Chemosphere 288 (2022) 132561

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Greener production of compost from agricultural biomass residues amended with mule dung for agronomic application

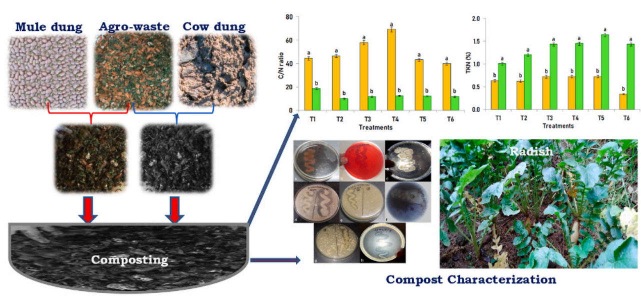
A. Sofia vizhimalar [a], M. Vasanthy [b], C. Thamaraiselvi [a,***], Muniyandi Biruntha [c], J. Arockia John Paul [d], Anand Thirupathi [e,**], Soon Woong Chang [f], Zhi Xu [g], Sarah Al-Rashed [h], Ganesh Munuswamy-Ramanujam [i], Balasubramani Ravindran [f,*]

[a] Department of Biotechnology, Mother Teresa Women's University, Kodaikanal, TamilNadu, India
[b] Department of Environmental Biotechnology, Bharathidasan University, Trichy, Tamilnadu, India
[c] Department of Animal Health and Management, Alagappa University, Karaikudi, 630 003, Tamil Nadu, India
[d] Department of Zoology, Arumugam Pillai Seethai Ammal College, Tiruppattur, 630 211, Tamil Nadu, India
[e] Faculty of Sports Science, Ningbo University, Ningbo, 315211, China
[f] Department of Environmental Energy and Engineering, Kyonggi University, Youngtong-Gu, Suwon, Gyeonggi-Do, 16227, Republic of Korea
[g] College of Resources and Environmental Science, Yunnan Agricultural University, Kunming, 650201, China
[h] Department of Botany and Microbiology, College of Science, King Saud University, P.O 2455, Riyadh, 11451, Saudi Arabia
[i] Interdisciplinary Institute of Indian System of Medicine, SRM-IST, Kattankulathur, Tamil Nadu, 603203, India

HIGHLIGHTS

- Equal parts of mule dung and agro waste (1:1, wt/wt) produced good quality compost.
- Isolated indigenous microbes had protease, amylase, cellulase and lipase activities.
- T2 final compost had pH 7.3, C/N ratio (10:1) after 90 days of aerobic degradation.
- Compost was non-phytotoxic with good manural stability and maturity index.
- Radish growth using T2 compost had good chlorophyll, vitamins and mineral values.

GRAPHICAL ABSTRACT



ARTICLE INFO

Handling Editor: Derek Muir

Keywords:
Agro-waste
Animal manure
Biodegradation
Manural stability
Raphanus sativus

ABSTRACT

In this study agro-waste (Agwt) was aerobically composted using cow dung (CD) and mule dung (MD). Totally six different sets of compost treatments were prepared, as T1 (Agwt + CD, 1:1), T2 (Agwt + MD, 1:1), T3 (Agwt + CD, 1:3), T4 (Agwt + MD, 1:3), T5 (Agwt + CD, 3:1) and T6 (Agwt + MD, 3:1) in individual containers. All the compost treatments were degraded for 90 days. The organic wastes in the treatment containers were maintained with proper moisture level. All the final composts reached good manural stability and maturity index after 90 days. Among the six treatments, the T2 with Agwt + MD in 1:1 proportion attained a 10:1 C/N ratio and a near neutral pH (7.3). Indigenous microbes isolated and identified from the T2 compost sample showed protease, cellulase, amylase and lipase activities. The germination of *Raphanus sativus* L. seeds and vigorous plant growth

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: thamaraibiotechnology@gmail.com (C. Thamaraiselvi), ananthzeal@gmail.com (A. Thirupathi), kalamravi@gmail.com (B. Ravindran).

https://doi.org/10.1016/j.chemosphere.2021.132561
Received 5 August 2021; Received in revised form 6 October 2021; Accepted 11 October 2021
Available online 12 October 2021

parameters confirmed the non-pathogenic phytotoxic-free nature of finished composts. The radish crops supplied with T2 compost showed healthy tuber growth parameters (16.6 cm width, 35.6 cm length) compared with other treatments. The results from the experiments established that, the composts derived are eco-friendly amendment to plants and it has also improved the soil fertility due to its stability and maturity index. Thus, the present study concluded that composting agricultural crops waste with animal manure, especially mule dung promoted excellent biodegradation of organic complexes. It is a nature friendly solution for the management of solid waste such as agro-wastes utilizing mule dung.

1. Introduction

Management of agro-wastes generated from agricultural practices has emerged as a significant global problem. Similarly, handling raw animal manure in a hygienic and in an eco-friendly process appears as a tedious process too. Composting technique is applied to convert organic waste into a splendidly decomposed component that improves the biological and physical nature of the recipient soil (Gautam et al., 2010). It is also a good option for recurring nutrients from croplands (Ali et al., 2012). In India, approximately 700 million tons of organic waste materials per year are disposed unsafely in the respective surrounding environment (Alfy et al., 2010). Yet, the countless indigenous soil microflora converts these biodegradable wastes into available nutrients to plants through their vigorous metabolic and enzymatic activities. The accessible organic nutrients improve the soil fertility, due to its good C:N content, pH stability, and also help in maintaining the ecological balance in a nature friendly manner (Dissara and Srimuang, 2010; Novinscak et al., 2008). So, there is an emergent need for cleaner and safe production methods of organic manures from biowastes (Ravindran et al., 2021).

Indeed, composting is an exothermic biological oxidation process widely accepted to recycle agricultural biomass residues under aerobic conditions. It transforms waste materials into a high quality fertilizer. Under stabilization, it is rich in organic matter, humic substance and nutrients (Insam and de Bertoldi, 2007). Thus the compost can be used as an effective soil conditioner. The microbes (bacteria, fungi and actinomycetes) degrade and break the complex organic matters into humus rich substances (Zeng et al., 2011). Waste stream comprising of food and agricultural wastes, cattle manure, paper and paper industry related byproducts, municipal and domestic organic waste including sludge are the potential sources of organic matter and play a key role in achieving sustainability in agricultural production, as all these provide good source of nutrients to improve soil productivity (Haq et al., 2016). The organic fertilizers have different plant residues, bio-oxidant decomposition minerals and primarily enhancer materials. The process of composting is reported that the CO_2 level rises in the initial stage as temperature elevates. The organic waste materials are reduced by mesophilic microbes as a result of protein and carbohydrate degradation. Subsequently, the increased temperature (45 °C–70 °C) permits the activity of the thermophiles over the degrading organic substances (Pedro et al., 2003; Schloss et al., 2003). During this stage, the pathogenic microbes get degraded. Finally at third stage, after saturation of decomposed materials the temperature in the compost piles declines. The compost transformation process involves the succession of specialized microbial communities that expresses a wide array of enzymes responsible for the changes in the physico-chemical properties of the substrate (Mondini et al., 2004). Monitoring the presence and activities of specific intracellular/extracellular enzymes during composting, provide great insights into the development of the waste biodegradation processes (Vargas-García et al., 2010).

