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Evaluation of Minerals Composition in Fish Bone Meal as Organic Fertilizer Development for Sustainable Environment

UMI THAQIFAH KHAIRUL, NOR IDZWANA MOHD IDRIS*, RAMISAH MOHD SHAH, IFFAH HAZIRAH MOHD NAWI and NORHIDAYAH CHE SOH

Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia.

Abstract

The improper disposal of agricultural waste leads to soil degradation and environmental harm, but this issue can be addressed by converting the waste into nutrient-rich fertilizer, promoting soil health and sustainable farming practices. This study evaluates mineral content in fish bones waste which may support plant growth. FBM was prepared from fish bones collected from the local food processing industry in Terengganu, Malaysia, and nutrient composition was analyzed using the ICP-OES and CHNS equipment. Macronutrient and micronutrient content were compared among *Sardinella fimbriata* commonly known as Tamban fish, *Decapterus tabl*, commonly known as *Selayang fish*, and *Chirocentrus dorab*, commonly known as Parang fish. Among the species studied, Tamban fish had the highest phosphorus content of 105.59 g/kg, important for energy storage in plants, while Parang fish had the highest potassium content of 2.99 g/kg, important for root development. The Selayang fish expressed the highest values of calcium at 125.05 g/kg, which helps to mitigate soil salinity; other nutrient contents such as magnesium, iron, zinc, manganese, and boron were highly variable. These findings highlight the potential of FBM as a sustainable alternative to synthetic fertilizers, supplying critical nutrients for plant growth as well as offering solutions to challenges related to waste management. To optimize its use, further research on blending FBM with other organic materials is recommended in order to balance nutrient availability for improved crop development, and thus support sustainable agriculture and circular economy.

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CONTACT Nor Idzwana Mohd Idris idzwana@umt.edu.my Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia.

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Introduction

Agricultural and fishery industries produce enormous organic waste worldwide, estimated at about 998 million tonnes of agricultural waste per year, which accounts for almost 80 percent of the total solid waste. In the state of Terengganu, Malaysia, particularly, wastes originating from fish, such as bones, heads, scales, and offal, have become a modern problem of escalating waste due to the demand for local delicacies made from fish, especially *keropok lekor* and *satar*. Undesirable methods of disposing of these by-products often lead to environmental pollution through methane emission, among others, and water contamination, representing also a lost opportunity in recovering useful nutrients. This calls for an urgent need for new innovations in waste management practices that are environmental-friendly and aid in sustainable agriculture.

Fish bones, being rich in important nutrients such as calcium and phosphorus, may provide a promising potential when revalorized into fish bone meal. FBM has already successfully been commercially developed in some countries, including the United States and Norway,[1] to be used in organic fertilizers, animal feed, high calcium flour,[2,3] catalyst of biodiesel,[4] among other applications. However, its potential within Malaysia remains underexplored; there are scant studies on its nutrient profile, and there is no standardized labeling for locally available products. This study focuses on three common fish species from the food processing industry in Terengganu- *Chirocentrus dorab* (Parang fish), *Sardinella fimbriata* (Tamban fish), and *Decapterus tabl*. Selayang fish-selected based on their abundance and their contribution to waste in the locality. This study will analyze the macro and micronutrient content of FBM, establishing its viability as an organic fertilizer and further encouraging sustainable agriculture through nutrient recycling and waste reduction. As chemical fertilizer undoubtedly promotes plant growth and higher yield however it also has adverse effects on our environment.[5] Fish bones have been studied recently for their importance in chemical content such as calcium, phosphorus, and calcium phosphate or hydroxyapatite.[6]

Previous study reported that 190 mg of Phosphorus was detected in red snapper fish bone followed by other elements such as Iron (Fe) with 1.0 mg and calcium (Ca) 20-35 mg.[7] This points out that phosphorus in fish bones could be a good source of phosphorus for humans and plants. Phosphorus's role in plant growth increases the cell division of plants and improves the strength of roots and stems. Phosphorus is the main element in fertilizer which is compulsory for plant growth.[8] The lack of phosphorus will affect plants in terms of shoot growth, leaf color degradation, and reduced production. Other than phosphorus, one of the other elements that could be found in fish bone is calcium. There is 5.8% of calcium based on a dry basis for fish by-products such as fish bone.[9] Research done in sandy loam soil reported that fish bone meal improves soybean performance in sandy loam soils, with a higher yield and higher protein content which might be due to the continuous phosphorus availability.[10]

Calcium (Ca) acts as the main element in protecting the plant. The function of calcium in plants is to build the cell wall and membranes which will give an effect on the structures of cell walls against the plant pathogen.[11] This showed that the application of fish bone in plants could contribute to protecting the plant from plant disease. The current fertilizer available in the market is chemical fertilizer with major elements such as NPK and does not have further details on Calcium. From this viewpoint, fish bone fertilizer could provide high phosphorus content and sufficient calcium for plant growth.

