Fish waste valorisation as biofertilizer: Impact on soil fertility and radish (*Raphanus sativus*) growth

Thendral Hepsibha Balraj*, Dayana Kuppani and Tharani Gopalakrishnan
Department of Biochemistry, Ethiraj College for Women, Chennai, Tamil Nadu, INDIA
*thendralhepsibha_b@ethirajcollege.edu.in

Abstract

The concept of the circular bioeconomy has enabled the conversion of fish waste into a valuable biofertilizer. By using this organic biofertilizer, the harm that chemical fertilizers do to the soil, human health and food security may be mitigated. Because of its high vitamin and nutrient content, Raphanus sativus (Radish; Brassicaceae) is consumed worldwide; yet, for a healthy yield, it needs the right fertilizer. This study attempted to analyse the effect of fermented fish waste biofertilizer (FFWB) on soil properties and growth of radish. The pot experiment has three treatments with 5 replications: Group – I (water control); Group – II (Chemical fertilizer NPK (120-65-100 kg/ ha); Group – III (1:100 diluted FFWB).

Among different treatments, FFWB fertilisation has demonstrated significant improvements in soil N, P, K, Ca, Mg, Mn, Zn, S, Cu, Fe, B and CEC on par with chemical fertilizer. Soil microbial analysis indicated that the population of all bacteria, yeast and mold, as well as nitrogen fixers and phosphate solubilizers, improved under the FFWB treatment. A significant improvement in growth traits of radish like plant height, leaf number, leaf area, root length, root diameter and root weight were evidenced in FFWB treatment. The findings indicated that the FFWB treatment has enhanced soil fertility and radish growth. Therefore, chemical fertilizers can be replaced with biofertilizer made from fermented fish waste. As a result, it is possible to develop sustainable organic agricultural practices and recover degraded soil fertility.

Keywords: Fermented fish waste, biofertilizer, soil fertility, radish (*Raphanus sativus*), soil microbes, growth traits.

Introduction

There is an intimidating challenge to feed the growing global population of 9 billion by 2050, along with a concern for food security and food sustainability. With the compounded rise in the middle-class group, increased spending power, concern for a healthy diet and increasing food demand, aquaculture will be a promising field. Aquaculture has made significant progress and is still growing with its sustainable credentials, like greater availability of nutrient-dense marine foods, species diversity, higher revenue and improved employability. Sea foods were preferred over terrestrial animals due to the superior quality of their protein. FAO[20] has reported that global seafood production is 214 million metric tons. Among the sea foods, fish has received considerable attention for its nutritional value and role in ensuring food security.

Fish is a healthy, readily available and affordable food for all groups of people. Fish is a rich source of protein, together with all essential amino acids, long-chain omega-3 fatty acids, vitamins (A, B and D) and minerals (Ca, I, Fe, Zn and Se). Healthy and balanced diet concerns have shifted consumer preferences from red meat to poultry and fish[48]. Global fish consumption is currently 20.4 kg per person and is predicted to rise to 21.2 kg per person by 2032, with Asia having the largest per capita consumption[27]. With a 7.96% share of the world's fish production, India ranks third in the world. By 2029, 200 million metric tons of fish were predicted to be produced worldwide[67]. According to Hou et al[26], 70% of fish that are captured are processed before being sold and every year, around 27 million tons of undesired fish are thrown into the ocean[15]. The nutritive value of fish by-products was similar in composition to fish fillets and fish products consumed[15].

Fish waste disposal in landfills produces greenhouse gasses, attracts predators and has a detrimental impact on the environment's health[45]. Additionally, surface slicks (a rise in organic content), oxygen demand and turbidity plumes are caused by marine disposal[69]. Achieving the inflow of organic matter and nutrients from waste and handling fish waste in an eco-friendly and effective manner currently depend on the shift from a linear to a circular economy. The demand for organic and natural biofertilizers for sustainable agricultural farming has resulted in the valorization of fish waste into a value-added fertilizer.

Fish waste can be naturally fermented by adding fish offal comprising of gut portions, muscles, frames and heads along with jaggery[64] and by utilizing the enzymes available in fish viscera. Enzymes like collagenase, chymotrypsin, pepsin and trypsin are commercially extracted from fish viscera and they are active and stable in a wide pH range[13,32,70]. Natural fermentation is always advantageous as it uses the enzymes available in the fish parts and does not use commercial enzymes or chemicals and the carbohydrate source (jaggery) added is not expensive.