Process of seed germination in plant life cycle is more significant and delicate (Ahmed, 2006). Acclimatizing a mature, non-dormant seed to an essential growth condition accelerated the physiological development leading to seed germination. Seed germination studies can be carried out under suitable substrate with experimental setup under observation for a period of time and growth. The nutrients from different sources of livestock wastes, cattle dung, poultry droppings, pig manure, and other biowastes can be recovered through different composting methods in a greener way to mitigate biowaste accumulation in the environment and green house gas emissions (Jayakumar et al., 2011; Rini et al., 2020; Chung et al., 2021). Importantly, the end products (composts) of biowaste stabilization are capable of improving crop growth, yield, and soil fertility in addition to reduced phytotoxicity (Ravindran et al., 2017; Siles-Castellano et al., 2020; Karmegam et al., 2021). Compost derived using plant sources usually constitutes low nutrient concentration, while the compost obtained by combining animal waste (dung/urine) along with plant sources has higher nutrient contents. Though cattle dung has been the major amendment material for biowaste composting, the use of mule dung in composting of agro-residues is not addressed. Hence, the present study was initiated with the aim to degrade the agricultural waste biomass accumulated in cultivation lands of Kodaikanal tribal hills, South India, along with mule dung and cow dung and analyzed for its microbiome. Also the study focused on the testing of phytotoxicity, maturity and stability index of prepared compost by growing *Raphanus sativus* L. crop and its yield quantification. This viewpoint could be substituted as effective and efficient strategies in the management of waste produced from agro-waste and dairy farm of Kodaikanal tribal hills, South India.

2. Materials and methods

2.1. Raw materials collected and used for the compost preparation

The raw materials used in this study, such as, agro-wastes and animal manures (cow dung: CD; Mule dung: MD) were freshly collected from the hills of Kodaikanal tribal villages. The non-commercial, poor graded vegetables that were segregated and left behind as waste biomass by the farmers in the agricultural fields, after crop harvest were utilized. The vegetables namely beans, cabbage, carrots, cauliflower, potatoes and leaves of radish were collected and collectively designated as agro-wastes. The animal manures, specifically CD and MD were collected from a dairy farm and cattle shed located in close proximity to the study area. Every part of the gathered raw-materials were used and prepared for composting process on the same day of collection. All the vegetable wastes were chopped to small pieces, approximately 3–5 cm size. The CD and MD were kept ready to prepare the composting treatments.

2.2. Preparation of compost substrates

Collected organic wastes were amended and blended into six different combinations with varied proportions. The treatments were prepared as T1 (Agwt + CD, 1:1), T2 (Agwt + MD, 1:1), T3 (Agwt + CD, 1:3), T4 (Agwt + MD, 1:3), T5 (Agwt + CD, 3:1) and T6 (Agwt + MD, 3:1). Sterile plastic containers were used to decompose the wastes materials aerobically. The moisture content in all the treatments was maintained between 40 and 50%. The composting treatments were maintained in triplicates and the process of composting was carried out for 90 days.

2.3. Compost characteristics

The compost samples degraded after 90 days were analyzed for its physico-chemical and manurial stability. The parameters such as pH, EC, total organic matter (TOM, %), total Kjeldahl nitrogen (TKN, %), total phosphorus (TP, %) and total potassium (TK, %). The TOC (total organic carbon) was analyzed following standard available protocols (Walkley and Black, 1934). Flame photometric method (Manohar, 2013) was adopted for the estimation of TK contents. The TKN content was estimated by acid digestion ($HClO_4$, HNO_3, H_2SO_4) followed by Kjeldahl procedure (Bremner, 1960). The contents of TP was calculated by Colorimetric method (American Public Health Association, 2006).

2.4. Isolation of bacteria and their characterization

The bacterial colonies isolated from the samples were purified through streak plate technique (Dye et al., 1974). The purified bacterial isolates were kept in slants containing nutrient agar medium. The phenotypic and cultural characteristics of the bacterial isolates were performed using standard procedures (Kandler, 1986). The bacterial isolates were tested for the production of amylase, protease, lipase and cellulase enzymes. Presence of amylase was confirmed using the methodology described by (Haddaoui et al., 1999). For this, microorganisms were grown on starch agar and after incubation; they were flooded with iodine for the formation of a zone which indicates presence of amylase. Casein hydrolysis assay was done to detect protease producing strains based on the method by (Vijayaraghavan and Vincent, 2013). Congo-red assay was done to identify the production of cellulase in the isolated bacteria. This was done by the standard protocol formulated by (Hendricks et al., 1995). Lipase producing bacteria produced hydrolysis zones in tributyrin agar medium (Lakshmi Narasu et al., 2010).

2.5. Effect of composts on *Raphanus sativus*

Phytotoxicity test was conducted for all the final composts obtained. A single set of commercial chemical fertilizer (FC) was also tested for its impact on *Raphanus sativus*. The plants were grown in field plots. The control plant (F0) was not provided with any additional nutrient substance for the growth enhancement, apart from water. The experimental plants (F1, F2, F3 and F4) were supplemented with composted (T1, T2, T3 and T4) samples respectively for the field assay. The test plots F1, F2, F3 and F4 were provided with 100 g of T1, T2, T3 and T4 compost samples respectively, before sowing the seeds on experimental field plots. Similarly, 100 g of chemical fertilizer was applied to FC test plot. Starting from seedling till development and growth, significant parameters, *viz.,* seed germination efficiency, height (stem and root), weight (fresh and dry), leaf area and number of leaves per plant were studied to analyze the manurial efficiency of the composts. Seeds of the plant *Raphanus sativus* were sown in 18 rows in triplicate for each individual treatments, 15 cm long, 1.5 m and 1 m wide, between 10 seeds on the course. The growth and yield performance of *Raphanus sativus* using chemical fertilizer was determined by procedures reported in past researches (Politud, 2016; Priyanka et al., 2018). The leaves of the radish plants were estimated for the total contents of chlorophyll using 80% acetone. The optical density was read using UV double beam spectrometer (Model: Systronics, 2202) at 645 and 663 nm for the leaf samples on the 30th, 60th, and 90th, days and the final values are expressed in mg/g (Li et al., 2018).

