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RESEARCH ARTICLE

Production of a Potential Liquid Biofertilizer via Aerobic Composting of Mixed Fruit Peels and Evaluation of its Efficacy on *Vigna mungo* L.*

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Abstract

Fertilizers are extensively used to replenish soil nutrients and maximize crop yields. They are broadly classified into two types: organic and synthetic fertilizers. In recent years, there is increasing attention to the valorisation of agricultural waste, particularly the bioconversion of fruits and vegetable peels into value-added agricultural products such as organic liquid fertilizers. This approach not only reduces the waste accumulation but also contributes to a sustainable product for agricultural purposes. In this present study, the five different fruit peels (*Citrus sinensis, Citrus limetta, Ananas cosmos, Citrus limon, and Citrullus lanatus*) were chosen to produce "Fruit Peel Organic Liquid Fertilizer" (FPOLF) through aerobic composting. The physicochemical properties of the aerobically composted fertilizers (F1, F2, F3, F4 and F5) were assessed, and their effects on seed germination and crop performance were also investigated using *Vigna mungo* L. plants through the pot culture method. Among the formulations, the combination of fruit peels and rice water (F2) exhibited superior plant growth and biochemical parameters. Treatment with FPOLF showed improved effects on shoot length, root length, shoot biomass, root biomass, total shoot biomass, leaf length, leaf breadth, germination rate, and germination index. Additionally, biochemical parameters such as carbohydrate, chlorophyll, and protein contents were found to increase in the crops treated with FPOLF. Overall, FPOLF improved crop performance, enhanced soil health, and promoted circular waste management in agriculture, particularly for smallholder and organic farming systems.

Keywords: Aerobic composting, fruit peel, organic liquid fertilizer, *Vigna mungo*, plant growth, waste valorization.

1. Introduction

The global rise in food consumption in recent years, fuelled mostly by overpopulation, has put enormous strain on the agricultural sector [1]. This increasing demand has deepened the need for sustainable farming practices, technological innovation and efficient resource management. This increasing demand has shifted attention towards sustainable practices, particularly the use of organic fertilizers, which play a vital role in maintaining soil health and productivity. Although synthetic chemical fertilizers are effective for growth, they lead to environmental degradation by leaching into groundwater and disrupting the natural balance of soil ecology. Organic fertilizer management has become essential for improving nutrient availability, enhancing soil microbial activity, and reducing the environmental hazards. Farmers often use excessive amounts of chemical fertilizers and insecticides to meet increased productivity demands [2]. such overuse of agrochemicals has a negative influence on soil health because their prolonged application alters soil pH [3]. In addition, the use of inorganic nitrogen and phosphorus fertilizers causes the release of hazardous chemical substances into agricultural soils, resulting in eutrophication and oxygen depletion in aquatic ecosystems, reducing biodiversity [4,5]. As a result, there is increased interest in producing biodegradable, and environmentally friendly fertilizers. Organic fertilizers are generally classified into two types - liquid and solid. An ideal fertilizer should be cost-effective, non-toxic, biodegradable, and available in sufficient amounts. Good absorption, free of lump formation, adequate moisture, easy to process and capable of buffering the pH are also desirable qualities of the ideal fertilizers. Recent research achieved a 93% yield of nutrient-rich liquid fertilizer from fruit and vegetable waste by combining hydrothermal treatment with *Weissella*-inoculated biological treatment. The resulting product meets international safety standards and offers an economical waste valorisation strategy, saving 13.6 USD per ton [6]. In developing countries like India, large amounts of fruit wastes are accumulated in open areas, contributing to environmental pollution when processed appropriately these biomass can be transformed into value-added products for the agro-industry [7, 8]. However, due to the risk of microbial contamination, fruit wastes cannot be directly applied to the soil therefore, controlled scientific methods such as aerobic composting and anaerobic digestion are employed to convert them into useful products[9]. Additives such as curd, and jaggery have been shown to speed up the bioconversion process of fruit peel into effective fertilizers and to enhance compost quality [10]. In this context, the present study is necessary to utilize the huge amount of fruit peel waste accumulated in Coimbatore district for producing organic liquid fertilizer (FPOLF). Aerobic composting method is cost-effective and feasible for farmers. This approach adopted in this research is cost effective and eco-friendly. The uniqueness of the research is that it aimed to evaluate the efficacy of liquid fertilizer (FPOLF) on seed germination, nutrient composition and plant growth on a model plant *Vigna mungo* L, under controlled conditions. Combinatorial fertilizer formulation consisting of *Citrus sinensis, Citrus limetta, Ananas cosmos, Citrus limon,* and *Citrullus lanatus* have not been investigated in previous studies. The growth parameters and biochemical characteristics also need to be investigated to substantiate the findings in such research.

2. MATERIALS AND METHOD

2.1 Sample Collection

Fresh fruit peel portions of *Citrus sinensis, Citrus limetta, Ananas comosus, Citrus limon, Citrullus lanatus* were collected from Thudiyalur vegetable market in Coimbatore, Tamil Nadu. The fruit varieties were identified as indigenous species and authenticated by a qualified botanist from recognized institution following standard taxonomic procedure [11]. The collected peels were rinsed thoroughly with tap water to remove surface debris and maintained under sterile conditions at room temperature. The dried samples were used for subsequent processing and experimental analysis [12].

2.2 Preparation of Fruit Peels Organic Liquid Fertilizer

Liquid fertilizers were prepared by modifying the previously established bio-enzyme method [12]. Fruit peels were cut into smaller pieces (~2cm) in size. A total of 1kg of mixed fruit peels was prepared by combining 200g from each of the five different types of fruit peels (5 × 200 g) (*Citrus sinensis, Citrus limetta,* Ananas comosus (wherever it appears), *Citrus limon,* and *Citrullus lanatus).* Subsequently, five different formulations were prepared in separate containers using a base of 1 kg mixed fruit peels for each formulation. In the first formulation (F1), the fruit peels were mixed with 1 liter of water. The second formulation (F2) consisted of 1 kg of mixed fruit peels combined with 1 liter of rice water. Rice water prepared by soaking the rice in sterile water for 10 hours and the water was drained for further use. The third formulation (F3) was prepared by mixing 1 kg of mixed fruit peels with 1 liter of curd. The fourth formulation (F4) contained 1 kg of mixed fruit peels mixed with 500 grams of jaggery. Finally, the fifth formulation (F5) was a combination of all components, 1 kg of mixed fruit peels mixed with 1 liter of tap water, 1 liter of rice water, 1 liter of curd, and 500 grams of jaggery. All the five formulations were kept in a separate container for further study. The temperature was maintained in the 10 x 10 Feet Sized room between 26°C and 30°C in the study period (December to March). Natural aeration was provided in the room through sufficient windows. Microbial involvement in the containers are very much necessary for the fermentation to occur in the