So, processing by natural fermentation is always an eco-friendly and cost-effective technique. The liquid form of fish biofertilizer was more preferred as it was easily absorbed, readily available and applied as a foliar spray. Liquid-fish-

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based biofertilizers have demonstrated promising growth potential in tomatoes[4], beans[28] and chili[17], brinjal[59] and mung bean[57].

Radish (*Raphanus sativus* L.) is a tender cruciferous root vegetable that is consumed worldwide for its rich vitamin and nutrient values. Radish extracts have been used since ancient times to treat urinary tract infections, stomach disorders, liver and heart problems and ulcers[24]. Radishes for their highest yield require optimum nutrients and soil richness. Continuous application of chemical fertilizer without a check on soil status has led to low nutrient use efficiency and low productivity. The beneficial effect of organic manures like farmyard manure, vermicompost, poultry, chicken and pig manure has yielded better quality radish. Hence, this present study aimed to investigate the effect of naturally fermented fish waste biofertilizer (FFWB) on soil fertility and growth of radish.

Material and Methods

Preparation of fermented fish waste biofertilizer (FFWB)[64]: Fish wastes (head, organs, intestines, fins with muscles) collected from the local fish market in Vanagaram, Chennai, Tamil Nadu, regardless of the species. Fish waste (1 kg) was cut into small pieces and minced coarsely using a mechanical grinder. The content was transferred to a plastic container and 1.5 kg of powdered jaggery along with 5 lits of water was added. The mouth of the container was closed with a muslin cloth to avoid the entry of flies and other contamination. The contents were mixed well daily and kept in the shade. After 3rd day, the aromatic smell of alcohol produced confirmed the start of fermentation. After 15 days, the contents were filtered and the filtrate was used as biofertilizer in 1:100 dilution.

Experimental design: Each green bag (pot) was filled with 20 kg of soil. Pot (green bag) experiments were conducted with 3 treatments and each treatment was replicated five times. Group I: Water (No Chemical fertilizer / Fermented fish waste biofertilizer); Group II: Chemical fertilizer (NPK and 120-65-100 kg/ ha (i.e. 2.609 g urea + 3.421 g single super phosphate (SSP) + 2.00 g Sulphate of potash (SOP) / pot[44]; Group III: Fermented fish waste biofertilizer (FFWB) (1: 100 dilution). Urea was applied in two splits 60% as basal application and 40% after a month, 100% of SSP and SOP as single basal application. Fermented fish waste biofertilizer was added as basal application and in 15-day intervals. *Raphanus sativus* L. seeds were procured from Tamil Nadu Agricultural University Extension, Agricultural seed store, Annanagar. Nearly 2 seeds per pot were sown by the hand dibbling method at 1.25 cm to facilitate good root growth. Watering and manual weeding were done as required. Throughout the study, the experimental plants received water and FFWB as recommended.

Physico-chemical parameters of the soil: Soil samples were collected from 3 pots in each treatment from the 0-15 cm plow layer after radish (*Raphanus sativus*) harvest. The samples were processed for physio-chemical properties and biological analysis. Soil pH, electrical conductivity, organic matter[65], available nitrogen[55], available phosphorus[49], available potassium[30], exchangeable Ca and Mg[56], available S[54], soil available nutrients (Cu, Fe, Zn)[37,44] and CEC[10] were determined.

Soil microbial load: The different microorganisms in the soil were enumerated by using specific culture media and conditions: Thornton's agar medium for total bacterial count[25] incubated at 37°C ± 1°C for 2 days; Rhizobium identified by yeast mannitol agar with congo red 28 ± 3°C for 2 - 5 days[60]; Azospirillum using azospirillum medium without agar (twin pack) incubated at 36 ± 1°C for 3 - 4 days[63]; Pseudomonas using King's B medium incubated at 28 ± 1°C for 12 days[33]; Jensen's medium for azotobacter incubated at 28 ± 3°C for 4 - 6 days[31]; Martin Rose medium for fungi and yeast incubated at 26 ± 1°C for 5 days in dark[41]; Pikovskaya's medium for phosphobacteria[50] incubated at 28 ± 2°C for 2 weeks. The experiments were done in triplicate and microbial populations were expressed as colony-forming units (CFU) / g soil.