There was also magnesium found in the fish bones of Black tilapia for less proportion comparing to calcium[6] and small amount in mackerel fish bone[12] but the concentration was enough because proper soil magnesium levels can mitigate cadmium toxicity by preventing plant uptake, emphasizing the importance of nutrient balance in agricultural practices for healthy plant growth and environmental sustainability.[13] Next, zinc was available within fish[14] but the study about the level of zinc in fish bone waste was still unclear. The zinc is known as micronutrient due to low concentration required for plant growth and rich in vermicompost.[15] Other micronutrients for plants that could be found in fish bone waste were copper (Cu), boron (B) and manganese (Mn).

Utilizing fish bone waste for organic fertilizer in Malaysia is still limited. Although a lot of fish bone fertilizer can be found in local online shopping platforms such as Shopee and Lazada, the mineral analysis has not been done with no proper labeling for mineral content. Other than that, prices of chemical fertilizer also have been fluctuated and increasing due to high demand from local farmers but the stock within country also limited. Thus, purpose of this study was to determine the mineral content of three common fish used for the food processing industry in Terengganu which were *Chirocentrus dorab* (Parang fish), *Sardinella fimbriata* (Tamban fish), and *Decapterus tabl* (Selayang fish) for possibility of complete organic fertilizer such as chicken dung and cow manure. Concentration of macro and micro elements in fish bone meal that are required for plant growth were observed in this study as an alternative to inorganic fertilizer.

Materials and Methods

Materials

Total of 60 kg fish bones waste for three different species have been collected from local fish-based food producers in three different districts within Terengganu state, Malaysia. *Chirocentrus dorab* (Parang) fish bone was collected at Batu Rakit, *Sardinella fimbriata* (Tamban) from Mok Kemas, Marang, and *Decapterus tabl* (Selayang) was collected from Seameq factory in Kuala Nerus, these three species been chosen due to the common fish species found to produce keropok or fish cracker. The sample were taken based on the similarity in length and shape of fish bones. All excess meat from the fish bones was removed and washed under running tap water. The fish bones then were patted dry using tissue before being dried in the oven with 100 ºC temperature for 24 hours to remove excess moisture. The dried fish bones were grinded using a dry blender (until they formed a fine texture in the laboratory) and stored in room temperature until further used.

The nitrogen content in FBM was determined by the Dumas dry combustion method using a CHNS Elemental Analyzer, vario EL cube, Elementar Germany. The method presented precision and reliability in the quantification of total N in solid organic samples,[16] and thus it was adopted as apt for the evaluation of the nitrogen content in fish bone waste as the main nutrient plant growth.

Indusctively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) was used for the analysis of macro- and micronutrients such as P, K, and trace elements (Model Optima 8300, PerkinElmer, USA). In such case, ICP-OES is very effective because of its high sensitivity and accuracy for multi-element analysis, especially in the determination of major and trace elements critical for plant health. The sample preparation, digestion and ash preparation ensured the removal of organic material and maximum recovery of elements to produce accurate and reproducible results.

This method is ideal for studying fish bones, given that fish bones have a complicated mineral composition, and detailed profiling is required to assess their potential as organic fertilizer.

These advance techniques of analysis were used in the study to accurately determine the nutrient composition of fish bone meal; this is crucial in establishing its feasibility as an alternative to chemical fertilizers.

Statistical Analysis

The data of Nitrogen percentage (%), Phosphorus, Potassium and micro elements from this study was analyzed using one-way ANOVA (Analysis of Variance) in SPSS (version 29, IBM, United States). The means were compared using the Tukey analysis test to assess significance between the means of each elements in three different fish bones sample and differences at $p<0.05$ were considered significant.