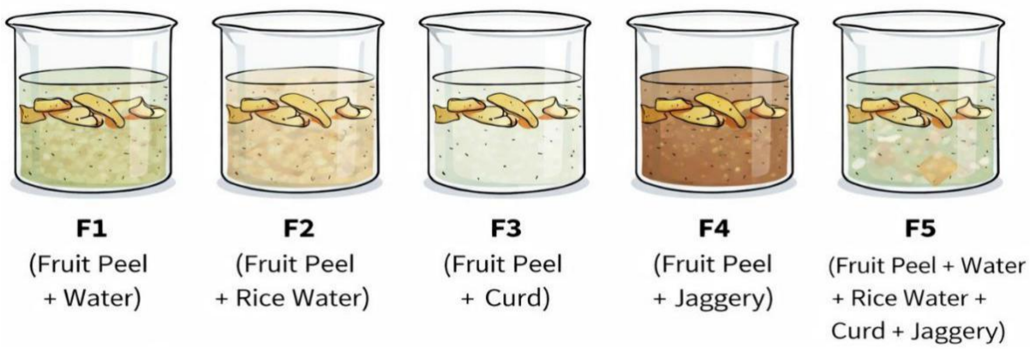

Figure 1: Five formulations of Fruit Peel

Each container was covered with muslin cloth to prevent the entry of insects and contaminants, while allowing for fermentation [13]. These containers were placed under shade to avoid direct sunlight and maintained under aerobic conditions for a period of 35 days. To promote fermentation, specific additions were made on the 10th, 20th, and 30th days of the process. On each of these days, 1 liter of water was added to all the containers to maintain proper moisture and support microbial activity. Additionally, 1 liter of curd was further added to containers 3 and 5 to enhance the fermentation process by providing extra beneficial microbes and nutrients. These steps were carried out consistently to ensure effective fermentation throughout the study period. All containers were stirred daily with wooden spatula to facilitate uniform fermentation. After 35 days the contents were filtered through clean cloth to separate the liquid extract. The homogenized liquid fertilizer was collected and stored in refrigeration for further study. Before application, the extract was diluted with distilled water and are used for seed germination and plant growth enhancement study [14, 15].

2.3. Nutrient Profiling of FPOLF Formulations

The five liquid organic fertilizers (FPOLF) were further subjected to macronutrient and micronutrient analysis. The collected fertilizer samples were submitted to Department of Soil Science and Agricultural Chemistry, Tamil Nadu agricultural university (TNAU), Coimbatore, Tamilnadu for detailed nutrient profiling. The following parameters were analyzed using standard protocols. Macronutrients are essential elements required by plants in larger amounts to support their growth and development. These include Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sulfur (S). Moreover, micronutrients are also contributing to various enzymatic processes, chlorophyll formation, and structural integrity, these are including Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), and Boron (B).

Total Nitrogen (N) was estimated by the Kjeldahl method [16], which measures organic and ammonium nitrogen in composts and organic matter and the Phosphorus (P) was quantified using the vanado-molybdate yellow colorimetric method [17], which allows for accurate determination of phosphorus concentration in liquid extracts. Moreover, Potassium (K) was measured by flame photometry [18], a rapid and sensitive technique that detects K+ ions based on their characteristic emission spectrum when exposed to a flame and the Calcium (Ca) and Magnesium (Mg) concentrations were determined using EDTA complexometric titration [16], carried out under controlled pH conditions. For micronutrient analysis (Iron (Fe), Zinc (Zn), Copper (Cu), and Manganese (Mn)), Atomic Absorption Spectroscopy (AAS) was employed [19,20]. The Boron (B) was estimated using the Azomethine-H colorimetric method [17], one of the rapid methods for detecting low concentrations of boron, based on the formation of a colored complex measuring the OD at specific wavelengths. Additionally, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) were measured using standard methods COD measures oxygen required to chemically oxidize total organic matter, while BOD measures oxygen demand by microorganisms to degrade biodegradable components. Lower values indicate greater stability and least environmental impact. All analytical tests were performed in triplicate with internal laboratory controls to ensure accuracy [20].

2.4 Seed Germination and Growth Enhancement Study Using *Vigna mungo L.*

2.4.1 Plant Material and Surface Sterilization

The *Vigna mungo L.* seeds were selected for both seed germination assay and growth enhancement (pot culture study). Seeds were procured from Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu. Seeds were washed with distilled water and surface -sterilized with 70% of ethanol to eliminate surface microbial contamination. Following sterilization, seeds were placed on filter paper and air dried under aseptic conditions before use [21].

2.4.2 Preparation of Fertilizer Dilutions

The Liquid fertilizer extract from each of the five formulations was diluted with distilled water to obtain final concentration of 1%,2%,3%, and 4% to avoid phytotoxicity. Dilutions were Prepared by equal volumes of distilled water with FPOLF while maintaining a constant total volume of 20 mL.

2.4.3 Seed Treatment

From each fertilizers type and concentration 10 seeds were soaked in respective dilution for 2 hours. Control group seeds were soaked in distilled water.

2.4.4 Germination Setup and Parameters Recorded

Treated seeds were transferred to sterile Petri dishes lined with cotton and filter paper. Each dish initially received 5 mL of the respective fertilizers' dilutions and distilled water for control. An additional 5 ml was applied subsequently to maintain adequate moisture. Germination proceeded for 7 days in a well-ventilated area with minimal sunlight exposure. The following germination parameters were recorded, Germination rate, Germination percentage, Plumule length, Radicle length, Radicle weight [15].

2.4.5 Pot Culture Study

Based on the germination results seeds were further treated with 2% concentration of FPOLF which showed optimal germination parameters. This phase of study is mainly aimed at evaluating the influence of the selected fertilizer on growth parameters under soil conditions, for simulating real agricultural environments. Red soil was collected was air-dried thoroughly in a well aerated place to remove excess moisture and stored in clean bags. Plastic nursery bags were filled with 1kg of soil each. The experiment followed a randomized complete block design (RCBD) with triplicates for each treatment. Treatments included 30% FPOLF (300 mL FPOLF + 700 mL water) and 50% FPOLF (500 mL FPOLF + 500 mL water), Applications were carried out on day 2 after sowing every alternate day therefore for 30days. These dilutions were chosen to minimize the phytotoxicity effects and to ensure balanced application of nutrient to threshold the tolerance of seedlings.