2.6. Estimation of nutritional and metal elements in *Raphanus sativus*

The radish roots grown in plots (F0, F1, F2 and FC) were tested for the accumulation of metals in their matured tissues. The plant tissues were subjected to centrifugation for 10 min at 15,000 rpm then filtered followed by suspension of particles. The residues obtained was dried and filtered. The weight of the mixture was measured and the amount of solubilized metal was estimated by means of gravimetric method and the metal concentration in digestate was gathered following filtration (Das and Ting, 2017). The micronutrients (Zn, Fe, Mn, and Cu) and macronutrients (N, P, K, Mg, Na and Ca) and organic matter in *Raphanus sativus.* grown using compost (T1 and T2) were determined by standard procedures. The total phosphorous was estimated using by the method described by Jackson (1973). The TOM and TKN were estimated as per the methods described in the compost analysis method. The parameters Na, Ca and Mg were subjected to widely use titrimetric chemical method. The S content was identified using the automatic elemental analyzer, while that of K, Fe, Zn, Cu and Mn were quantified using the wet digestion based on concentrate of H_2SO_4/H_2O_2 (Lowther, 2008). The contents of TK was determined on flame photometer and the contents of Fe, Cu, Mn and Zn were analyzed by the method adopted by (Manohar, 2013) using atomic absorption spectrophotometer (Thermo Fisher, Model: iCE3400AAS). The content of water soluble vitamins B complex and C were quantified by Datta et al. (2019) method.

Table 1
Physical and chemical characterization of raw materials used for composting.

Parameters	Agriculture waste	Cow dung	Mule dung
pH	8.40	8.10	8.50
EC (μS/cm)	486.58	472.10	480.40
TKN (%)	0.79	1.05	1.18
TOC (%)	47.56	32.14	46.45
TOM (%)	68.75	54.90	60.61
TP (%)	0.46	0.83	0.65
TK (%)	0.73	1.23	1.15
TN (%)	0.32	1.06	0.94
C/N ratio	60.20	30.61	39.36
C/P ratio	103.39	38.72	71.46

2.7. Statistical interpretations

The results obtained in the study are expressed as average of triplicate values of the conducted experiments. The treatments were carried out in a factorial in a completely randomized block design. The experimental data results were computed with two-way analysis of variance (Two-way ANOVA) by $P < 0.05$ significance level.

3. Results and discussion

3.1. Characteristics of compost

The physico-chemical characterization of all the control treatments and the test treatments were analyzed. Table 1 represents the results of all control treatments such as, Agwt, CD and MD. The pH of all the control sets fell under alkaline condition with 8.40 (Agwt), 8.10 (CD) and 8.50 (MD). Appearance of alkalinity in the compost sets was due to microbial interactions and ammonification of the raw materials along with its corresponding N, P and K concentrations. The electrical conductivity of the raw materials was 486.58 μS/cm, 472.10 μS/cm and 480.40 μS/cm for Agwt, CD and MD respectively. The compost stability and quality rely on the nature of its raw materials (Benito et al., 2003; Ranalli et al., 2007; Wang et al., 2004). In the composting process, different parameters are to be analyzed to determine the maturity and stability of the compost (Pan et al., 2011). Agricultural wastes, when compared with other materials, involve greater content of air and less capacity of retention of water (Iris Estévez-Schwarz et al., 2012). The agriculture waste products revealed higher content of almost all parameters such as TK, TOM, TN, TP and C/N ratio when compared with other raw materials because of the high percentage of organic material. The concentration of TK was 0.79% (Agwt), 1.05% (CD) and 1.18% (MD). The TN (%) was 0.73, 1.23 and 1.15 for Agwt, CD and MD respectively. The organic carbon content was 47.56% (Agwt), 32.14% (CD) and 46.45% (MD). The C/N ratio has reduced in the final compost thereby improving the productivity of the plant. These parameters were stable even after formation of compost thereby improving the growth and nutrition of *Raphanus sativus* with no side effects.

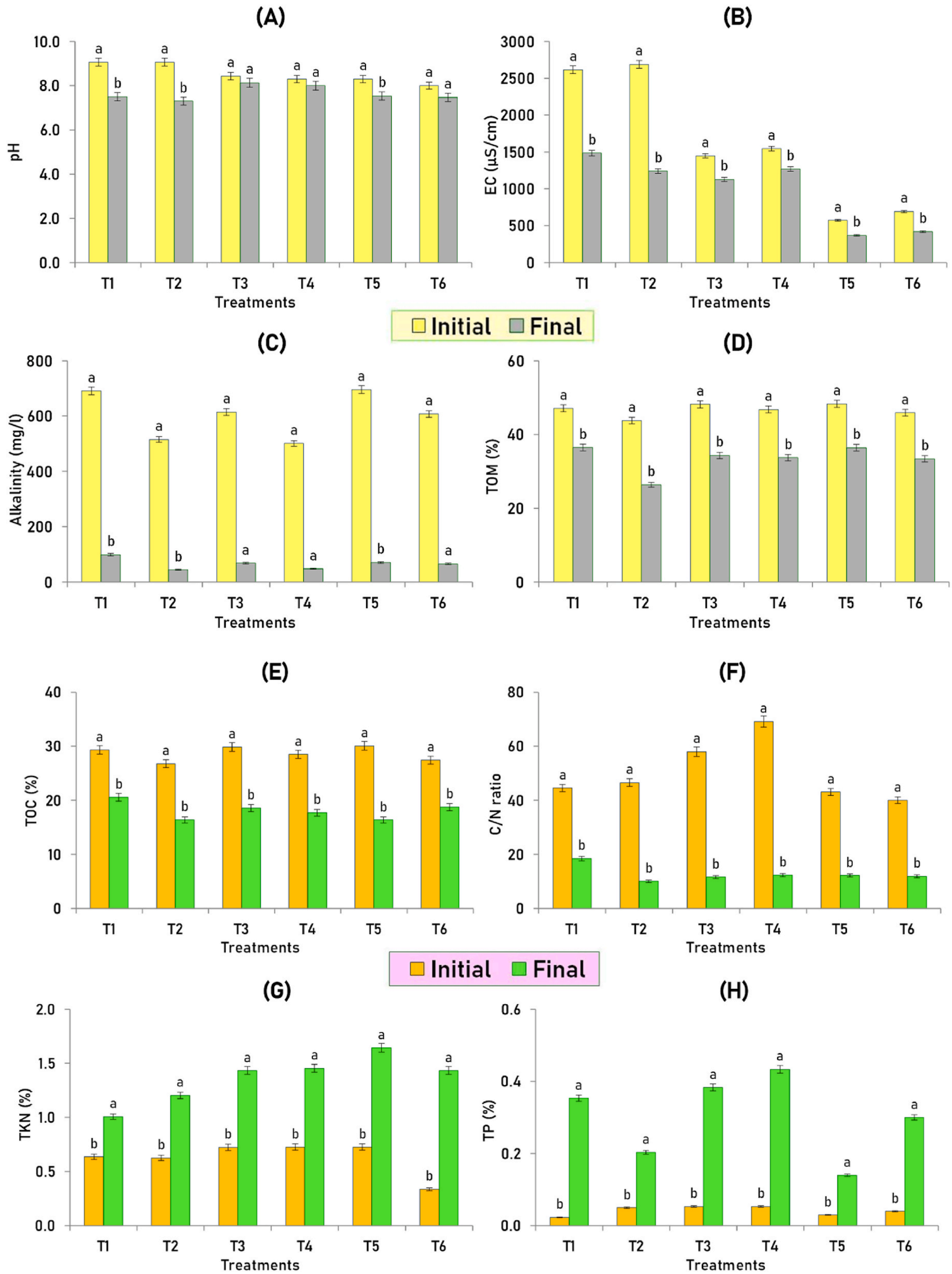


Fig. 1. Physico-chemical characterization of initial and final composts: (A) pH, (B) Electrical conductivity, (C) Alkalinity, (D) Total organic matter content (TOM), (E) Total organic carbon (TOC), (F) C/N ratio, (G) Total Kjeldahl nitrogen (TKN) and (H) Total phosphorus. Values are mean ± SD (error bars). T1 = Agwt + CD (1:1); T2 = Agwt + MD (1:1); T3 = Agwt + CD (1:3), T4 = Agwt + MD (1:3); T5 = Agwt + CD (3:1); T6 = Agwt + MD (3:1); Agwt-Agricultural waste, CD - Cow dung, MD - Mule dung.