Results

Fish bone meal, a byproduct of fish processing, is an organic fertilizer valued for its rich nutrient content, particularly phosphorus and calcium. It is used in organic farming to improve soil fertility, enhance plant growth, and promote sustainable agricultural practices. As a natural alternative to synthetic fertilizers, fish bone meal offers both environmental and economic benefits, contributing to healthy, high-yielding crops. Each plant need nutrients to grow in maximum growth, the nutrient are divided into 2 categories which are macro and micro nutrients.[17] Six macronutrients; nitrogen (N), phosphorus (P), potassium (P), calcium (Ca), magnesium (Mg) and sulphur (S) required in plant growth have been observed in this study. The macro elements consist of two types which are primary and secondary that been categorized based on the amount required for plant growth. For primary macronutrient, mineral content for 3 species of fish were shown in table 1. Nitrogen concentration was observed and *Decapterus tabl* had the highest nitrogen (30.2%) percent but resulted with no significant difference when comparing with other species. Other studies also found out the nitrogen percent in the same species for this study which were *Chirocentrus dorab* and *Sardinella fimbriata* with 11.7%.[18] Fish bone is another organic fertilizer with a relatively high nitrogen content, typically around 4% to 7%.[1] Nitrogen is essential in metabolic reactions like absorption, transportation, and photosynthesis. This element is related to the protein involved cell structure, 20.4% protein available in *Sardinella fimbriata.*[19] Next, the phosphorus is known to be mainly an element in the bones. The results shown *Sardinella fimbriata* have the highest concentration of phosphorus (105.59 g/kg) and different significantly comparing to other fish bones species. 185 g/kg of phosphorus was found in the same species and also got the highest concentration of phosphorus comparing to other *Sardinella sp.*[20] Phosphorus help plant produces maximum yield due to its role in crop energy storage and transfer, such as supporting most physiological processes in plants, such as photosynthesis and respiration.[21] Meanwhile, potassium (K) was significantly high in *Chirocentrus dorab* with 2.99 g/kg compared to *Decapterus tabl* (1.9 g/kg) and *S. fimbriata* (1.29 g/kg). Potassium is a major element in plant growth and plays an important role in root uptake of K+ by diffusion. This procedure involved soil water content and aided in increasing water and nutrient uptake in the form of K+.[22,23] Plant growth required nitrogen, phosphorus and potassium in huge amounts and many companies have come out with chemical fertilizers that could provide all 3 elements based on plant growth such as 15-15-15 which is known as NPK Green for plant growth at early stages. But nowadays, chemical fertilizer prices have fluctuated and many farmers have to bear the cost. Thus, organic fertilizer is another option to reduce the costing. In addition, the use of FBM further assists with agricultural wastes by reutilizing fish by-products for a circular economy in which there will be reduced challenges in waste management.[1] The waste problem could be solved with profitable solution which converting the waste into organic fertilizer.

Table 1: Content of primary macro element for mineral concentration in fish bone waste based on 3 different species.

Fish species	N (%)	P (g/kg)	K (g/kg)
Decapterus tabl	30.2	99.94**	1.90**
Sardinella fimbriata	28.1	105.59*	1.29*
Chirocentrus dorab	26.8	100.48**	2.99***

#Nitrogen has been analysed by using CHNS equipment while phosphorus and potassium were by using ICP-OES.* ** *** shown there was a significant difference between each species.

For the secondary macronutrient, there was significant different (refer figure 1) for calcium (Ca); *Sardinella fimbriata*, 125.05 g/kg while in *Chirocentrus dorab*, 122.71g/kg and *Decapterus tabl*, 110.67g/kg. For plants, calcium is an element that involves regulatory mechanisms that allow plants to adjust such as drastic temperature, water stress and salinity. It helps maintain the integrity and stability of cell membranes, ensuring proper functioning of various cellular processes.[24] Calcium in fish bone has been studied by many researchers for their nutritional value such as for supplements that showed the potential in biomedical field for Black tilapia fish bones[6] and the study shown development of calcium supplement using yellowfin tuna (*Thunnus albacares*) for human consumption.[25] After that, Magnesium (Mg) concentration has significant different in fish bone between each species; *Sardinella fimbriata* with 2.48 g/kg while in *Chirocentrus dorab*, 2.62g/kg and *Decapterus tabl*, 2.29g/kg (refer table 2). Contrary to other studies, magnesium in fish by product such as fish bone was detected with only 0.002 g/kg[9] from the waste of lizardfish-surimi product. On the other hand, plants required Mg for the photosynthesis process and enzymes stimulator. Additionally, magnesium plays a crucial role in activating various enzymes involved in energy metabolism and is also required for the synthesis of chlorophyll, the pigment responsible for photosynthesis.[26] Last secondary macro element was Sulphur (S) in fish bone was low in fish bone for *Decapterus tabl*, with 0.17g/kg followed by *Chirocentrus dorab* with 0.11g/kg contradicting *Sardinella fimbriata* with 0.21g/kg.There was no significant difference between each species for sulphur concentration. Thus, the species of fish does not contribute to the most suitable fish that could be used for the fish bone meal. The primary source of sulphur for growth is sulphates absorbed by the roots, though it has to first be reduced to sulphide before being further metabolised.[27]