Morphological assessment: Growth and yield parameters of radish (*Raphanus sativus*) like leaf area (length (cm) * breadth (cm)) and number of leaves per plant, plant height (cm), root length (cm), root diameter (cm) and fresh root weight (g) (n=10) were measured after 40 days of germination. Plant height was measured from the base of the radish tuber to the tip of the youngest leaf. The fresh weight of the radish tuber was measured after removing the adhering soil by washing it in water and blotting it with tissue paper. Leaf length was measured from the base to the leaf tip. Leaf and radish width was measured at the widest part. Radish length was measured from the tip to the base of the crown region.

Statistical analysis: Data collected were expressed as mean ± SEM. One-way Analysis of Variance (ANOVA) was performed to assess the statistical significance followed by Tukey's multiple comparison tests using computerized Graph Pad Prism version 5.0, Software package (Graph Pad Software Inc.; San Diego, CA, U.S.A.). p value < 0.05 was considered as statistically significant.

Results and Discussion

Soil properties influenced by FFWB: Plants rely on soil for a critical supply of nutrients. Soil nutrition and crop nutrition are closely linked. Soil is a healthy ecosystem that supports life by transforming and recycling the essential elements of plants, animals and humans in the food chain.

The complex interplay between the physical structures and chemical and biological features of the soil controls and influences the flow of nutrients and the uptake of those nutrients by the plants. The primary factors influencing soil microbial biomass are pH and soil organic carbon.

Table 1
Effect of FFWB on soil fertility status

Parameter	Group I (Water)	Group II (Chemical fertilizer – NPK)	Group III (FFWB) (1:100 dilution)
pH	8.10 ± 0.10	8.00 ± 0.15^{NS}	7.8 ± 0.12^{NS}
EC (mS/cm)	0.07 ± 0.07	0.15 ± 0.01**	0.16 ± 0.01**
Organic matter (%)	0.69 ± 0.01	0.98 ± 0.02**	1.23 ± 0.03**
Available nitrate Nitrogen (mg/kg)	15.47 ± 0.62	25.05 ± 0.06***	29.36 ± 0.37***
Available Phosphorus (mg/kg)	11.82 ± 0.09	39.54 ± 0.61***	41.67 ± 0.71***
xchangeable Potassium (mg/kg)	96.33 ± 0.88	430.00219 ± 4.93***	528 ± 5.29***
Calcium Exchangeable (ppm)	1106 ± 51.47	1349 ± 25.56**	1864.33 ± 25.1***
Magnesium Exchangeable (ppm)	155 ± 4.58	222.67 ± 5.36***	231 ± 6.35***
Sulphur Exchangeable (ppm)	20.30 ± 0.87	28.73 ± 0.43***	30.77 ± 0.30***
Zinc available (ppm)	2.63 ± 0.32	3.18 ± 0.13NS	4.66 ± 0.19**
Manganese available (ppm)	9.86 ± 0.30	18.94 ± 0.14***	21.01 ± 0.15***
Iron available (ppm)	12.67 ± 1.20	16.90 ± 0.06 *	19.59 ± 0.97**
Copper available (ppm)	2.10 ± 0.05	3.10 ± 0.07*	3.77 ± 0.31**
Boron available (ppm)	0.50 ± 0.06	0.80 ± 0.06*	0.80 ± 0.06*
CEC Meq/100g	10.83 ± 0.02	11.33 ± 0.18*	13.01 ± 0.03***

Values are expressed as mean ± S.E.M (n=10). ANOVA followed by Tukey's multiple comparison tests was used to analyse the data. Statistically significant variations are expressed as *p < 0.05, **p < 0.01, *** p < 0.001, NS- non-significant. Group I vs Group II and Group III.