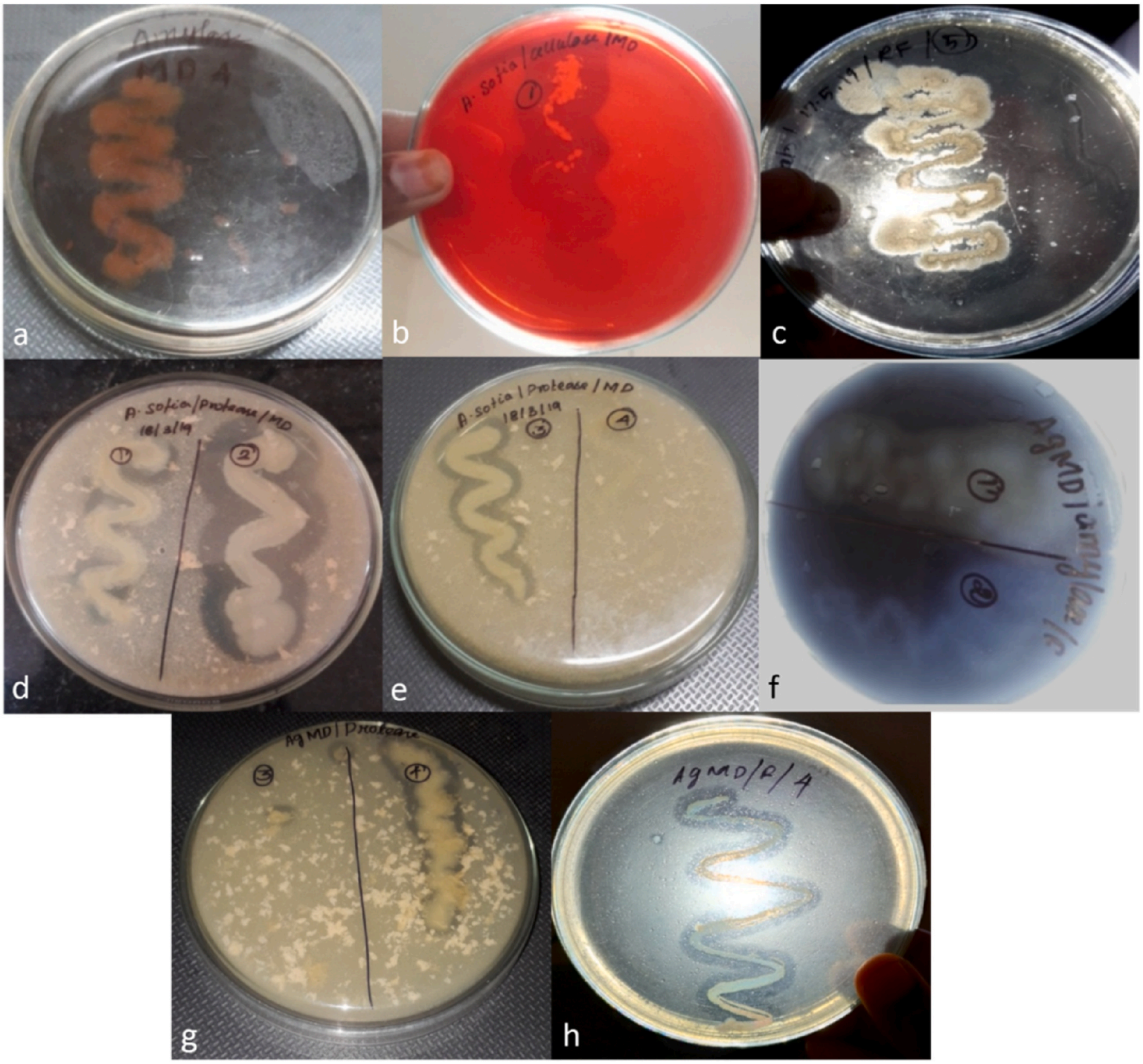


Fig. 2. Enzyme activities of isolates from agricultural waste with mule dung (Agmd) composts: **a.** amylase activity of the strain Agmd IV; **b.** cellulase activity of Agmd I; **c.** lipase activity of Agmd V; **d.** protease activity of Agmd I and II; **e.** protease activity of the strain Agmd III; **f.** amylase activity of the strain Agmd I and II; **g.** protease activity of the strains Agmd III and IV; **h.** lipase activity of Agmd IV.

The physical and chemical features of the compost obtained through mixing of Agwt, CD and MD in 6 different ratios were shown in Fig. 1 (A-H). Among all the six treatment compost sets T3 (8.1) and T4 (8) had alkaline pH, T1, T2, T3 and T6 attained near neutral pH. The alkalinity in the T4 and T4 composts were formed by ammonification of blended raw wastes. The near neutral condition of compost T1, T2, T3 and T6 was due to the process of acidification by the acidic bacteria and degradation of organic substances. The TK contents in the final composts were 0.31 (T1), 1.39 (T2), 1.15 (T3), 2.13 (T4), 0.63 (T5) and 1.26% (T6). The total organic nitrogen is estimated as total nitrogen minus inorganic nitrogen. In general, $>$ 95% of total compost nitrogen organically bound nitrogen. Completely decomposed materials during composting reach a stable C:N ratio between 10 and 15 while the composts made with woody materials usually have higher C:N ratios (above 20). The composts with broad range of C/N ratio may increase the nitrogen fertilizer requirement when applied to soil. Composts with low C/N ratio ($<$10) supply a considerable amount of plant available nitrogen in short period (Sullivan et al., 2018). The increase in potassium concentration in each compost sets is due to the assimilation and immobilization of potassium by microorganisms (Sharma et al., 2017). The potassium concentrations from the initial mixture were increased in the final phase of composting. Our results also support this study where the well-composted final compost showed much lesser C: N ratio. The final compost shows good physical properties than the initial compost.

