. The composting substrate was prepared from coir, rice husk ash, and biochar in a 45:45:10 ratio, supplemented with 0.3% microbial inoculants (*Trichoderma* sp., *Bacillus* sp., *Streptomyces* sp.), and mixed on July 17. Five treatments were established with varying proportions of fish by-products and substrate, each comprising 8 kg of material, incubated in foam boxes covered with cloth to minimize odor, with continuous monitoring of temperature and periodic measurement of mass.

Nutrient analyses included pH determination (TCVN 13263-9:2020), moisture content (TCVN 9297:2012), nitrogen quantification via the Kjeldahl method (TCVN 8557:2010), and organic carbon assessment using the Walkley–Black method (TCVN 9294:2012). Temperature data were processed using Excel and

represented as line graphs, while mass was recorded at six-day intervals to evaluate decomposition-related losses. In addition, the composting mixtures were manually turned every 5–6 days to enhance aeration and homogenization. Sensory evaluation of odor intensity was conducted using a 10-point scale, where 1 indicated mild odor and 10 represented extremely strong odor.

Result and Discussion

In the study of composting fish by-products combined with different substrates, the team monitored temperature changes across five treatments (NT1–NT5) from July 18 to August 21. Results showed that temperatures fluctuated strongly in the early days, then gradually decreased and stabilized toward the end of the period. NT4 (yellow line) recorded the highest temperatures, frequently exceeding 60°C, indicating a significantly hotter environment compared to the other treatments. NT3 (gray) also maintained high temperatures, fluctuating around 50–60°C. Meanwhile, NT1 (blue) and NT5 (light blue) had the lowest and most stable temperatures, only around 28–35°C. NT2 (orange) was intermediate, ranging from 35–45°C. Sudden drops in temperature were explained by the removal of equipment for turning, which caused inaccurate system readings. After turning, temperatures rose again due to the creation of aerobic conditions that allowed microorganisms to resume vigorous activity. Toward the end of the experiment, temperatures remained higher than the ambient environment because of residual heat in the bins. The team concluded that when the temperature approaches the ambient level (around 35°C) and remains stable, the composting process can be considered complete.

Regarding leachate, the team observed that it only occurred in Experiment 1 and Experiment 2.

Evaluation of product quality showed that Sample 4 fully met the standards to qualify as certified organic fertilizer according to TCVN 6166:2002 – Nitrogen-fixing microbial fertilizer. Specifically, Sample 4 had moisture $\leq 35\%$, pH between 6–7.5, total nitrogen $\geq 0.15\%$, and organic carbon $\geq 8\%$. These indicators are suitable for maintaining microbial activity, creating favorable conditions for decomposition, and ensuring nutrient absorption by crops. In contrast, Samples 1, 2, and 3 had excessively high moisture, which significantly reduced microbial activity. Their organic carbon and total nitrogen contents were too high, potentially disrupting soil microbial balance and negatively affecting crop yield and quality. Moreover, the pH of these samples was too low, creating an acidic environment unfavorable for microbial activity.

From these results, the research team confirmed that NT4 was the optimal treatment, ensuring an effective composting process and producing certified compost suitable for sustainable agricultural application.

Conclusion

Through analysis and monitoring, Treatment 4, with 50% fish by-products and substrate, has been proven to be optimal for producing compost fertilizer. The composting process of Treatment 4 was considered complete at hour 770 under aerobic conditions with a 6-day turning cycle. The nitrogen-rich fertilizer

produced exhibited nearly ideal nutritional parameters: moisture content 35.49%, pH 6.47, organic carbon (OC) 19.9, and total nitrogen 1.7.

Declarations

Authors' Contributions

The research was conducted under the supervision and guidance of MSc. Võ Thị Thúy Huệ, MSc. Nguyễn Minh Quang, Engineer Đặng Thế Hiển, and Engineer Phạm Thị Quỳnh Anh. Sample analysis was carried out by the Institute of Biotechnology and Environment, University of Agriculture and Forestry, Ho Chi Minh City. The remaining processes (material preparation, transportation, sampling, turning, photo and video documentation, data recording and analysis, preparation of proposals, reports, logs, etc.) were performed by students Đỗ Trần Khánh Ngọc, Nguyễn Thị Minh Khánh, Lê Huỳnh Minh Tâm, and Ngô Bảo Khoa.

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- Institute of Biotechnology and Environment, University of Agriculture and Forestry, Ho Chi Minh City
- Faculty of Biological Sciences, University of Agriculture and Forestry, Ho Chi Minh City
- Scientific – Technological – Engineering Research Program, High School for the Gifted, Viet Nam National University Ho Chi Minh City
- AI is employed for translation to overcome language barriers.