2.4.6 Growth Parameter Assessment

The following phyto-morphological parameters were recorded Number of branches, Number of leaves, Leaf length, Number of leaf veins (days 5,10,20,30) and the final growth measurements were recorded, which included Root length, Shoot length, Total number of leaves, Total number of branches, Shoot biomass, and Total shoot biomass on 30th Day. All measurements were conducted using standard plant phenotyping protocols [7].

2.5 Biochemical Parameter Estimation

On day 30, fresh leaf samples were collected from each group of the plants for biochemical analysis to assess their physiological status. The chlorophyll content was estimated using Arnon method [22]. In addition, total carbohydrates were measured by the phenol-sulfuric acid method [23], a widely used colorimetric assay that estimates carbohydrate concentration. The total protein content was determined using the Lowry method [24], which relies on protein-copper complex formation followed by reduction of the Folin–Ciocalteu reagent.

2.6 Statistical Analysis

Data obtained from the seed germination assay (three replicates per treatment) and pot culture experiments (triplicates per treatment) were subjected to statistical analysis. All results from the study are expressed as mean ± Standard Deviation (SD). All the experiments were repeated for three time and triplicate values were calculated. Statistical analysis was determined by using paired-sample *t*-tests to compare treatment groups with the control. Correct Computer software SPSS version 20.1 analyzer was used for analyzing.

3. RESULTS AND DISCUSSION

3.1 Decomposition

Aerobic composting of the FPOLF formulations was carried out for 30 days. Physical changes were monitored daily. Day1-10: semi-solid and fibrous texture indicated early microbial digestion. 20th Day: consistency becomes colloidal and homogenous, signifying advanced decomposition. 30th Day: fully digested compost was obtained and filtered. (tab-1) (fig 3). All the formulations except F5 showed a thick, sludgy consistency, while F5 appeared slightly watery due to combined water and fermentable substrates These findings align with previous research showing that the incorporation of sugar sources (e.g., jaggery) and microbial-rich starters (e.g., curd) accelerates the rate of composting and nutrient solubilisation in organic waste treatments [25, 2].

Table 1- physical examination of FPOLF formulation after 30 days of aerobic composting

Formulation Group	Physical Appearance
F1 (Fruit Peel + Water)	Sludgy
F2 (Fruit Peel + Rice Water)	Sludgy
F3 (Fruit Peel + Curd)	Sludgy
F4 (Fruit Peel + Jaggery)	Sludgy
F5 (Fruit Peel + Water + Rice Water + Curd + Jaggery)	Slightly Watery

3.2 Nutrient Analysis of FPOLF

Decomposed cum processed organic waste is a rich source of macro and micro nutrients which are highly beneficial in organic farming by improving soil fertility, promoting nutrient cycling and aiding with reduced waste management [24]. The processed FPOLF formulations contained primary (N, P, K), secondary (Ca, Mg, S) and micronutrients (Mn, Zn, Fe, Cu, B). Among the formulation F2 exhibited the highest levels of Fe, Mg, and N. While F5 showed elevated N, P, K Ca, Zn which were often deficient in synthetic fertilizer (Fig 2A, Fig 2B). The COD (620–760 mg/L) and BOD (372–456 mg/L) values indicated nutrient-rich, microbial active formulations, which requiring dilution to 30% and 50% for use. These values match earlier reports [14,20,26,27,28] confirming FPOLF's role in enhancing bioavailability, soil quality, and microbial activity.

Table 2: Nutrient composition of FPOLF fertilizer

PARAMETERS	GROUPS (Values are triplicate, mean± SD)				
	F1	F2	F3	F4	F5
pH	6.2±0.21	6.5±0.212	6.5±0.01	5.86±0.01	6.01±0.01
Total nitrogen%	0.9±0.11	1.2±0.201	0.6±0.05	1.0±0.17	0.8±0.891
Total phosphorus%	0.24±0.15	0.32±0.121	0.48±0.19	0.51±0.03	0.68±0.44
Total potassium %	1.42±0.25	1.17±0.201	0.98±0.31	1.20±0.22	1.47±0.29
Total calcium (mg/kg)	34.0±0.13	20.0±0.110	30.1±0.56	25.9±0.81	41.0±0.92
Total iron (mg/kg)	14.5±0.61	18.9±0.121	17.6±0.32	15.0±0.52	15.0±0.61
Total manganese (mg/kg)	8±0.32	8.6±0.23	7.5±0.91	5.06±0.66	6.0±0.72
Total zinc (mg/kg)	21±0.102	24±0.67	28±0.82	17±0.82	22±0.81
Total copper (mg/kg)	19±0.112	12±0.81	13±0.24	8±0.92	6±0.27
COD (mg/L)	760±0.09	668±0.31	640±0.45	720±0.33	620±0.63
BOD(mg/L)	456±0.24	400.8±0.13	384±0.37	432±0.88	372±0.21

Note: (F1 = Fruit Peel + Water; F2 = Fruit Peel + Rice Water; F3 = Fruit Peel + Curd; F4 = Fruit Peel + Jaggery; F5 = Fruit Peel + Water + Rice Water + Curd + Jaggery)