3.2. Bacterial strains and characterization

Microbial counting analysis is important for certain applications. However, the biology of compost is very diverse, and when compost is applied to the soil, the organisms in the compost can be short-lived. Although these tests are of limited use in most fields of agriculture, controlled experiments to test the relationship between microbial test results and crop growth have not been performed (Dan M. Sullivan et al., 2018). Samples taken from a mixture of Agwt + MD (1:1) were examined to calculate the total microbial load of bacteria and 10^{-4} dilutions were distributed in vessels ranging from 60.5×10^{-4} to 175×10^{-4} CFU/ml, with the lowest concentration observed at 10^{-6} dilutions ranging from 23.5×10^{-6} to 80.5×10^{-6} CFU/ml. The isolated strains such as Agmd I, Agmd II and Agmd IV were Gram positive primers, and Agmd III was Gram negative for rods and had endogenous spore formation. The indigenous microbes capably transformed insoluble organic matter into soluble complex easily absorbed by the plant roots. The microbes effectively survived on the carbon sources applied through the compost and improved the soil condition. The microbial colonies of the

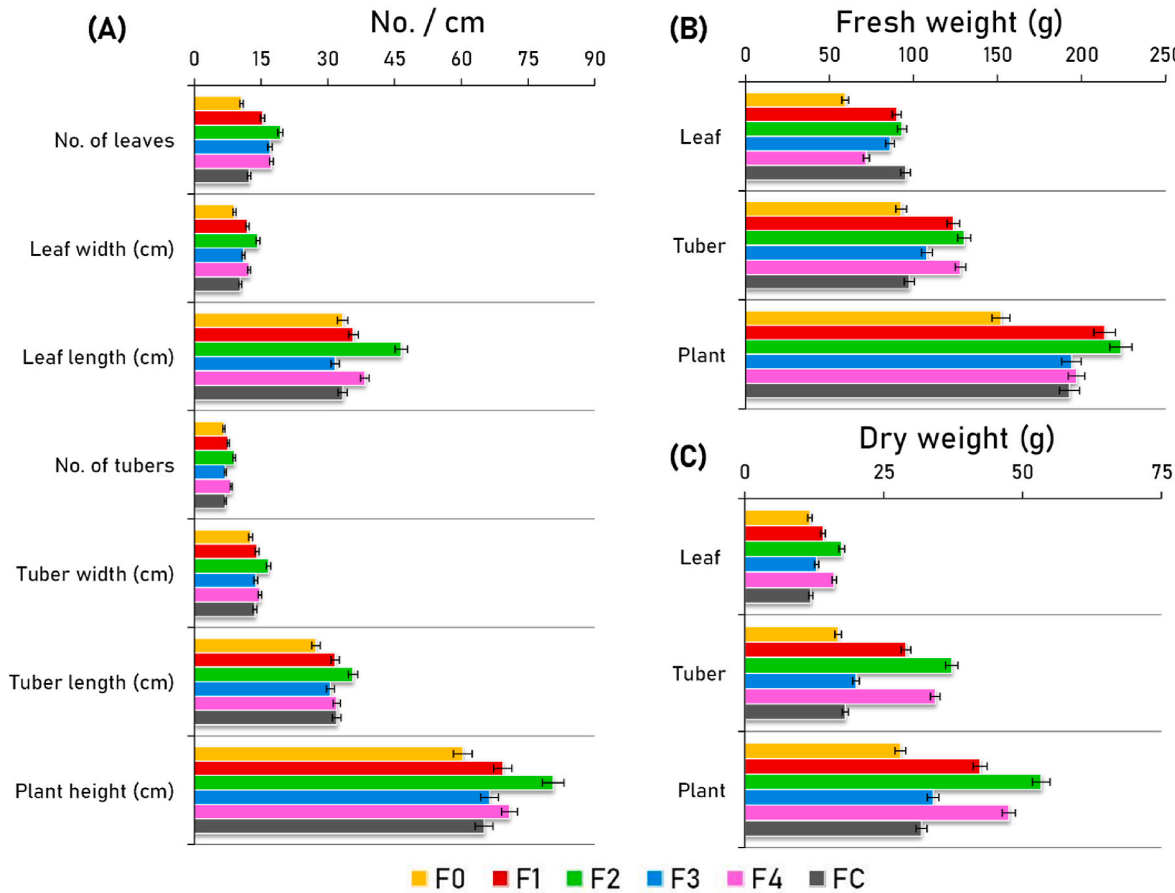


Fig. 3. Growth and yield characteristics of *Raphanus sativus* in different treatments. F0 = Control without compost/fertilizer; Values are mean ± SD (error bars). F1 = T1 compost; F2 = T2 compost; F3 = T3 compost; F4 = T4 compost; FC = Chemical fertilizer.

compost samples efficiently increased the activity of rhizosperic microbes in the plant growth promoting factors. In bacterial cells, biochemical reactions are regulated by factors such as enzymes. Enzymes are essentially hydrolyzed and can break down into smaller components when added to water, polysaccharides, lipids, and proteins (Teo and Teoh, 2013). The isolated bacteria were tested for protease, amylase, cellulase, and lipase activity (Fig. 2), three strains were active in amylase production and 4 strains produced proteases. The strains, Agmd I, Agmd II and Agmd IV showed amylase activity. Agmd IV and V showed lipase activity and the Agmd I isolate was able to produce cellulase.

3.3. *Effect of compost on Raphanus sativus*

Fig. 3 shows quality characteristics of radish using the organically prepared compost and also usage of inorganic fertilizer in combination with organic manure (Agwt, CD, and MD). In plants, the number of leaves increased when treated with a mixture of Ag waste and MD, and less production was shown by the plant without fertilizer. The number of radish yield was also higher in the plant treated with Ag waste and MD mixture and low number production were observed in the plant with no fertilizer treatment, these finding were also in accordance with (Islam et al., 2017a,b) findings. The number and weight of radishes is the paramount component and leaf number was also significantly influenced by the application of either organic fertilizer alone or combined use of inorganic sources. Enhanced yields were recorded from combined fertilizer applications in comparison to the treatment without fertilizer. The organic compost prepared from biodegradable wastes had enriched nutrients and microbial community. These microbes and their resultant enzymes have positive impact on environment and agriculture. Application of organic fertilizers elevated the acidic conditions of the soil and thereby produced good crop yield. Long-term application of chemical fertilizer for crop growth, steadily decreased the fertility of soil, increased the acidity and heavy metal concentrations of soil, degraded the natural soil micro flora, thus converting the soil to an impotent status (Li et al., 2018).

However, quality parameters were only slightly increased in Agwt and MD mixture as well as the chemical fertilizers. A similar response was noticed in the study of (Jadoon et al., 2003). The application of F2 (Agwt + MD, 1:1 ratio) produced the maximum weight of fresh root, dry root; fresh or dry leaf and height of fresh and dry plant also. The lowest numbers of leaves were found with the control, the other factors were also low in the control group. The height of the plant varied in different ratios of fertilizer mixer treatments. The higher value of plant height (80.33 cm) was recorded in the T2. The treatment with fertilizer was found to be good for the production of radish which might have attributed to the nutrient availability and release from compost and fertilizer time to time for the crop. There were previous reports supporting the results obtained in the present investigation. Combined treatment (mixed) resulted in enhanced yields in comparison with compost and urea applied alone (Islam et al., 2017a,b). The best yield of radish was found when the inorganic fertilizer is mixed with cow dung (Imthiyas and Seran, 2017). The microorganisms enhance the availability of nutrients, efficiency and influence the growth of the plant as it help in synthesis of plant hormones or the facilitating the uptake of nutrients from soil with several mechanisms such as fixation of atmospheric nitrogen, phosphorus solubilization and synthesizes of siderophores for Fe sequestration, making nutrients available to plants (Bona et al., 2016).

