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Evaluating the effect of neem cake and urea to enhance the nitrogen content during food waste composting

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ABSTRACT:

Low nutrient content, especially nitrogen, often reduces the market value of the compost products. This study aimed at composting food waste (FW) with neem cake (NC) as co-substrate and urea (UR) to achieve a high-nutrient compost. The food waste and sawdust mixed at 1:1 ratio (on a dry basis) were mixed with 30% of NC and this mix was added with urea at 1.5% and 3% individually, while the FW and FW+NC served as controls to evaluate the influence of NC and added urea, respectively. The substrates were composted in 20-L in-vessel composters with aeration for 42 days. Addition of 30% NC resulted in a decrease in the EC from 2.60 mS/cm to 2.25 mS/cm. Total Kjeldahl nitrogen (TKN) content gradually decreased at the beginning of the composting and gradually increased thereafter. The TKN contents were 2.33 ± 0.17% in FW+NC30, 2.84 ± 0.50% in FW+NC30+UR1.5, 3.11± 0.30% in FW+NC30+UR3 and 1.89±0.01% in control treatments. The results indicate addition of 3% urea showed maximum N content; however, the compost products exerted phytotoxicity as evidenced from the very low seed germination index. Addition of 1.5% urea alongwith 30% neem cake is recommended to increase the nitrogen content of the food waste compost.

Keywords: Food waste, co-composting, neem cake, urea, nitrogen content.

1. Introduction

India is the world's largest populated country and a fastest-developing nation, but it also produces a massive volume of municipal solid waste (MSW). The production of MSW and its controlled handling, disposal, and treatment are important global issues that affect India as well. Food waste is the largest organic fraction of MSW by weight and constitutes about 14-40% in different countries. These organic wastes are complex in composition and rich in organic matter and plant nutrients (Selvam et al., 2021a) that can be recycled to reduce the dependence on the mineral ores for fertilizers. However, food waste's undesirable physicochemical characteristics, such as its acidity, compact structure, and high moisture content, result in a significant production of compounds that are harmful to plants (Wang et al., 2022). The fact that substantial amounts of food produced but not eaten by humans has substantial negative impacts: environmentally, socially, and economically. Estimates suggest that 8-10% of global greenhouse gas emissions are associated with food that is not consumed (UNEP, 2024). Treatment techniques such as anaerobic digestion, incineration, landfill, and pyrolysis are unable to recover nutrients from food waste (Zhang et al., 2020). Composting is one of the most promising biological disposals for organic solid waste resources due to its low cost, ability to handle various waste components, and production of organic fertilizers which facilitate the recycling of nutrients (Chen et al., 2024). Since organic waste is not viewed as a loss but rather is recycled back into the ecosystem to provide plants with essential nutrients, composting closes the environmental loop.

Nitrogen loss during food waste composting is a key issue resulting in odor emission and products with low nitrogen content. Nitrogen in the composting process was lost through the volatilization of NH_3, nitrification, and denitrification. The nitrogen loss due to NH_3 emissions is a major reason for the reduced compost quality and odor problem in the composting process (Wang et al., 2013; Selvam et al., 2021b). Nitrogen could be conserved by adopting *in-situ* composting methods such as C/N ratio adjustment, and amending with physical, chemical, or microbial additives (Zhao et al., 2020). The composting of food waste has caused increased emissions of ammonia and volatile fatty acids, sulfides, and organic sulfur compounds resulting in high malodours (Qamar-Zaman and Milke, 2012). Many optimization techniques have been developed to improve composting performance, including bulking agent addition, process parameter change, and additive regulation (Zhang et al., 2024).

Several studies have demonstrated the use of additives to effectively mitigate NH_3 and N_2O emissions during composting, such as biochar (Manu et al., 2021), zeolite (Chan et al., 2016), medical stone (Wang et al., 2016), Sulfur powder (Xiong et al., 2023), vermiculite (He et al., 2018), mature compost (Li et al., 2023). Additives used can alter the water content and porosity of compost materials during the composting (Pan et al., 2024).