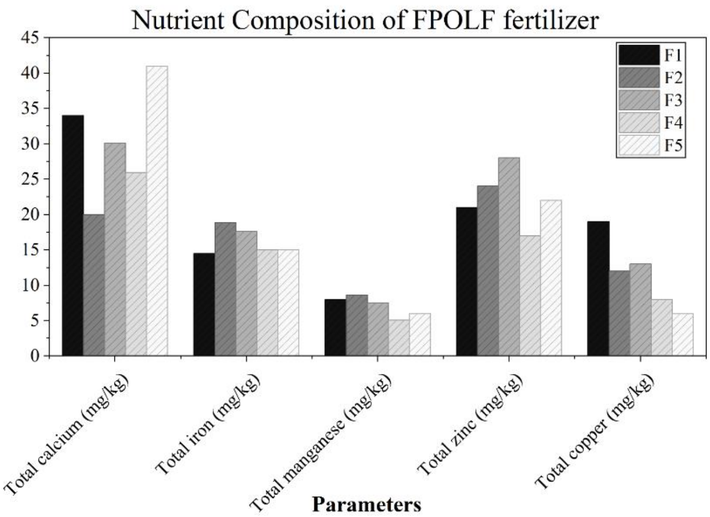

Figure 2 (A): Nutrient Profiling of FPOLF Formulations

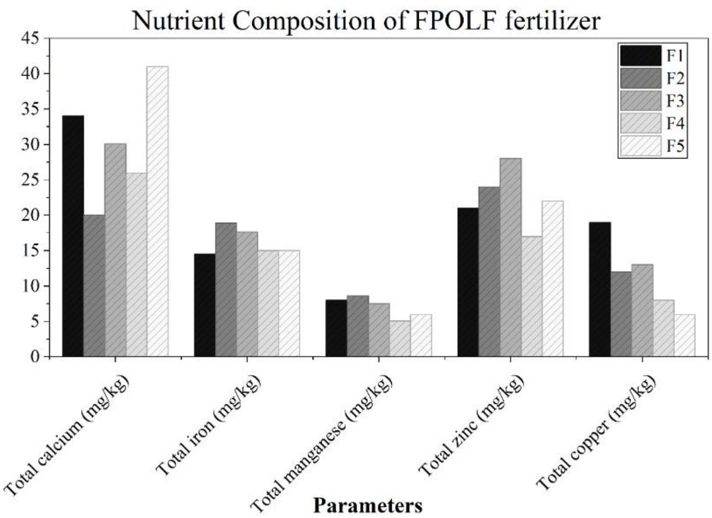

Figure 2 (B): Nutrient Profiling of FPOLF Formulations

3.3 Seed Germination Assay

Seeds treated with FPOLF formulation exhibited higher germination rates (90-100%) than the controls (Table 3). Treatments F2 (fruit peel + rice water), F3 (fruit peel + curd), and F4 (fruit peel + jaggery) showed increases in plumule and radicle lengths (Figures 4–6; Graph 1), consistent with earlier reports linking organic compost amendments to reduce phytotoxicity and enhanced seed germination [29].

Figure 3: First, third and ninth day of germination in seeds pre-treated with FPOLF

Table 3- Growth parameters of germinated seeds treated with FPOLF

Treatment	Conc. (%)	Germination (%)	Germination index	Plumule length (cm)	Radicle length (cm)	Seed vigour index
Control	–	90	90	10.1 ± 2.27	3.40 ± 1.00	1350
F1	2	100	111.1	7.78 ± 1.11	3.88 ± 1.04	1166
F2	2	100	111.1	10.88 ± 0.73	4.55 ± 0.97	1532
F3	2	100	111.1	11.05 ± 1.20	3.94 ± 1.09	1510
F4	2	100	111.1	10.40 ± 0.96	3.82 ± 0.88	1406
F5	2	100	111.1	7.53 ± 0.87	4.30 ± 1.44	1129

3.4 Pot Culture Study

Seeds from the optimal germination treatment were grown in pots with FPOLF at 30% and 50% concentration. These pot culture trials are particularly useful in validating the agronomic potential of organic formulation like FPOLF allowing for precise monitoring of growth parameters and soil interactions [30,31]. The treatments were applied regular intervals over 30 days. Key plant growth parameters including Number of leaves, branches, and leaf length were recorded on days of 5,10,20 and 30 after plantation also number of veins remained between 6-7 in all the plants, also out of 10 seeds sown almost all groups have 10 plants, visual assessment also included leaf color, texture and overall vigor (Fig 4).

Figure 4- : Days 3,5,10,20, and 30 of pot cultured plants that are treated with FPOLF

Effect of Fertilizer on Plant Growth Parameters

Plants treated with FPOLF formulation plants, particularly F2, at 30% and 50% concentration showed the higher leaf length, root length and shoot elongation compared to untreated controls ((Fig 5 - 11). Notably, F2- treated plants had longer and thicker roots, increased shoot elongation and more lateral branching which indicates better nutrient absorption and photosynthetic efficiency. Other formulations such as F3A (fruit peel + curd 30%), F3B (fruit peel +curd), and F4A/F4B (fruit peel+ jaggery) also enhanced vegetative growth, though to a lesser degree.

Table 4- Day 30 growth parameters of pot-cultured plants

Parameter	Unit	C	F1A	F1B	F2A	F2B	F3A	F3B	F4A	F4B	F5A	F5B
Root length	cm	6.95 ± 2.59	8.93 ± 2.28	10.18 ± 2.89	14.10 ± 2.38	12.70 ± 1.64	11.46 ± 1.35	11.30 ± 1.35	10.70 ± 2.98	11.42 ± 4.60	12.00 ± 4.80	11.90 ± 1.37
Root biomass	g	0.20 ± 0.112	0.21 ± 0.049	0.27 ± 0.136	0.68 ± 0.235	0.70 ± 0.34	0.76 ± 0.23	0.42 ± 0.034	0.58 ± 0.270	0.52 ± 0.38	0.63 ± 0.44	0.88 ± 0.294
Shoot length	cm	37.30 ± 35.6	21.80 ± 0.55	22.20 ± 2.15	15.49 ± 12.9	24.96 ± 2.57	21.90 ± 1.13	19.56 ± 1.83	18.96 ± 2.03	12.07 ± 10.64	21.40 ± 0.98	20.10 ± 0.87
Leaf count	no.	8.73 ± 1.10	10.00 ± 1.92	9.40 ± 0.20	8.86 ± 1.20	12.26 ± 2.77	8.57 ± 1.45	7.46 ± 1.30	9.26 ± 2.03	11.93 ± 6.12	8.73 ± 0.83	10.50 ± 0.41
Leaf biomass	g	0.50 ± 0.81	0.57 ± 0.09	0.55 ± 0.82	0.60 ± 0.10	0.84 ± 0.30	0.72 ± 0.12	0.51 ± 0.13	0.62 ± 0.05	0.44 ± 0.17	0.47 ± 0.11	0.61 ± 0.02
Total shoot biomass	g	0.92 ± 0.48	0.92 ± 0.25	1.16 ± 0.10	0.95 ± 0.25	1.64 ± 0.54	1.11 ± 0.05	1.11 ± 0.14	1.06 ± 0.08	0.93 ± 0.22	1.02 ± 1.15	1.09 ± 0.05
Shoot biomass	g	0.52 ± 0.12	0.48 ± 0.10	0.59 ± 0.03	0.50 ± 0.07	0.87 ± 0.31	0.63 ± 0.14	0.51 ± 0.29	0.55 ± 0.13	0.48 ± 0.05	0.54 ± 0.01	0.53 ± 0.06
Number of branches	no.	4.20 ± 1.74	3.06 ± 0.23	3.10 ± 0.06	2.80 ± 0.52	3.13 ± 0.53	2.60 ± 0.11	2.20 ± 0.20	2.20 ± 0.20	2.31 ± 0.04	1.19 ± 0.12	2.40 ± 0.40

Note : (F1 = Fruit Peel + Water; F2 = Fruit Peel + Rice Water; F3 = Fruit Peel + Curd; F4 = Fruit Peel + Jaggery; F5 = Fruit Peel + Water + Rice Water + Curd + Jaggery) [Values are statistical calculations of triplicates].