The chlorophyll content alteration may be because of factors such as

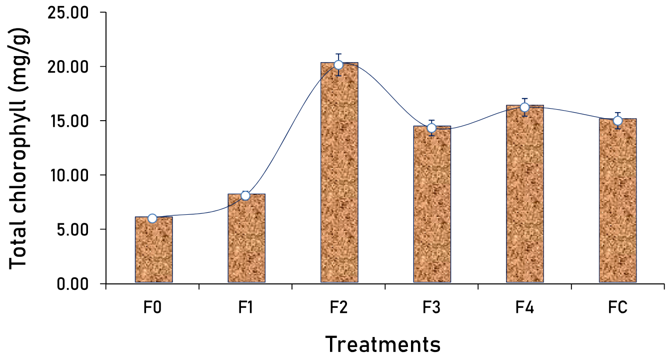


Fig. 4. Average total chlorophyll content of *Raphanus sativus* different treatments. F0 = Control without compost/fertilizer; Values are mean ± SD (error bars). F1 = T1 compost; F2 = T2 compost; F3 = T3 compost; F4 = T4 compost; FC = Chemical fertilizer.

Table 2
Proximate composition of metal content of *Raphanus sativus sativus* using compost (dry weight basis, mg/100 g).

Parameters	F0	F1	F2	FC
Ca	26 ± 0.06	32 ± 0.02	46 ± 0.05	30 ± 0.03
Na	20 ± 0.03	28 ± 0.00	48 ± 0.06	24 ± 0.01
K	16 ± 0.00	26 ± 0.00	42 ± 0.03	23 ± 0.03
Mg	13 ± 0.03	17 ± 0.03	20 ± 0.05	15 ± 0.00
Fe	1.01 ± 0.03	3 ± 0.00	4 ± 0.06	2 ± 0.03
Cu	0.02 ± 0.03	0.03 ± 0.02	0.08 ± 0.06	0.02 ± 0.00
Zn	0.1 ± 0.00	0.20 ± 0.03	0.41 ± 0.02	0.21 ± 0.02
Mn	0.04 ± 0.01	0.1 ± 0.03	0.23 ± 0.00	0.08 ± 0.02

F0 = Control without compost/fertilizer; F1 = T1 compost; F2 = T2 compost; FC = Chemical fertilizer.

Table 3
Vitamins content (in mg/g) of *Raphanus sativus* roots (dry weight).

Vitamins	F0	F1	F2	FC
Thiamin (B1)	0.12 ± 0.05^{c}	0.18 ± 0.03^{b}	0.24 ± 0.04^{a}	0.15 ± 0.06^{bc}
Riboflavin (B2)	0.13 ± 0.02^{b}	0.14 ± 0.02^{b}	0.18 ± 0.03^{a}	0.16 ± 0.03^{ab}
Niacin (B5)	1.60 ± 0.05^{d}	2.7 ± 0.03^{b}	3.3 ± 0.04^{a}	2.0 ± 0.04^{c}
Vitamin C	14.0 ± 0.03^{b}	20 ± 0.03^{ab}	23 ± 0.06^{a}	19 ± 0.04^{b}

F0 = Control without compost/fertilizer; F1 = T1 compost; F2 = T2 compost; FC = Chemical fertilizer. The same alphabet between treatments are non-significant by ANOVA ($P < 0.05$). Values are mean ± SD.

water, soil, temperature stress, including other parameters which incidentally impact the leaf development and functionality. The high concentration of growth regulators of the plant shows higher content of chlorophyll (Sardoei et al., 2014). The findings demonstrated that the chlorophyll content ranged between 6 and 20.14 mg/g and from the result it is also seen that the organic fertilizer Ag waste and MD mixture treated plant had the highest concentration of chlorophyll (Fig. 4). The control group (without fertilizer) was found to have the least quantity of chlorophyll content. Six sets of fertilizers were used for the experiment, each one showed little difference in the chlorophyll concentration. The quantitative variation of content of chlorophyll could be influenced by health and habitat of the plants, surface area of leaf and soil nutrition (Bojovic and Stojanovic, 2005). The chlorophyll content showed remarkable variation between different treatments.

3.4. Nutritional analysis from the roots of Raphanus sativus

The use of different fertilizers in *Raphanus sativus* significantly influenced the uptake of metal components and the vitamin precursors contained in a solid waste matrix into different fractions, based on their composition. The contents of Ca and Na were found in large quantities. A considerable part of TK continued to be combined with organic matter. Like other results, the mixture of Ag waste and mule dung compost treated plant showed presence of more quantity of metals. As shown from Table 2, in F2 the Ca and Na were abundantly present. The employment of sequential extraction procedures is fundamental determinant factor in the most effective acid digestion methodology for a particular kind of waste, as it allows insight into the chemical forms of various metals. Table 3 shows the quantity of vitamins, vitamin C was highly present in the plant and riboflavin (B2) was the least quantity of vitamin in the plant under study. The mule dung amended compost showed significantly higher contents ($P < 0.005$) than other treatments.

4. Conclusions

Among differently proportioned compost treatments, the Agwt amended with mule dung (1:1) attained higher stability and maturity index within 90 days. Thus acquired near neutral pH and good C/N ratio, it enhanced the growth and development of crop *Raphanus sativus* vigorously by supplementing the most essential nutrients. The matured and stabilized compost possessed environmentally beneficial and efficient microbes which converted the available nutrients to the crop from complex to simple form. The splendid organic compost T2 enhanced the soil fertility and support radish growth. It was obvious from the quantity of nutrients and plant growth factors tested. This study concluded that agricultural biomass wastes and the mule dung can be used as an alternate resource in waste decomposition and the end product could be used as an organic nutrient supplement for enhancing soil fertility and supporting crop growth in an eco-friendly manner.

Credit author statement

C. Thamaraiselvi, Balasubramani Ravindran, M. Vasanthy, Anand Thirupathi: Conceptualization, Methodology, Software A. Sofia vizhimalar, Muniyandi Biruntha, J. Arockia John Paul: Data curation, Writing- Original draft preparation. C. Thamaraiselvi, Balasubramani Ravindran: Visualization, Investigation. Sarah Al-Rashed,A.Sofia vizhimalar, Ganesh Munuswamy-Ramanujam, Balasubramani Ravindran: Software, Validation A. Sofia vizhimalar,C. Thamaraiselvi, Balasubramani Ravindran, M. Vasanthy, Soon Woong Chang, Zhi Xu, Sarah: Writing- Reviewing and Editing,

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors gratefully acknowledge the support rendered by Tamil Nadu State Council for Science and Technology (TNSCST/S&T projects/VR/ES/02/2018-2019), Chennai for carrying out this work. This work was supported by the National Research Foundation of Korea by the Korean Government (Ministry of Science and ICT ~ MSIT) (2020R1G1A1012069). The authors extend their appreciation to the Researchers Supporting Project number (RSP-2021/200), King Saud University, Riyadh, Saudi Arabia.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chemosphere.2021.132561.