The addition of biofertilizer made from fermented fish waste in this study has dynamically altered the physical, chemical and biological characteristics of the soil. The soil properties, pH, EC, organic matter, nitrate- N, P, K, Ca, Mg, S, Zn, Fe, Cu, B and CEC influenced by chemical fertilizer and fermented fish waste biofertilizer amendment were presented in table 1. The lowest pH (7.8 ± 0.12) was recorded in FFBW treatment though not significant, a 3.7% reduction was observed than control. The electrical conductivity (EC) of the soil was significantly increased ($p<0.01$) in both chemical fertilizer and FFWB treatments in comparison to the control. The highest soil organic matter (SOM) content was recorded in group III (1.23 ± 0.03 %; $p<0.01$) followed by group II (0.98 ± 0.02 %; $p<0.05$). The lowest SOM was recorded in the control group (0.69 ± 0.01 %).

The treatments using chemical fertilizer ($p<0.001$) and organic biofertilizer (FFWB) had more available nitrate nitrogen, potassium and phosphorus than the control ($p<0.001$). Group - II soil had exchangeable calcium levels of 1349 ± 25.56 mg kg^{-1} ($p<0.01$). The FFWB treatment had the highest exchangeable magnesium content (231 ± 6.35 mg kg^{-1}) ($p<0.001$). The control soil had the lowest amount of accessible sulfur (20.30 ± 0.87 mg kg^{-1}1). Comparing the application of FFWB to the control, the available Zn, Mn, Fe and Cu increased by 77%, 114.08%, 54.61% and 79.52 % respectively. Zn, Mn, Fe and Cu levels have increased by 20.9%, 92.98%, 33.38% and 47.61 % respectively, following chemical fertilizer application compared to the control.

The boron (B) content has increased by 60% (0.80 ± 0.06 mg kg^{-1}soil) compared to the control group with both FFWB and chemical treatment. The cation exchange capacity trended as follows under different treatments: control (10.83 ± 0.08 meq 100 g^{-1} soil) < chemical fertilizer (11.33 ± 0.18 meq 100 g^{-1} soil; $p<0.05$) < FFWB (13.01 ± 0.03 meq 100 g^{-1} soil; $p<0.001$). The reduction in pH in FFWB treatment was due to the acidic nature of the biofertilizer[58] and it might also be attributed to CO_2, the aliphatic hydroxyl-organic acids and aromatic acids released by the decomposition of organic matter by microbes[43,53]. The acidic pH of FFWB will be a suitable additive that suits radish (*Raphanus sativus*) cultivation[42].

This was due to the increase in organic carbon content and decrease in soil density in group III which has increased soil porosity, water filtration and water holding capacity. As a result, an improvement in soil moisture was achieved. This soil condition, due to FFWB, provides suitable conditions for nutrient transformation and nutrient availability influenced by soil microbes and thus improves soil quality. Wang et al[66] have reported similar improvements in soil properties and maize yield when ox manure was applied. In Group - II, the application of chemical fertilizer has led to soil compaction as a result impedes water penetration, moisture content and hence less soil nutrient status.

The increase in nitrate form of N_2 in FFWB treatment was due to the fractions of N present in FFWB and microbial-mediated transformation of organic to inorganic form. The organic acids produced during microbial metabolism solubilize the insoluble phosphate and potassium[68]. The sesquioxide layer produced by organic matter reduces P and K binding and thus makes these nutrients available in the soil[35].

An increment in NPK soil content was observed when farm yard manure was added for pearl millet-wheat crops[34] and vermicompost in onion and okra[52]. The high Fe content might be contributed by jaggery and fish wastes, sources of iron in FFWB. The increment in Zn content in group III was due to the addition of Zn to the soil present in FFWB and also due to the biochemical process that makes inaccessible zinc available to plants. Organic matter forms complexes with metals thereby reducing the fixation, adsorption and precipitation of micronutrients and making them available[18]. Zn and Cu easily form complexes with organic matter that cannot be adsorbed or migrated and are found easily available[38].

The overall improvement in soil macronutrient and micronutrient availability was due to the synergistic effect of added liquid FFWB and microbial metabolic effects. The effect of liquid biofertilizers (panchagavya and jeevamrut) along with organic manure has improved the soil nutrient status and brinjal yield[51].

Soil Microbiology: The effects of chemical fertilizer and FFWB on viable microbial counts are shown in table 2. A significant improvement in total bacterial count was noted in group III (FFWB treatment) (52.67 ± 2.72 * 10^5 CFU/gm soil; p<0.001) and group II (Chemical fertilizer) (42.62 ± 1.76 * 10^5 CFU/gm soil; p<0.01) (Table 2). The yeast and mould count were recorded in the following order FFWB > Chemical fertilizer > Water control. The highest rhizobium and azotobacter counts were recorded under FFWB treatment (p<0.001). A significant increase in phosphobacteria count was observed only in FFWB treatment. The lowest count of pseudomonas fluorescens was noted in water treatment (10.66 ± 0.88 * 10^5 CFU /gm soil).