This enhanced performance in these treatments can be attributed due to the synergistic effect of organic constituents from FPOLF such as proteins and microbial enhancing additives which help in promoting rhizosphere microbial activity and nutrient uptake [8, 20, 28]. The nutrient rich nature of FPOLF formulation with essential micro and macro nutrients like (N, P, K) has more likely contributed to the growth of these plants. Fermentable substances like curd, jaggery are known to enhance microbial populations by supplying easily fermentable sugars while improving nutrient mineralization and soil health[8]. Post-Soil analysis showed a slight improvement in quality parameters in pH and moisture retention in FPOLF treated pots, underscoring its dual benefits for plants and soil system. Overall, these results highlight that FPOLF not only enhances plant growth performances but also offers an eco-friendly alternative to chemical fertilizers compared to normal untreated soil, suggesting additional benefits of soil enrichments and plant growth. These findings are corroborating previous studies indicating that liquid fertilizer which are derived from foods and fruit waste can improve both soil fertility and plant growth performance through sustained nutrient release and microbial stimulation [9, 20, 28].

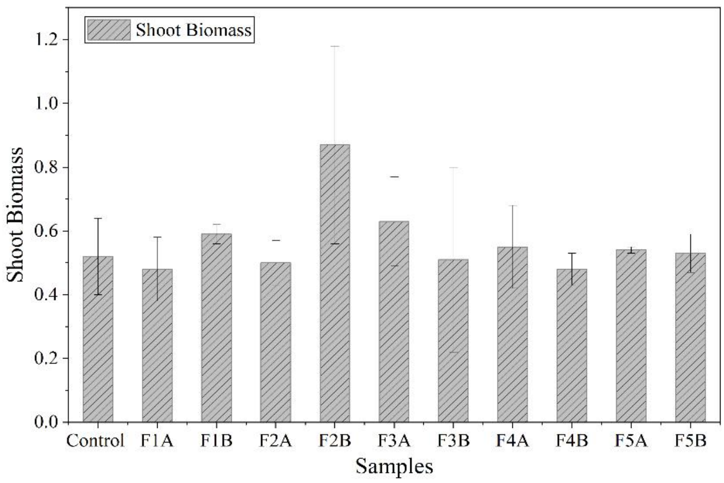

Figure 5: Shoot Biomass measured in *Vigna mungo*

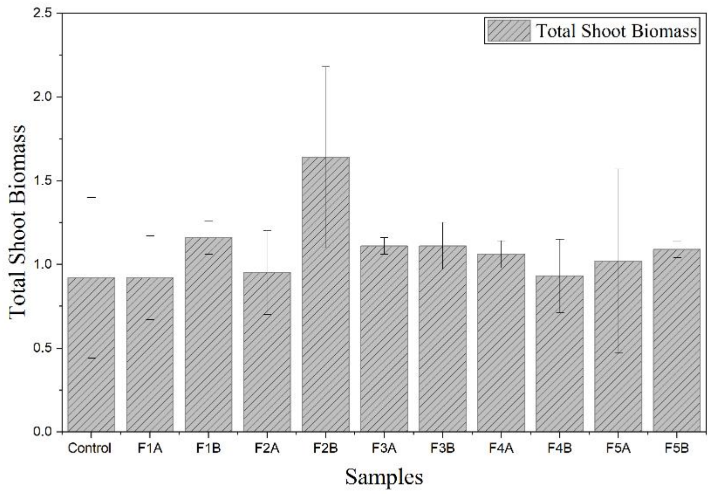

Figure 6: Total Shoot Biomass measured in *Vigna mungo* L

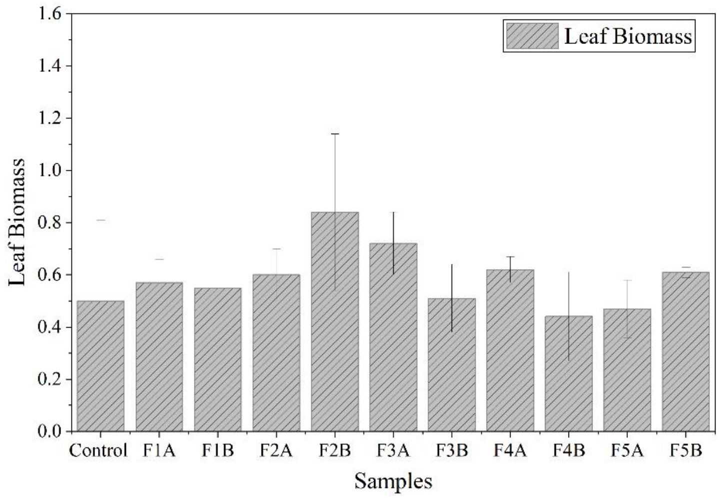

Figure 7 (A): Leaf Biomass measured in *Vigna mungo* L

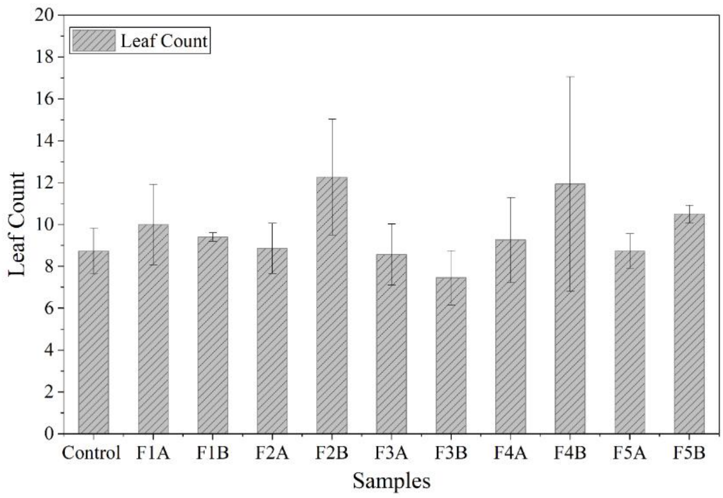

Figure 7 (B): Number of Leaves counted in *Vigna mungo* L

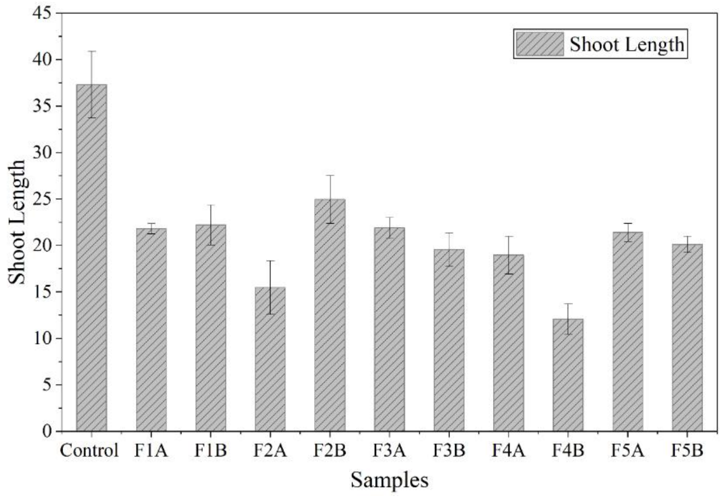

Figure 8 : Shoot measured in *Vigna mungo* L

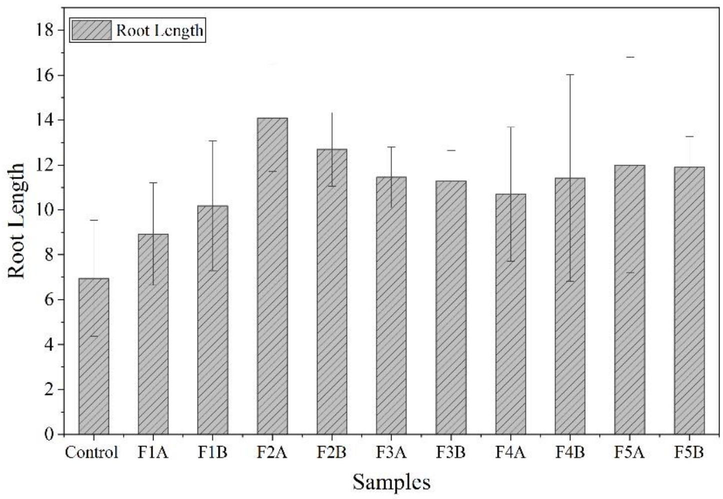

Figure 9 : Root length measured in *Vigna mungo* L

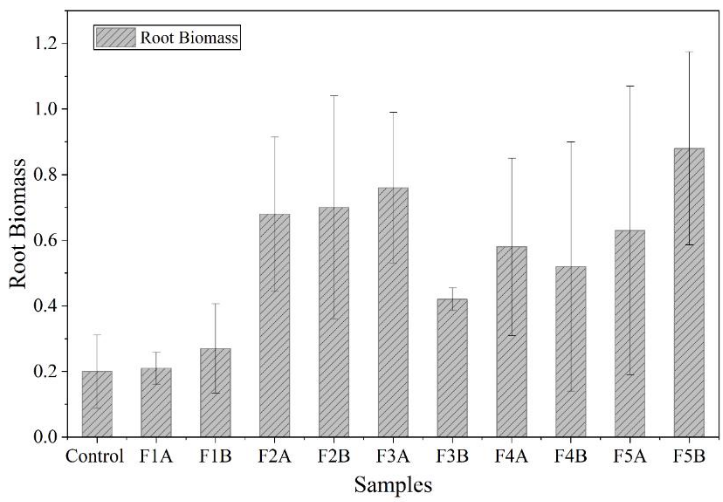

Figure 10 : Root Biomass measured in *Vigna mungo* L

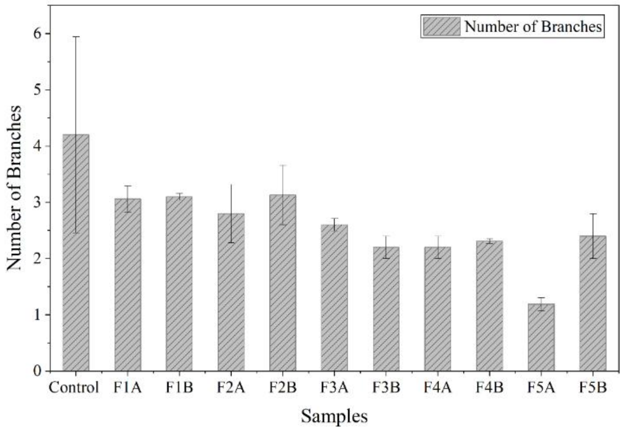

Figure 11: Number of Branches counted in *Vigna mungo* L