To mitigate NH_3 emission, the addition of sawdust as a bulking agent was recommended due to the high C/N ratio, high moisture absorption properties, and high reactive surface area (Manu et al., 2021). The bulking agent is one of the most important factors that highly influence compost maturity. In turn, the efficiency of bulking agents could be influenced by the substrate-bulking agent mixing ratios (Zhou et al., 2018). Some additives such as mature compost can also improve the physical environment of the composting mass favourably. Although many studies have focused on the effects of zeolite, biochar, vermiculite, mature compost, medical stone, and struvite as additives to reduce GHG and NH_3 emissions during composting, the use of neem cake to mitigate nitrogen loss during food waste composting as a co-substrate was inadequately addressed in the literature.

The addition of oil seed cake, the leftover material from oil extraction, as manure, affects a variety of soil properties, including electrical conductivity, buffering capacity, nutrient availability and transformation, and soil response. Oil cakes are added as a source of organic matter and nutrients. Neem oil cake contains 5.2% of nitrogen (N), 1.2% of phosphorus (P), and 1.4% of potassium (K). Using neem cake will also strengthen the soil structure and increase its ability to retain water. When combined with soil, neem cake can also lower the alkalinity of the soil by generating organic acids (Gupta, 2022).

Urea is widely used in agriculture as a feed additive and fertilizer due to its relatively high N content (46%) and ease of handling. It also shows the highest water solubility. Because of its high nitrogen content, urea provides a greater quantity of nitrogen to plants and soil in comparison with other nitrogenous fertilizers (Beig et al., 2020). Urea is hydrolyzed through the urease enzyme, producing gases of NH_3 and carbon dioxide (Cordero et al., 2019). Then, the molecules of NH_3 are hydrolyzed, producing NH_4^+ and hydroxyl (OH-), increasing the soil pH within the urea zone. Several studies used urease inhibitors, for example, to lower ammonia volatilization by regulating urease activity. Urease inhibitors, however, cause a rather variable reduction in ammonia volatilization rates (Mariano et al., 2019). Thus, other materials like compost and charcoal have been suggested in addition to urea to lower ammonia volatilization (Sha et al., 2019).

Urea can be added to the composting mass to increase the nitrogen content of the product, however, controlling the nitrogen loss through appropriate additives is warranted to reduce the N-based odours and N-loss. This study investigates the use of neem cake as a co-substrate to reduce nitrogen loss. In a previous study (Anishla et al., 2024), adding neem cake at 10% improved the physical structure of the composting mass and relatively higher nitrogen content in compost compared to the control. Therefore this study aimed at improving the nitrogen content of the compost product through addition of urea and control the nitrogen loss through addition of neem cake as a co-composting substrate.

2. Materials and Methods

2.1 Substrate preparation and characterization

A synthetic food waste (FW) prepared by mixing boiled rice, fried chapati, bread, vegetables, and dhal in the ratio of 13:10:10:10:5 (w/w, wet weight basis) was used in the experiment. The use of synthetic food waste facilitates the comparison of different experiments and eliminates the heterogeneity of real food waste. All the components of the food waste were size reduced to 0.5 cm^3. The sawdust (SD) was procured from a local sawmill, while the neem cake (NC), and urea (UR) were procured from a local fertilizer shop. The food waste and sawdust were mixed at 1:1, on a dry basis, and mixed with neem cake at 30% on a dry basis (FW: NC30) while FW-SW mix was used as a control. The FW: NC30 mix was added with 1.5% and 3% urea individually.

Aeration was provided from the bottom of the reactor continuously at 1.5 L/min/kg VS for two weeks and reduced to 0.5 L/min/kg VS thereafter. The initial moisture contents of the composting mixtures were adjusted to~ 55%. About 14 kg of the composting mixture was prepared for each treatment and composted for 42 days in 20-L homemade bench-scale composting reactors. The composting mass was mixed thoroughly every three days for the first two weeks and once a week thereafter until 42 days. Compost samples were collected on days

0, 3, 7, 14, 21, 28, 35, and 42 after a thorough mixing, for analysis of physicochemical properties. After sampling, the moisture content was adjusted to~55% if necessary.