The increased microbial population of N_2 fixers (Rhizobium, Azotobacter, Azospirillum), phospho bacteria and pseudomonas, yeast and mold (Table 2) in group III was due to the increase in soil organic carbon level and alkaline pH when compared to chemical fertilizer. The increase in rhizobacterial count in group III (FFWB) confirms that, their endurance in the rhizosphere will help radish to gain the plant growth-promoting potential.

Naveed et al[47] and Bellabarba et al[9] have reported that consortia of bacteria and fungi as biofertizer inoculants will improve the growth of plants than a single inoculant. FAO [21] has defined biofertilizer as a product with one or more microorganisms either in a live or dormant state[21]. Biofertilizer, when amended to soil, will help to solubilize or mobilize the nutrients and will increase the nutrient utilization efficacy of plants. In par with this definition, in the present study, the biofertilizer prepared from fish waste was reported to have a consortium of bacterial population (nitrogen fixers and phosphate solubilizers) along with fungi and also has a load of nutrients required for plant growth[58].

So, this could serve as a natural biofertilizer thereby eliminating the cost of commercial microbial formulations. The addition of fermented fish waste biofertilizer adds organic matter and minerals to the soil and provides conditions for the proliferation of its microbes and native soil microbes.

Table 2
Soil microbial population influenced by FFWB

Group	Group I (Water)	Group II (Chemical fertilizer – NPK)	Group III (FFWB) (1:100 dilution)
Total bacterial load (CFU/ml) *10^5	28.33 ± 0.88	42.66 ± 1.76**	52.67 ± 2.72***
Yeast and Mold (CFU/ml) *10^4	5 ± 0.57	7.66 ± 0.78^{NS}	8.33 ± 0.80^{NS}
Rhizobacterial load (CFU/ml) *10^5	12 ± 0.57	22.33 ± 2.02**	29.33 ± 1.45***
Azospirillum (CFU/ml) *10^4	1.66 ± 0.32	4.66 ± 0.53**	2.00 ± 0.21^{NS}
Phosphobacteria (CFU/ml) *10^4	4.33 ± 0.88	6.33 ± 0.60^{NS}	11 ± 0.57**
Azotobacter (CFU/ml) *10^5	8.33 ± 1.20	21.33 ± 2.08**	28.33 ± 1.20***
Pseudomonas fluorecens (CFU/ml) *10^5	10.66 ± 0.88	16.66 ± 1.20*	20 ± 1.15**

Values are expressed as mean ± S.E.M (n=3). ANOVA followed by Tukey's multiple comparison tests was used to analyse the data. Statistically significant variations are expressed as *p < 0.05, **p < 0.01, *** p < 0.001, NS- non-significant. Group I vs Group II and Group III.

The results obtained by the addition of biofertilizers like panchagavya and jeevamrut are in line with the current results and their effects on paddy, maize and beans were evidenced[5,62]. Rhizobia promotes plant growth through several mechanisms like fixing up of nitrogen, solubilizing phosphates, producing plant hormones (cytokinin, auxin, gibberellins) and protecting the plants from stress, pathogens and systemic resistance[8,61].

Co-inoculation with rhizobium and another PGPR has improved the nodulation and nitrogen content of *Phaseolus vulgaris*[22] and rhizobium–bacillus has improved nodulation and root morphology of soybean, pigeon pea and bean[9], Bradyrhizobium, on dry matter of radish[3]. Pseudomonas, azotobacter and azospirillum are highly efficient extracellular PGPR[1]. *Pseudomonas* promotes plant growth by fixing up nitrogen, solubilizing potassium and phosphate, phytohormones and controlling diseases by producing organic acids, lytic enzymes, antibiotics and secondary metabolites[16,19].