3.5 Bio-Chemical Parameters

To assess physiological changes, chlorophyll, protein and carbohydrate content were measured on day 30 of the pot culture study. These biomarkers reflect photosynthetic efficiency, metabolic capacity and overall plant health.

3.5.1 Chlorophyll Content

The Highest chlorophyll content was recorded in F5A group (*23.5 ± 0.40 mg/g*) of plants, followed closely by F2B (*22.5 ± 0.40 mg/g*) and F3A (*19.4 ± 0.4 mg/g*), while the lowest content was observed in the water-treated control (*0.433 ± 0.66 mg/g*) (Table 5 & Fig 12). The increase in the chlorophyll content in FPOLF plants indicates enhanced photosynthetic potential and enhanced nutrient uptake. These effects are likely due to bio-enhancing additives like rice water, curd, and jaggery to supply essential elements like magnesium and nitrogen, which were key components in chlorophyll biosynthesis [28, 32].

3.5.2 Protein

The maximum Protein accumulation was observed in F2A treatment (*7.46 ± 0.37 mg/g*), representing a 21.6% increase compared to the control (*6.13 ± 2.08 mg/g*). In contrast, F4B and the water-treated group showed comparatively lower protein levels ((Table 5 & Fig 12). The higher protein content in F2A is attributed to the presence of fermentable sugars and amino acid precursors in rice water and fruit peel combination which promote microbial nitrogen fixation and protein biosynthesis [29, 32].

3.5.3 Carbohydrate

Total carbohydrate content was observed that maximum in F2A (*2.8 ± 0.10 mg/g*) and F1A (*2.23 ± 0.15 mg/g*), while the lowest value was observed in F3B (*1.46 ± 0.21 mg/g*) and the control (*1.4 ± 0.43 mg/g*). All FPOLF combination have showed equal or higher carbohydrate levels compared to control (Table 5 & Fig 12). This Suggests that fruit peel such as (citrus *sinensis, citrus limetta, Ananas comosus, citrus limon, citrullus lanatus)* has improved the nutrient content in all combination especially (FP + rice water) has better result compared to standard facilitating easily absorbable nutrients [8, 20].