2.2 Analytical Methods

The temperature was monitored and recorded every day by using a digital sensor thermometer inserted into the middle of the reactor. pH and electrical conductivity (EC) were measured in 1:5 w/v, wet basis, water extracts using Eutech PC 700 pH/EC meter. This water extract was also used for the analysis of extractable ammonium (NH_4^+-N) using the indophenol blue method (TMECC, 2002) and seed germination index (SGI) using cress seed (*Lepidium sativum*) following the method of HKORC (2005). Moisture content was determined gravimetrically and the dried material was used for the analysis of total organic carbon (TOC). The dry sample was digested and used to analyze the total Kjeldahl nitrogen (TKN) using the indophenol blue method (TMECC, 2002). The dry sample was ground to a fine powder and the TOC was determined using the modified Walkey-Black method (Nelson and Sommers, 1996). Analysis was made using three independent samples and the data were subjected to statistical analysis using SPSS version 11.0, and the multiple range test was performed at $p<0.05$.

3. Results and Discussion

3.1 Temperature Profile

Temperature is one of the most important parameters of compost quality and reflects the microbial activity in the composting mass. During composting, microbes degrade organic matter resulting in the release of heat and an increase of temperature within the composting mass. The thermophilic phase reached within 3 to 4 days (≥ 55°c) and lasted for about 10 days in all treatments (Fig.1). Temperatures of all the treatments showed a similar trend with an initial high temperature for two weeks. Li et al. (2023) reported that the high temperature was recorded within 2 days during manure composting. Increasing temperature can also increase the acidification rate and composting rates (Ravindran et al., 2022). After 4 weeks the temperature slowly decreased and reached ambient temperature, which means rapid degradation of organic matter was completed within the periods. Among the treatments, 30% neem cake added treatment (FW+NC30) showed a relatively higher temperature during the first week of composting compared with other treatments. Addition of neem cake and urea resulted in a relatively higher temperature when compared with the FW control. After day 42, the temperature in all the treatments reached the ambient temperature.

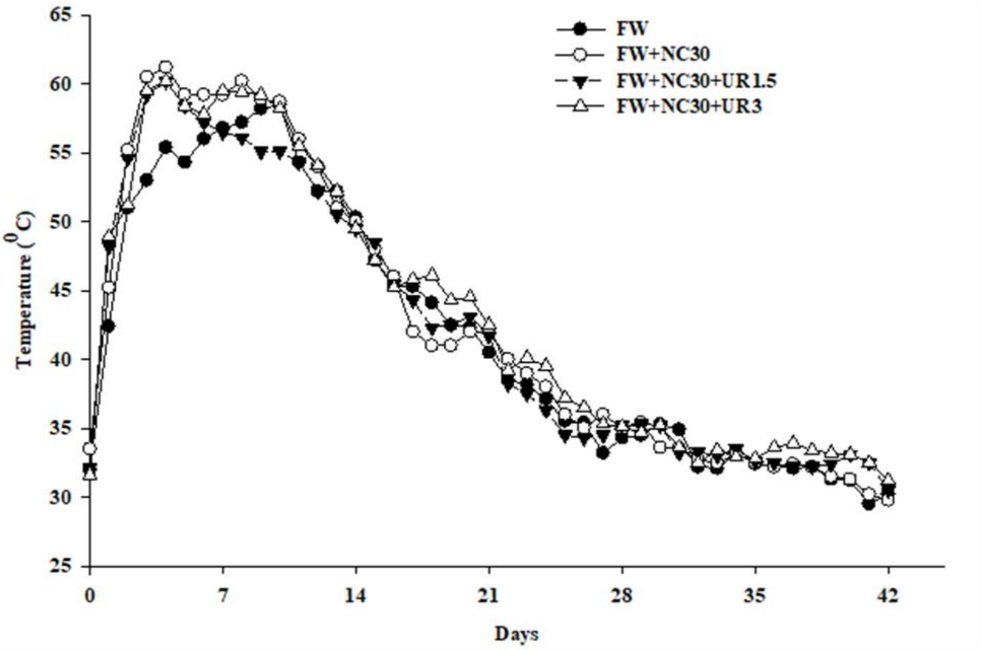

Figure 1. The changes in temperature during composting of food waste (FW) with 30% neem cake (NC) and 1.5% and 3% urea (UR).