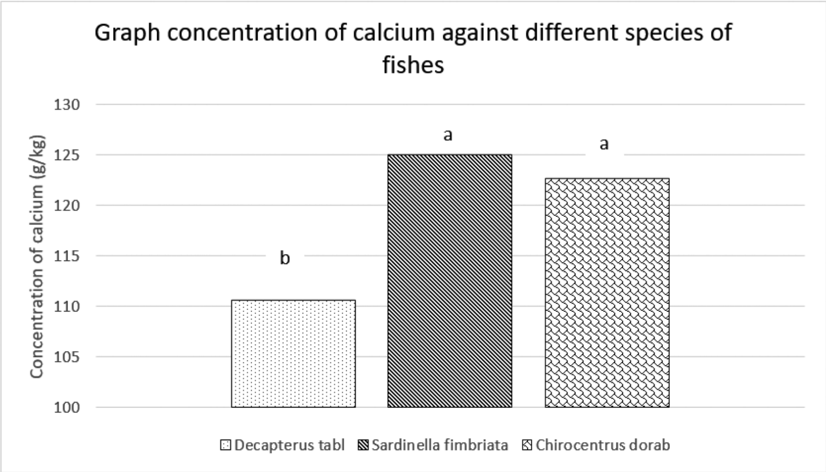

Fig. 1: Concentration of Calcium in the fish bones waste. Different a-b lowercase subscript indicates in the graph indicates significantly different at p<0.05

Table 2: Content of microelement for mineral concentration in fish bone waste based on 3 different species.

Fish species	Mg (g/kg)	S (%)	Zn (g/kg)	B (g/kg)	Cu (g/kg)	Mn (g/kg)
Decapterus tabl	2.62***	0.17	0.71*	0.08**	0.002	0.01*
Sardinella fimbriata	2.49**	0.21	1.26***	0.47*	0.001	0.65**
Chirocentrus dorab	2.31*	0.11*	0.85**	0.14**	0.003	0.68**

All elements have been analyzed by using ICP-OES. * ** ***Shown there was a significant difference between each species

Microelement is still required in plant but in the smaller amount compared to the macronutrient. Due to the small concentration, many farmers do not realize the importance of microelements such as zinc and magnesium. By having the fish bone waste as the organic fertilizer, many farmers can provide the microelement to plant without extra effort on buying additional chemical fertilizer from industry. In particular, this has broad implications for sustainable agriculture as a substitute for inorganic fertilizers. FBM is a slow-release nutrient profile that gradually provides trace elements like zinc, magnesium, and boron together with important macronutrients like potassium, calcium, and phosphorus. By reducing the likelihood of nutrient leakage, a major issue with inorganic fertilizers, this gradual release of nutrients ensures long-term soil fertility[28] and reduces contamination in water systems.[5]

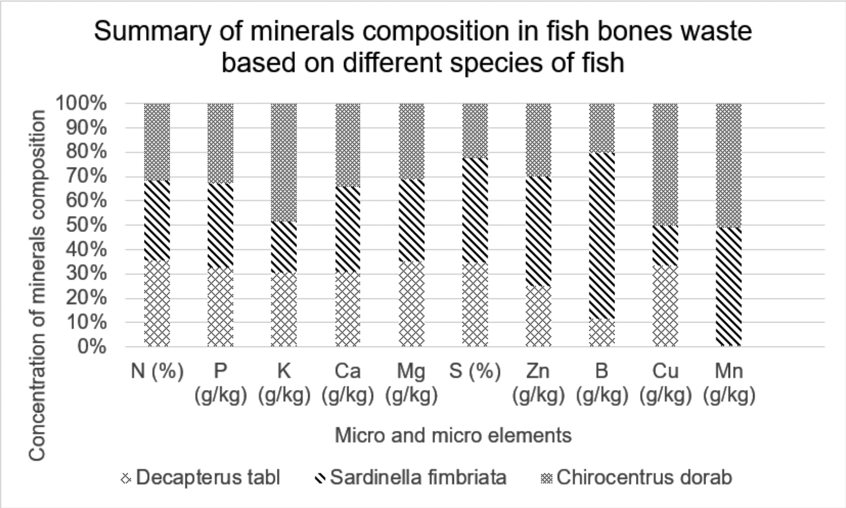

Fig. 2: Concentration of overall minerals in the fish bones waste.