Table 5. Biochemical parameters of *Vigna mungo* L. treated with different FPOLF formulations on day 30

Treatment	Chlorophyll (mg/g FW)	Protein (mg/g FW)	Carbohydrate (mg/g FW)
Control (Water)	0.433 ± 0.66	6.13 ± 2.08	1.40 ± 0.43
F1A (Fruit peel 30%)	19.63 ± 0.51	7.06 ± 0.15	2.23 ± 0.15
F1B (Fruit peel 50%)	18.33 ± 0.58	6.46 ± 0.28	1.73 ± 0.32
F2A (Fruit peel + Rice water 30%)	2.37 ± 0.46	**7.46 ± 0.37**	**2.80 ± 0.10**
F2B (Fruit peel + Rice water 50%)	**22.50 ± 0.40**	6.76 ± 0.12	1.86 ± 0.57
F3A (Fruit peel + Curd 30%)	19.40 ± 0.40	6.60 ± 0.36	1.63 ± 0.40
F3B (Curd 50%)	15.06 ± 5.68	6.16 ± 0.23	1.73 ± 0.06
F4A (Jaggery 30%)	19.40 ± 0.10	6.30 ± 0.20	1.56 ± 0.25
F4B (Jaggery 50%)	18.40 ± 0.10	6.03 ± 9.12	1.46 ± 0.21
F5A (Fruit peel + Rice water + Curd 30%)	**23.50 ± 0.40**	6.93 ± 0.29	2.33 ± 0.32
F5B (Fruit peel + Rice water + Curd 50%)	21.70 ± 0.40	6.03 ± 0.15	1.83 ± 0.05

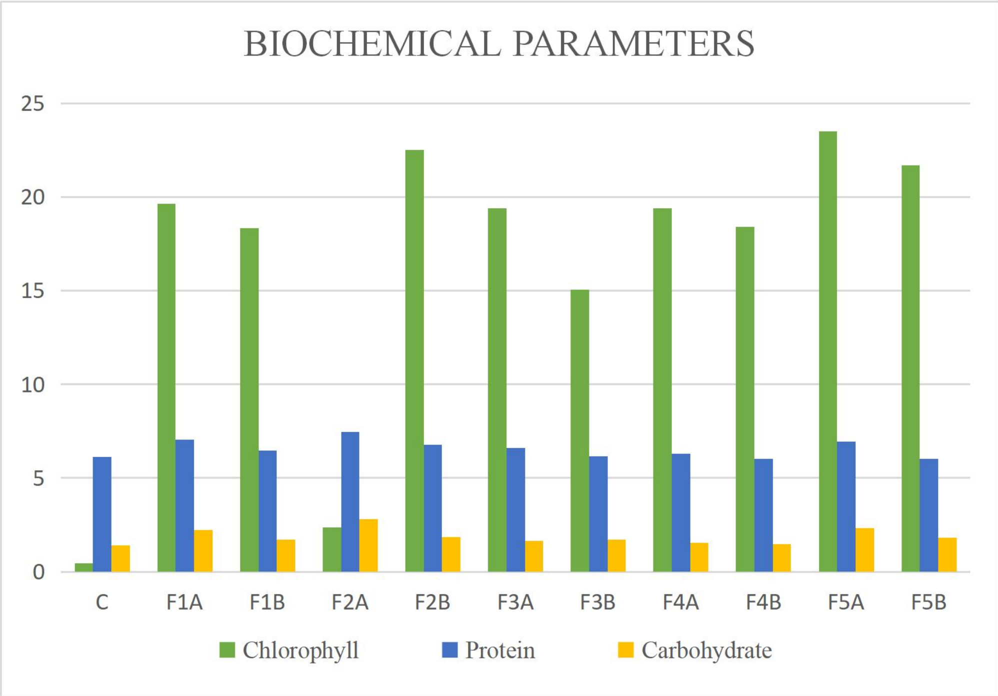

Figure 12: - Effect of FPOLF formulations on biochemical parameters (chlorophyll, protein, and carbohydrate) in *Vigna mungo* L. at 30 days.

Overall, the results indicate that FPOLF, particularly F2, is an effective, sustainable, and environmentally friendly alternative to chemical fertilizers. These formulations support plant growth, improve biochemical composition, and promote soil health, making them feasible for household gardens, smallholder farms, and organic farming systems.

4. CONCLUSION

The present study, fruit peel-based liquid organic fertilizer FPOLF, especially the F2 formulation (fruit peel + rice water), enhanced the growth and biochemical parameters of *Vigna mungo* L. Compared to untreated controls, FPOLF improved germination rate, seedling vigor, shoot and root biomass, and level of chlorophyll, protein, and carbohydrate levels. The enriched nutrient profile, bioactive compounds and micronutrients derived from fruit peels with additives such as rice water, curd, and jaggery. These plants exhibit enhanced nutrient bioavailability and increased microbial activity [28, 8]. These findings were aligned with previous research showing that low-concentration organic fertilizer derived from fruit waste can enhance both overall plant metabolism and soil health [32]. In conclusion, FPOLF represents a cost-effective, sustainable, environmentally friendly, responsible, and better alternative to chemical fertilizer supporting both plant growth and circular waste management. These fruit peel organic fertilizers are easily feasible in household settings and are relevant for smallholders, organic farming systems, and integrated nutrient management strategies.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. The authors have no financial, personal, or professional relationships that could have influenced the work reported in this study.

AUTHOR CONTRIBUTIONS

Sivasankar Murugesh : Conceptualization, methodology, investigation, data curation, formal analysis, visualization, Data analysis, interpretation of results, and writing original draft preparation. Santhoshkumar Muthu: Conceptualization, methodology, Supervision, validation, manuscript review and editing, project administration and manuscript review. Co-authors have also contributed for data curation, formal analysis, visualization, Data analysis, and interpretation of results.

REFERENCE

1. Kumari, A., Chauhan, S. and Singh, P., (2022). Global agricultural intensification: consequences and sustainable solutions. *Sustainable Agriculture Reviews*, 56, pp.23–40.
2. González-Sánchez, E.J., Ordóñez-Fernández, R. and Carbonell-Bojollo, R., (2023). Environmental implications of pesticide

overuse: challenges and potential alternatives. *Agriculture, Ecosystems & Environment*, 349, p.108456.