As most of the agricultural lands are deficient in nitrogen and phosphorus, this novel approach of amending FFWB, a polymicrobial biofertilizer will benefit the agricultural sector, as an eco-friendly substitute for chemical fertilizer which could reduce the use of inorganic fertilizers or pesticides. Bargaz et al[7] have also confirmed the positive effect of polymicrobial inoculation on agricultural production. In the present study, the presence of a microbial consortium of rhizobium, azospirillum, phosphobacteria, azotobacter, pseudomonas fluorescens, yeast and mold in soil will surely increase and supplement each other's efficacy in improving soil fertility.

Growth traits of radish: The results revealed that application of recommended chemical fertilizer (49.75 ± 1.72 cm; p<0.001) and FFWB (45.56 ± 1.56 cm; p<0.001) have resulted in significant tallest radish (*Raphanus sativus*) plants (Table 3; Fig. 1 and Fig. 2) when compared with control (21.18 ± 2.04 cm). A similar trend was obtained with the length of radish as control < chemical fertilizer < FFWB. The increment in plant height and root length might be due to the availability of N, P and K along with micronutrients which have enhanced the assimilation of protoplasm leading to a greater number of cells and tissues, increased cell division and vigor of radish.

The addition of FFWB has resulted in improved soil nutrient status incremented by soil microbial activity which has made the nutrients easily available and absorbable. The macronutrient nitrogen plays an important role in cell expansion, synthesis of enzymes, chlorophyll and enzymes and increases the root length. The present results are incongruent with the findings of Kushwah et al[36] who observed an improvement in radish (*Raphanus sativus*) growth after the addition of organic manure and biofertilizers.

Radish requires a higher amount of nitrogen with a constant amount of P and K as it is a fast-growing vegetable [6]. Phosphorus plays an indirect role in increasing the ability of the plant to absorb nitrogen N[2]. K is essential to induce taproot formation and for cell expansion, photosynthesis, translocation and protein synthesis[12,29]. The root structure of rice was improved by the addition of Azospirillum, Azotobacter and Rhizobium biofertilizers[14]. In the present study, amended FFWB adds all essential nutrients and it enhances the activity of native rhizomicrobes facilitating radish (*Raphanus sativus*) growth.

A maximum number of leaves and leaf areas were observed in FFWB and chemical treatment (Table 3 and Fig. 2 and Fig. 3) with the least count in control. This increase in leaf area and leaf number was mainly due to the nitrogen supplied as inorganic NPK in group II and attributed by FFWB in group III.

Table 3
Effect of FFWB and chemical fertilizer on plant height, leaf count and leaf area of *Raphanus sativus*

Group	Plant height (cm)	No. of leaves	Leaf area (cm^2)
Group – I (Water control)	21.18 ± 2.04	7.28 ± 0.5	139.27 ± 2.36
Group - II Chemical Fertilizer (NPK)	49.75 ± 1.72***	12.57 ± 0.30***	167 ± 5.7***
Group – III (1:100 diluted FFWB)	45.56 ± 1.56***	12.42 ± 0.4 ***	161.25 ± 2.03***

Values are expressed as mean ± S.E.M (n=10). ANOVA followed by Tukey's multiple comparison tests was used to analyse the data. Statistically significant variations are expressed as *p < 0.05, **p < 0.01, *** p < 0.001, NS- non-significant. Group I vs Group II and Group III.

Table 4
Radish root parameters influenced by FFWB

Group	Radish length (cm)	Radish Diameter (cm)	Radish weight (gm)
Group – I (Water control)	11.25 ± 1.32	2.9 ± 0.31	97.22 ± 9.6
Group - II Chemical Fertilizer (NPK)	22 ± 1.21***	4.17 ± 0.30*	198.33 ± 19.77 ***
Group – III (1:100 diluted FFWB)	23 ± 1.52***	4.09 ± 0.36*	199.29 ± 15.96***

Values are expressed as mean ± S.E.M (n=10). ANOVA followed by Tukey's multiple comparison tests was used to analyse the data. Statistically significant variations are expressed as *p < 0.05, **p < 0.01, *** p < 0.001, NS- non-significant. Group I vs Group II and Group III.