References

Ahmed, S., 2006. Effects of soil salinity on the yield and yield components of mungbean. Int.J.Biol.Biotech 3, 753–756.

Alfy, Z. El, Elhadary, R., Elashry, A., 2010. Integrating GIS and MCDM to Deal with landfill site selection. Int. J. Eng. Technol. 10, 36–42.

Ali, M., Duba, K.S., Kalamdhad, A.S., Bhatia, A., Khursheed, A., Kazmi, A.A., Ahmed, N., 2012. High rate composting of herbal pharmaceutical industry solid waste. Water Sci. Technol. 65, 1817–1825. https://doi.org/10.2166/WST.2012.082.

American Public Health Association, 2006. Standard Methods for the Examination of Water and Wastewater —Section 9222D Thermotolerant (Fecal) Coliform Membrane Filter Procedure. American Water Works Association, Water Environment Federation, Washington, D.C.

Benito, M., Masaguer, A., Moliner, A., Arrigo, N., Palma, R.M., 2003. Chemical and microbiological parameters for the characterisation of the stability and maturity of pruning waste compost. Biol. Fertil. Soils 373 37, 184–189. https://doi.org/10.1007/S00374-003-0584-7, 2003.

Bojovic, B., Stojanovic, J., 2005. Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. Arch. Biol. Sci. 57, 283–290. https://doi.org/10.2298/ABS0504283B.

Bona, E., Cantamessa, S., Massa, N., Manassero, P., Marsano, F., Copetta, A., Lingua, G., D`Agostino, G., Gamalero, E., Berta, G., 2016. Arbuscular mycorrhizal fungi and plant growth-promoting pseudomonads improve yield, quality and nutritional value of tomato: a field study. Mycorrhiza 271 27, 1–11. https://doi.org/10.1007/S00572-016-0727-Y, 2016.

Bremner, J.M., 1960. Determination of nitrogen in soil by the Kjeldahl method. J. Agric. Sci. 55, 11–33. https://doi.org/10.1017/S0021859600021572.

Chung, W.J., Chang, S.W., Chaudhary, D.K., Shin, J., Kim, H., Karmegam, N., Govarthanan, M., Chandrasekaran, M., Ravindran, B., 2021. Effect of biochar amendment on compost quality, gaseous emissions and pathogen reduction during in-vessel composting of chicken manure. Chemosphere 283, 131129. https://doi.org/10.1016/J.CHEMOSPHERE.2021.131129.

Das, S., Ting, Y.-P., 2017. Evaluation of wet digestion methods for quantification of metal content in electronic scrap. Mater. Res. 6, 64. https://doi.org/10.3390/RESOURCES6040064. Page 64 6.

Datta, S., Sinha, B.K., Bhattacharjee, S., Seal, T., 2019. Nutritional composition, mineral content, antioxidant activity and quantitative estimation of water soluble vitamins and phenolics by RP-HPLC in some lesser used wild edible plants. Heliyon 5, e01431. https://doi.org/10.1016/J.HELIYON.2019.E01431.

Dissara, Y., Srimuang, N., 2010. Chemical physical and microbiological changes during composting of the water hyacinth article in Pakistan. J. Biol. Sci. https://doi.org/10.3923/pjbs.2010.985.992.

Dye, D.W., Lelliott, R.A., Buchanan, R., Gibbons, N., 1974. Genus II. Xanthomonas Dowson 1939, 187.

Estévez-Schwarz, Iris, Seoane-Labandeira, Socorro, Núñez-Delgado, Avelino, López-Mosquera, María Elvira, 2012. Production and characterization of compost made from garden and other waste [WWW document]. Pol. J. Env.

Gautam, S.P., Bundela, P.S., Pandey, A.K., Awasthi, M.K., Sarsaiya, S., 2010. Composting of municipal solid waste of jabalpur city. Global J. Environ. Res. 43–46.

Haddaoui, E., Chambert, R., Petit-Glatron, M.F., Lindy, O., Sarvas, M., 1999. Bacillus subtilisα-amylase: the rate limiting step of secretion is growth phase-independent. EMS Microbiol. Lett. 173, 127–131.

Haq, T., Begum, R., Ali, T.A., Iqbal, S., Khan, F.A., 2016. Tooba Haq, Razia Begum , Tasneem Adam Ali (2016).... - Google Scholar Int J Sci Res Publ 6, 257–262.

Hendricks, C.W., Doyle, J.D., Hugley, B., 1995. A new solid medium for enumerating cellulose-utilizing bacteria in soil. Appl. Environ. Microbiol. 61, 2016–2019. https://doi.org/10.1128/AEM.61.5.2016-2019.1995.

Imthiyas, M.S.M., Seran, T.H., 2017. Marketable tuber yield of radish (*Raphanus sativus* L.) as influenced by compost and NPK fertilizers. Res. J. Agric. For. Sci. 5, 1–4.

Insam, H., de Bertoldi, M., 2007. Chapter 3 Microbiology of the composting process. In: Waste Management Series. Elsevier, pp. 25–48. https://doi.org/10.1016/S1478-7482(07)80006-6.

Islam, Md Ashraful, Ferdous, G., Akter, A., Hossain, M.M., Nandwani, D., 2017a. Effect of organic, inorganic fertilizers and plant spacing on the growth and yield of cabbage. Agric. For. 7 https://doi.org/10.3390/AGRICULTURE7040031.

Islam, M. Ashraful, Islam, S., Akter, A., Rahman, M.H., Nandwani, D., 2017b. Effect of organic and inorganic fertilizers on soil properties and the growth, yield and quality of tomato in mymensingh, Bangladesh, 2017 Agric. For. 7, 18. https://doi.org/10.3390/AGRICULTURE7030018. Page 18 7.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India.

Jadoon, M., Bhatti, A., Khan, F., 2003. Effect of farm yard manure in combination with NPK on the yield ofmaize and soil physical properties. Pakistan J. Soil Sci. 22, 47–55.

Jayakumar, M., Sivakami, T., Ambika, D., Karmegam, N., 2011. Effect of Turkey litter (*Meleagris gallopavo* L.) vermicompost on growth and yield characteristics of paddy, *Oryza sativa* (ADT-37). Afr. J. Biotechnol. 10 https://doi.org/10.5897/ajb11.2253.

Kandler, O., 1986. Genus lactobacillus beijerinck 1901. Bergey's man. Syst. Bacteriol. 2, 1063–1065. https://doi.org/10.1016/J.JBIOSC.2009.12.010.