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Figures

Experiment	% Fish Waste	% Substrate
1	100	0
2	90	10
3	70	30
4	50	50
5	30	70

Figure 1

Experiment Design



Figure 2

July 18, 2025 – Fish by-products before and during grinding

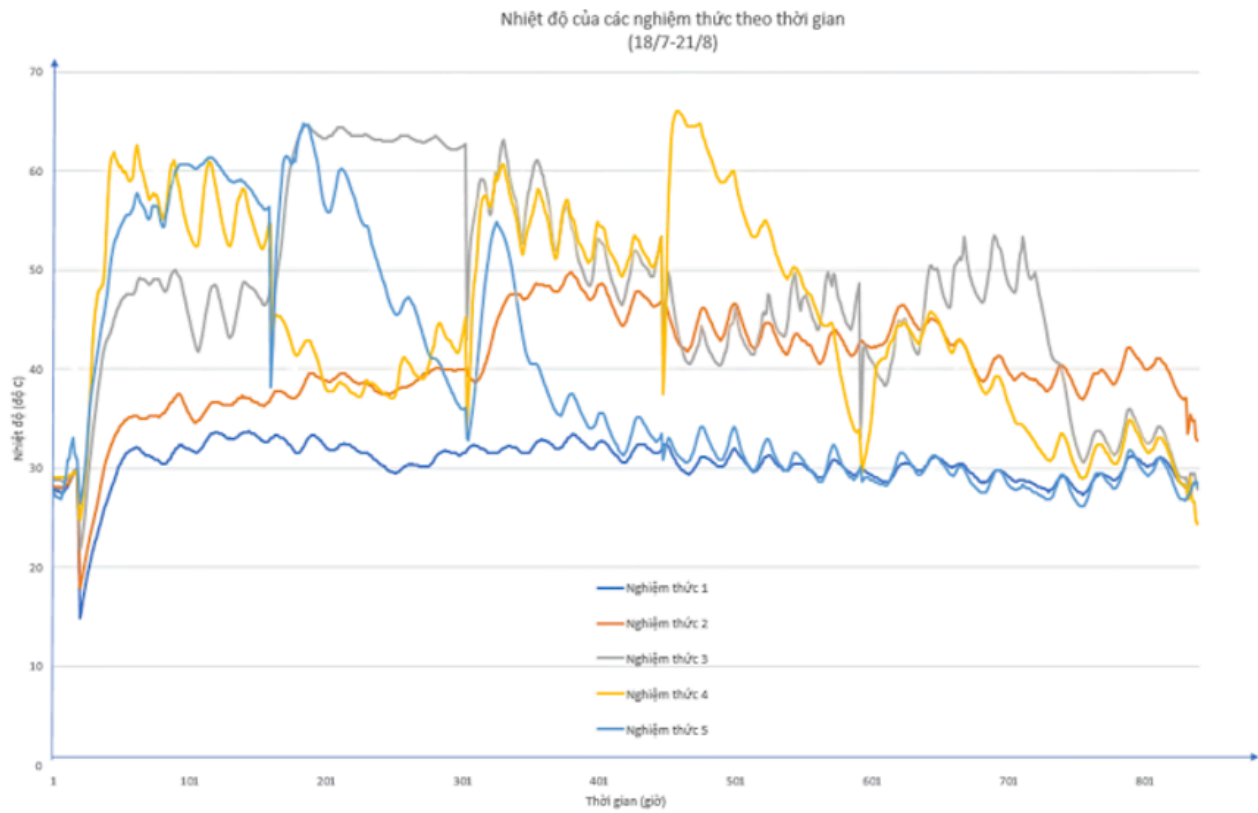


Figure 3

Temperature monitoring chart during the composting process

Sample	Moisture (%) TCVN 9297:2012	pH TCVN 13263-9:2020	OC (%) TCVN 9294:2012	Total Nitrogen (%)	C/N Ratio
Experiment 1 (Day 0)	65.67	5.62	20.64	2.04	10.12
Experiment 1 (Day 31)	69.26	5.95	20.11	1.02	19.72
Experiment 4 (Day 0)	48.5	5.76	21.67	1.35	16.05
Experiment 4 (Day 31)	35.49	6.47	19.9	1.70	11.71
Standard Compost (QCVN 01-189:2019/BNNPTNT)	≤ 15	4 – 8.5	≥ 15	≥ 0.5	≤ 12

Figure 4

Nutrition in Experiment

Note:

Sample 1: Control sample taken on Day 1

Sample 2: Treatment 1 after completion of the composting process

Sample 3: Treatment 5

Sample 4: Final product (Treatment 4)