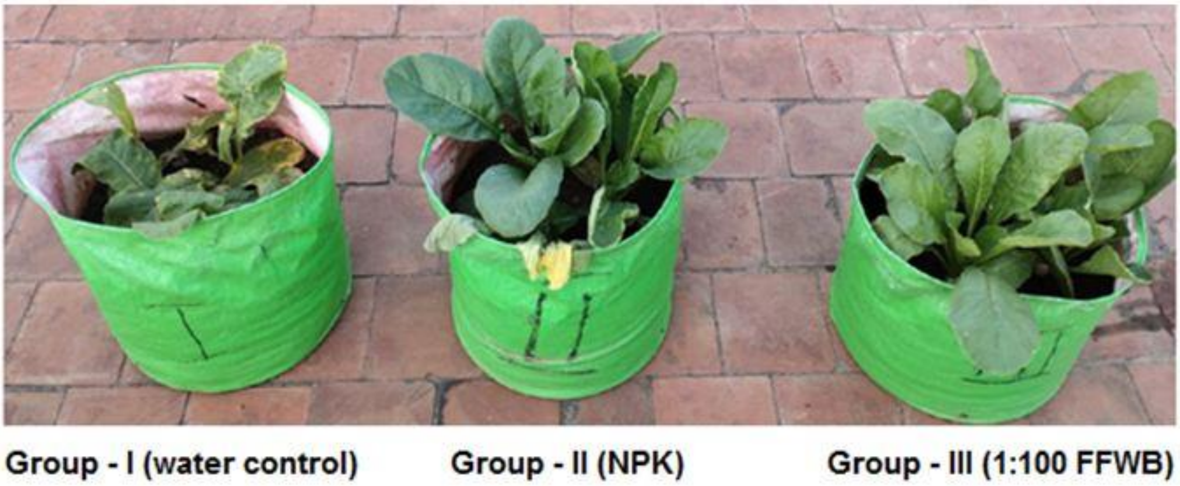

Figure 1: Growth of *Raphanus sativus* on Day 30 under various treatments

Figure 2: Length of *Raphinus sativus* influenced by FFWB

Figure 3: Leaf area of *Raphanus sativus* on Day 40 under various treatments

Nitrogen is a vital component of DNA, amino acids, proteins, coenzymes, phytohormones and alkaloids, promotes cell growth, cell division and cell expansion.

This might have resulted in increased leaf area. Along with the nutrient N, soil microbes produce and promote the activity of growth-promoting substances, making the nutrients available and leading to an increase in leaf area. The findings made by Nandish et al[46] were consistent with the aforementioned results when chicken manure and biofertilizer consortium of azotobacter, phosphate and potassium solubilizers were added with NPK. Potassium also leads to an increase in leaf area and plant growth[23].

The observed increase in leaf area of radish (*Raphanus sativus*) in FFWB treatment might also contribute to the increase in radish weight as they distribute the photosynthates to the roots. Mahsa et al[39] observed an increase in the fresh weight of radish using tea waste compost due to an increase in leaf area.

Significant improvements in root attributes like root length, root weight and root diameter were noted in group II (NPK) and group III (Table 4; Fig. 2) while the control group recorded the minimum root weight and diameter. The addition of FFWB has shown improvement in soil organic matter; hence, an increase in porosity and water-holding capacity and a decrease in bulk density have contributed to the space and volume of radish (*Raphanus sativus*) roots. Bloom [11] has demonstrated the notable influence of nitrogen on cytokinin production which increases the cell elasticity, cell growth and number of meristematic cells. An increase in metabolic activities and auxin synthesis will also increase the root length, weight and yield.

Radish (*Raphanus sativus*) root being the storage organ the increase in weight would be the result of nitrogen assimilated in the amino acids which combine to form complex proteins responsible for the better growth of radish. Mali et al[40] got similar results in radish length and weight when phosphate-solubilizing bacteria and vermicompost were added.

Conclusion

This study demonstrated that the strategy of sustainable fish waste management and utilization for biofertilizer preparation achieves a circular bioeconomy with the nutrient influx and prevents the negative impact on the environment and human health. The results of the conducted study confirm that fermented fish waste biofertilizer improves the soil nutrient status and increases the soil microbial population. Application of fermented fish waste biofertilizer has shown a significant improvement in the growth traits of Radish (*Raphanus sativus*) on par with chemical fertilizer.

Hence, the burden caused by chemical fertilizer on health and the environment could be reduced or removed by the application of fermented fish waste. This is an economical and eco-friendly approach towards an alternative sustainable agricultural practice to ensure food security and availability.

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