3.2 Changes in pH and Electrical conductivity (EC)

pH is a critical factor influencing microbial activities and microbial community during composting. As shown in Fig. 2a, the pH values of the composting mass decreased during the first week of composting, which might be due to the generation of organic acids produced by the microbial reaction as reported previously (Xu et al., 2021). Later on, the pH gradually increased with the mineralization of organic nitrogen which eventually released alkalinity. In addition, the organic acid produced is used up by the microorganisms. The addition of urea resulted in slightly higher pH when compared with FW and FW+NC30 during second and third weeks; however, the differences eventually disappeared. There is no difference among the NC and urea treatments after 42 days. The pH values after 42 days of composting for the treatments were 7.30±0.06 in FW, 8.31±0.13 in FW+NC30, 8.25 ±0.29 in FW+NC30+UR1.5, 8.33± 0.37 in FW+NC30+UR3.

Electrical conductivity (EC) indicates the salt concertation and is presented in Fig. 2b. The addition of neem cake at 30% increased the EC of the FW: SD mix from 0.77±0.23 mS/cm to 2.6±0.15 mS/cm. The addition of urea at 1.5% and 3% further increased the EC to 4.32±0.35 mS/cm and 4.72±0.20 mS/cm, respectively. Since the urea is highly water soluble, the ammonium ions released should have contributed to this increase in EC. All the treatments experienced a similar trend of initial increase, especially during the thermophilic stage, and decreased thereafter. The initial increase in EC values could be linked to the rapid degradation of organic substances into simple compounds with the release of ions (Ravindran et al., 2022). Initially, EC values increased until day 7 in control and 30% neem cake treatments and until day 14 in 1.5% and 3% urea treatments. Then the EC gradually decreased from days 7 and 14. The EC values were decreased due to immobilization by the microbes, precipitation of salts, and ammonia volatilization (Waqas et al., 2018). After 42 days, the EC values of all treatments were decreased and ranged between 1.28 mS/cm and 4.97 mS/cm. Among the NC and urea amended treatments, the highest EC of 4.97±0.56 mS/cm was observed in FW+NC30+UR3, followed by 4.56±0.44 mS/cm in FW+NC30+UR1.5, 2.25±0.31 mS/cm in FW+NC30 and the lowest value 1.28±0.20 mS/cm was observed in the control. There was a significant difference among the treatments ($p<0.05$). Generally, a maximum EC value of 4 mS/cm is suggested for the toxin-free compost. Considering this limit, the higher values observed in urea-amended treatments indicate the requirement for a longer treatment period or other suitable additives. For example, addition of 10% zeolite reduced the electrical conductivity from 6.45 mS/cm to 2.82 mS/cm during struvite food waste composting (Chan et al., 2016).