3. Meena, R.S., Kumar, S., Datta, R., Lal, R., Vijayakumar, V., Brtnicky, M., Sharma, M.P., Yadav, G.S., Jhariya, M.K. and Jangir, C.K., (2020). Impact of agrochemicals on soil microbiota and management: A review. *Land*, 9(2), p.34. https://doi.org/10.3390/land9020034
4. Hayat, S., Li, P., Menhas, S., Liu, W. and Hayat, K., (2025). Exploring the nutrient nexus in environmental systems: Nitrogen and phosphorus cycling, removal, recovery, and management. *Environmental Research*, 284, p.122162. https://doi.org/10.1016/j.envres.2025.122162
5. Al-Karaki, G.N. and Al-Omoush, M.A., (2021). Phosphorus and nitrogen pollution in agro-ecosystems: management strategies and emerging trends. *Agronomy*, 11(11), p.2303.
6. Li, X., Yang, J., Karroum, S., Bousseta, A., Wen, Y., Yan, Z., Zhong, Y., Xu, D., Luo, T., Zhong, B., Habibi, Y., & Wang, X. (2026). In-situ anchoring of hydroxyapatite nanorods on waste orange peel-derived phosphorylated carbon spheres for enhanced fertilizer stability. *Journal of Agricultural and Food Chemistry, 74*(6), 5078–5091. https://doi.org/10.1021/acs.jafc.5c12812
7. Ramesh, R., Das, S., & Reddy, G. (2023). Bio-valorization of fruit and vegetable waste: A sustainable solution to agricultural and environmental problems. *Environmental Technology & Innovation, 31*, 102057.
8. Kaushik, R., Morya, S., Bashir, O., Bhadha, J. H., & Kasankala, L. M. (2025). Valorization of fruit waste through reutilization approach: A comprehensive review. *eFood, 6*, e70073. https://doi.org/10.1002/efd2.70073
9. Yuan, X., Li, M., & Tang, Q. (2024). Comparison of aerobic composting and anaerobic digestion of fruit waste: Process performance and microbial dynamics. *Journal of Environmental Management, 348*, 119051.
10. Karthikeyan, S., Rani, A., & Suresh, M. (2022). Microbial acceleration in organic composting using jaggery and dairy inoculants. *Bioengineering, 13*(1), 8901–8914.
11. Lubisi, N. P., Matlala, M. E., Ramarumo, L. J., & Ndhlovu, P. T. (2025). Ethnobotanical and nutritional evaluation of understudied wild edible fruits in South Africa: Bridging indigenous knowledge and food security: A review. *Foods, 14*(10), 1726. https://doi.org/10.3390/foods14101726
12. Kumar, S., Rani, A., & Meena, V. S. (2022). Fruit and vegetable waste-derived bio enzymes: An eco-friendly approach for plant growth promotion. *Bioresource Technology Reports, 18*, 101049.
13. Muthukumar, T., Elango, D., & Rajkumar, R. (2023). Preparation of value-added compost using fruit and vegetable waste: A sustainable biowaste management approach. *Bioresource Technology Reports, 21*, 101275.
14. Itamah, E., Bello, T. K., & Waziri, S. M. (2025). Production and characterization of liquid bio-fertiliser from orange peels, banana peels, and eggshell. *Discover Agriculture, 3*, 174. https://doi.org/10.1007/s44279-025-00342-0
15. Min, J., Park, H., & Lee, K. (2014). Effects of low-concentration liquid fertilizer from food waste on seed germination and seedling growth. *Journal of Environmental Biology, 35*(5), 937–944.
16. Ramzan, K., Zehra, S. H., Balciunaitiene, A., Viskelis, P., & Viskelis, J. (2025). Valorization of fruit and vegetable waste: An approach to focusing on extraction of natural pigments. *Foods, 14*(8), 1402.
17. Food and Agriculture Organization of the United Nations. (2021). *Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region* (3rd ed.). Author.
18. Hussain, A., Iqbal, Z., Sabir, A., Alhomaidi, E., & Ahmad, M. (2026). Comparative impact of bio-organic and inorganic fertilizer application on soil health, grain quality and yield stability in nutrient deficient regions. *SOIL, 12*, 133–149. https://doi.org/10.5194/soil-12-133-2026
19. Kumar, S., Sharma, A., & Yadav, D. (2023). Comparative assessment of organic and synthetic fertilizers through nutrient content and bioavailability using AAS and colorimetric methods. *Soil and Environment, 42*(1), 13–22.
20. Singh, R., Meena, V. S., & Kumar, S. (2022). Evaluation of nutrient content in organic composts and biofertilizers using standard soil testing protocols. *International Journal of Recycling of Organic Waste in Agriculture, 11*(1), 45–55.
21. Warghane, A., Thakkar, J., Chauhan, K., Zala, D., Patel, H., Bhatt, V., & Chopade, B. A. (2025). Evaluating the impact of natural fertilizers on growth dynamics and yield performance of *Solanum melongena* L. *Frontiers in Sustainable Food Systems, 9*, 1668080. https://doi.org/10.3389/fsufs.2025.1668080
22. Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts: Polyphenol oxidase in *Beta vulgaris*. *Plant Physiology, 24*(1), 1–15.
23. Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 28*(3), 350–356.
24. Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry, 193*(1), 265–275.

25. Sharma, V., & Gupta, R. (2023). Bio-enhanced liquid organic fertilizers from fruit waste: A sustainable approach for soil and plant health. *Agricultural Research and Innovation, 9*(1), 45–52.
26. Singh, N., Verma, P., & Kumar, A. (2017). Bioactive properties of fruit peel-based composts: A strategy for plant protection. *Plant Pathology Journal, 33*(2), 121–128.
27. Bhardwaj, M. L., Sharma, R. C., & Kaushal, R. (2013). Organic farming in India: Problems and prospects. *Indian Journal of Agricultural Sciences, 83*(3), 240–245.
28. Singh, R., Kumar, R., & Meena, V. S. (2021). Evaluation of liquid biofertilizers in pot experiments for growth and yield performance of leguminous crops. *Agricultural Research, 10*(3), 402–410.
29. Tadesse, T., Dechassa, N., Bayu, W., & Gebeyehu, S. (2013). Effects of farmyard manure and inorganic fertilizers on the growth, yield and moisture stress tolerance of maize (*Zea mays* L.). *African Journal of Agricultural Research, 8*(35), 4576–4582.
30. Halim, Arma, M. J., Rembon, F. S., & Basruddin. (2025). Chemical characteristics of eco-enzymes as liquid organic fertilizer from vegetable waste and its impact to improve the growth of red onion (*Allium ascalonicum* L.) on marginal dry land. *International Journal of Agriculture and Biosciences, 14*(4), 582–588. https://doi.org/10.47278/journal.ijab/2025.050
31. Verma, R., Sharma, A., & Yadav, A. (2023). Development and optimization of fruit peel-based organic liquid fertilizers using microbial fermentation. *Waste and Biomass Valorization, 14*(6), 1923–1933.
32. Zhang, Y., Li, M., & Zhao, W. (2024). Conversion of citrus peel waste into bio fertilizer using thermophilic aerobic composting: Physicochemical and microbiological insights. *Bioresource Technology Reports, 17*, 101043.