Plant growth is significantly impacted by zinc, boron, copper, and manganese. Zinc was significantly different in *Sardinella fimbriata* comparing to other fish bones species. Zinc is an essential micronutrient in higher plants, playing numerous biochemical and physiological roles.[29] Same as zinc, only *Sardinella fimbriata* having the significant difference in boron with 1.26 g/kg concentration (refer table 2). Boron is an important microelement as deficiency negatively impacts plant growth, development, and performance such as an interruption of growth at the growing tips, or meristems, is one of the earliest defects found upon boron deficiency.[30] Copper is crucial for photosynthesis, electron transport chain, mitochondrial respiration, cell wall metabolism, lignin synthesis, response to oxidative stress, and hormone signaling pathways.[31] Even though there was a lot of importance of copper in plants, the plant only required a small amount of it and there were no significant differences between each fish bone species. Maintaining an optimal copper concentration is essential for ensuring proper plant growth and development. Lastly for manganese, *Decapterus tabl* has the significantly lowest value which was 0.01 (g/kg) - refer table 2 compared to other fish species but it is also required by enzymes in metabolic pathways, photosynthesis and in plant defense.[32]

Discussion

In organic farming, fish bone meal is applied to the soil to enhance phosphorus availability, which is crucial for root development and flowering in plants. It is particularly effective in growing crops like tomatoes, peppers, and leafy greens. By improving soil structure and nutrient balance, fish bone meal helps increase soil fertility over time, promoting robust, healthy plants. Its slow-release nature ensures that crops receive a steady supply of nutrients throughout their growing cycle. For macronutrients, *Decapterus tabl*, with its high nitrogen content, is ideal for use in organic fertilizer for leafy vegetables and crops requiring substantial nitrogen input but requires a longer period to decompose fully. In contrast *Sardinella fimbriata*, while providing a balanced nutrient profile, is more suited for slow-release fertilizers that enhance long-term soil health and can be main fish bones species for flowering or fruit vegetables such as eggplant and tomato. *Chirocentrus dorab*, offering the highest potassium content, is particularly beneficial for crops requiring strong root structure and the potassium ion (K+) will help in water exchange in root zones thus, reduces the water stress in root zones.[23]

Application of such knowledge to organic farming involves the use of FBM as a sole organic amendment or combined with other organic materials like compost or manure for a balanced fertilizer mixture.[17] This can result in higher crop yields, better nutrient density in produce, and reduced dependence on costly chemical inputs. When compared to conventional NPK fertilizers, fish bone meal offers a slower, more controlled release of nutrients, reducing the risk of nutrient leaching and runoff into waterways. Even though the concentration of certain elements were varied based on different species (refer figure 2), all fish bones species could be used as organic fertilizer based on the elements within the fish bones. While synthetic fertilizers can boost crop yields in the short term, they often degrade soil health by disrupting microbial activity and causing nutrient imbalances5. In contrast, fish bone meal enriches the soil with essential nutrients while supporting beneficial soil organisms, making it a superior choice for sustainable organic farming practices.[1]

Conclusion

The study reveals variations in macro and micro element content among three fish species: *Decapterus tabl*, *Sardinella fimbriata* and *Chirocentrus dorab*. Phosphorus levels are highest in *Sardinella fimbriata*, while potassium content varies significantly. This highlights species considerations for organic fertilizer production. Different species of fish bones have different microelements mineral composition. *Sardinella fimbriata* is the fish bones species that contain the most significant different amount of macro and micro element for plant growth compared with other fish bones species. While it may require complementary fertilization for optimal nitrogen and potassium levels, fish bone meal's slow-release properties and eco-friendly nature make it a valuable tool in promoting long-term soil health and sustainable agricultural practices. Fish bone waste may be transformed into an inorganic fertilizer that promotes plant growth, however further study is needed to come out with balanced minerals by combining the fish bone meal with other organic waste such as banana peels, eggshell or paddy husk. By incorporating FBM into agricultural practices, farmers can achieve sustainable productivity while promoting environmental stewardship, aligning with global efforts to reduce synthetic input usage and enhance food security.

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Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Nor Idzwana Mohd Idris:** Conceptualization, Methodology, Writing – Original Draft.
- **Umi Thaqifah Khairul:** Data Collection, Analysis, Writing – Review & Editing.
- **Ramisah Mohd Shah:** Visualization, Supervision, Project Administration.
- Iffah Hazirah Mohd Nawi & Norhidayah **Che Soh:** Funding Acquisition, Resources, Supervision.

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