Karmegam, N., Jayakumar, M., Govarthanan, M., Kumar, P., Ravindran, B., Biruntha, M., 2021. Precomposting and green manure amendment for effective vermitransformation of hazardous coir industrial waste into enriched vermicompost. Bioresour. Technol. 319, 124136. https://doi.org/10.1016/j.biortech.2020.124136.

Lakshmi Narasu, M., Sirisha, E., Rajasekar, N., 2010. Isolation and optimization of lipase producing bacteria from oil contaminated soils. Adv. Biol. Res. 4, 249–252.

Li, S., Tian, Y., Wu, K., Ye, Y., Yu, J., Zhang, J., Liu, Q., Hu, M., Li, H., Tong, Y., Harberd, N.P., Fu, X., 2018. Modulating plant growth–metabolism coordination for sustainable agriculture. Nat 595–600. https://doi.org/10.1038/s41586-018-0415-5, 2018 5607720 560.

Lowther, J.R., 2008. Use of a single sulphuric acid - hydrogen peroxide digest for the analysis of pinus radiata needles. Commun. Soil Sci. Plant Anal. 11, 175–188. https://doi.org/10.1080/00103628009367026.

Manohar, R.S., 2013. Practical Manual for Soil, Plant and Water Analysis [SCHEM 4412] 2013. Department of Soil Science and Agricultural Chemistry.

Mondini, C., Fornasier, F., Sinicco, T., 2004. Enzymatic activity as a parameter for the characterization of the composting process. Soil Biol. Biochem. 36, 1587–1594. https://doi.org/10.1016/J.SOILBIO.2004.07.008.

Novinscak, A., Filion, M., Surette, C., Allain, C., 2008. Application of molecular technologies to monitor the microbial content of biosolids and composted biosolids. Water Sci. Technol. 57, 471–477. https://doi.org/10.2166/WST.2008.019.

Pan, I., Dam, B., Sen, S.K., 2011. Composting of common organic wastes using microbial inoculants. 3 Biotech 22 (2), 127–134. https://doi.org/10.1007/S13205-011-0033-5, 2011.

Pedro, M.S., Haruta, S., Nakamura, K., Hazaka, M., Ishii, M., Igarashi, Y., 2003. Isolation and characterization of predominant microorganisms during decomposition of waste materials in a field-scale composter. J. Biosci. Bioeng. 95, 368–373. https://doi.org/10.1016/S1389-1723(03)80069-5.

Politud, E.R.R., 2016. Growth and yield performance of radish (Raphanus sativus L.) 'cv' "SNOW WHITE" in response to varying levels of vermicast applications. Int. J. Sci. Res. Publ. 6, 53.

Priyanka, M., Lakshmi, K.S., Reddy, P.S.S., Reddy, D.S., Krishna, S.B., 2018. Nteraction effect of varieties and sowing dates on growth and quality of radish in southern agro climatic zone of Andhra Pradesh. Int. J. Pure Appl. Biosci. 6, 227–231.

Ranalli, G., Bottura, G., Taddei, P., Garavani, M., Marchetti, R., Sorlini, C., 2007. Composting OF solid and sludge residues from agricultural and food industries. BIOINDICATORS OF MONITORING AND COMPOST MATURITY 415–436. https://doi.org/10.1081/ESE-100103473 https://doi.org/10.1081/ESE-100103473 36.

Ravindran, B., Mupambwa, H.A., Silwana, S., Mnkeni, P.N.S., 2017. Assessment of nutrient quality, heavy metals and phytotoxic properties of chicken manure on selected commercial vegetable crops. Heliyon 3. https://doi.org/10.1016/j.heliyon.2017.e00493.

Ravindran, B., Karmegam, N., Yuvaraj, A., Thangaraj, R., Chang, S.W., Zhang, Z., Kumar Awasthi, M., 2021. Cleaner production of agriculturally valuable benignant materials from industry generated bio-wastes: a review. Bioresour. Technol. 320, 124281. https://doi.org/10.1016/j.biortech.2020.124281.

Rini, J., Deepthi, M.P., Saminathan, K., Narendhirakannan, R.T., Karmegam, N., Kathireswari, P., 2020. Nutrient recovery and vermicompost production from livestock solid wastes with epigeic earthworms. Bioresour. Technol. 313, 123690. https://doi.org/10.1016/j.biortech.2020.123690.

Sardoei, A.S., Rahbarian, Parviz, Shahdadneghad, Mojgan, 2014. Evaluation chlorophyll contents assessment on three indoor ornamental plants with plant growth regulators. Eur. J. Exp. Biol. 4, 306–310.

Schloss, P., Hay, A., Wilson, D.B., Walker, L.P., 2003. Tracking temporal changes of bacterial community fingerprints during the initial stages of composting. FEMS Microbiol. Ecol. 46, 1–9.

Sharma, D., Sudharsan Varma, V., Kunwar Yadav, D., Kalamdhad, A.S., 2017. Evolution of chemical and biological characterization during agitated pile composting of flower waste. Int. J. Recycl. Org. Waste Agric. 6 https://doi.org/10.1007/s40093-017-0155-9.

Siles-Castellano, A.B., López, M.J., López-González, J.A., Suárez-Estrella, F., Jurado, M. M., Estrella-González, M.J., Moreno, J., 2020. Comparative analysis of phytotoxicity and compost quality in industrial composting facilities processing different organic wastes. J. Clean. Prod. 252, 119820. https://doi.org/10.1016/J.JCLEPRO.2019.119820.

Sullivan, D.M., Bary, A.I., Miller, R.O., Brewer, L.J., 2018. Interpreting Compost Analyses.

Teo, K., Teoh, S., 2013. Preliminary biological screening of microbes isolated from cow dung in Kampar. Afr. J. Biotechnol. 10, 1640–1645. https://doi.org/10.4314/ajb.v10i9.

Vargas-García, M.C., Suárez-Estrella, F., López, M.J., Moreno, J., 2010. Microbial population dynamics and enzyme activities in composting processes with different starting materials. Waste Manag. 30, 771–778. https://doi.org/10.1016/j.wasman.2009.12.019.

Vijayaraghavan, P., Vincent, S.G.P., 2013. A simple method for the detection of protease activity on agar plates using bromocresolgreen dye. J. Biochem. Technol. 628–630.

Walkley, A., Black, I.A., 1934. AN examination OF the DEGTJAREFF method for determining soil. Soil Science. Soil Sci. 37, 29–38.

Wang, P., Changa, C.M., Watson, M.E., Dick, W.A., Chen, Y., Hoitink, H.A.J., 2004. Maturity indices for composted dairy and pig manures. Soil Biol. Biochem. 36, 767–776. https://doi.org/10.1016/J.SOILBIO.2003.12.012.

Zeng, G., Yu, Z., Chen, Y., Zhang, J., Li, H., Yu, M., Zhao, M., 2011. Response of compost maturity and microbial community composition to pentachlorophenol (PCP)-contaminated soil during composting. Bioresour. Technol. 102, 5905–5911. https://doi.org/10.1016/J.BIORTECH.2011.02.088.