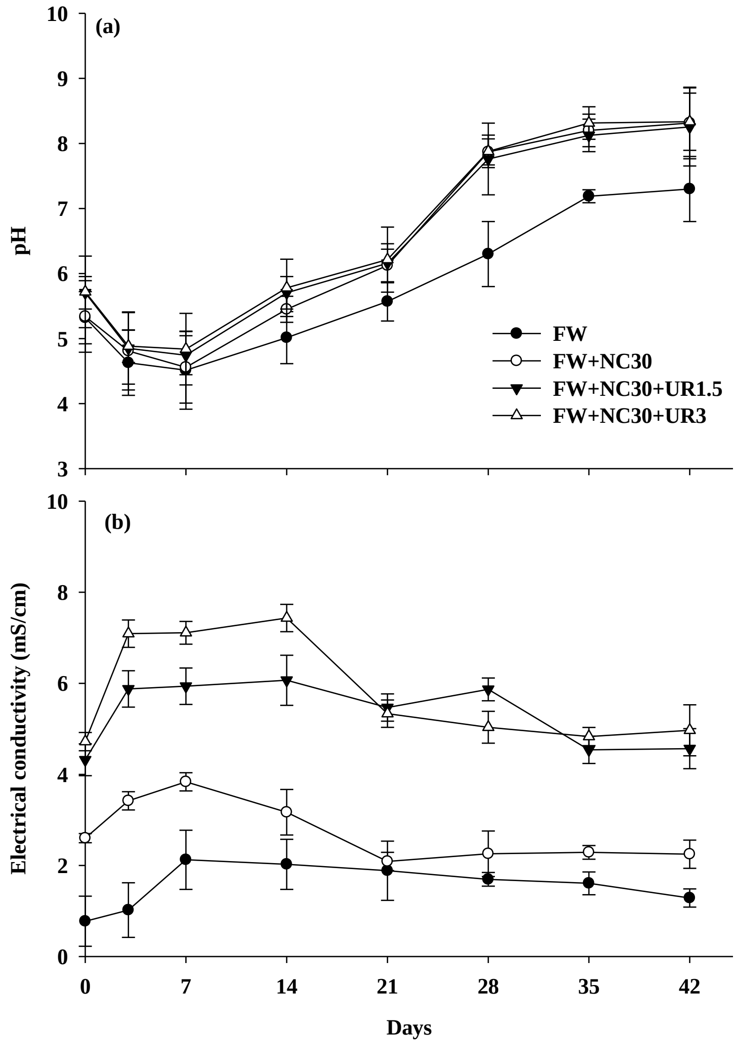

Figure 2. The changes in pH (a) and electrical conductivity (b) during composting of food waste (FW) with 30% neem cake (NC) and 1.5% and 3% urea (UR).

3.3 Changes in extractable ammonium nitrogen (NH_4^+-N)

The changes in the concentration of NH_4^+-N in the composting mass of different treatments are shown in Fig. 3a. In the control and FW+NC30 treatments, NH_4^+-N concentrations increased up to 7 and 14 days, respectively, while in urea amended treatments NH_4^+-N concentrations steeply decreased for about 3 weeks (Fig. 3a) High solubility of urea resulted in high NH_4^+-N concentrations during the initial stage and the reduction in NH_4^+-N concentrations indicates the loss of NH_4^+-N during this period. Often, alkaline pH is linked with the volatilization NH_4^+-N; however, despite an acidic pH (between 5 and 6), the volatilization was significant. After three weeks, the NH_4^+-N concentrations stabilized and slightly reduced until 42 days with a final concentration of 1842±115.5 mg/kg and 1985±40 mg/kg in 1.5 and 3% urea amended treatments, respectively. In FW and FW+NC treatments, the NH_4^+-N concentrations reached the peak value of 3006±170.3 mg/kg and 2165±54.8 mg/kg on days 7 and 14 and the NH_4^+-N concentrations decreased thereafter to 611±38.6 mg/kg and 482±53.4 mg/kg after 42 days, respectively. The results indicate that the NH_4^+-N available through urea was not captured in the composting mass as evidenced by the TKN contents (Fig. 3b). There is a significant difference among the treatments ($p<0.05$). The lesser NH_4^+-N concentration in FW+NC treatment when compared with FW treatment indicates that NC played a positive role in controlling the availability of ammoniacal nitrogen. The release of NH_4^+ -N through ammonification coincided with the active degradation of organic matter during the thermophilic phase. Wang et al. (2013) reported that the high temperature, pH, and ammonium concentration, inhibit the growth and activity of nitrifying microorganisms. Ammonia emission is inevitable during composting when the organic matter is mineralized, and the pH and temperature are high.

3.4 Changes in Total Kjeldahl Nitrogen

Addition of NC at 30% increased the TKN content of the FW: SD mix from 1.58±0.16% to 2.36±0.09% owing to the higher N content of the neem cake. As expected, the addition of urea to FW+NC30 at 1.5% and 3% increased the TKN contents to 3.14±0.15% and 3.83±0.16%, respectively. In the early stage of composting, the TKN concentration of FW and FW+NC30 treatments showed a marginal decrease for 1 week probably due to the loss of nitrogen caused by the volatilization of NH_4^+-N and emission of NH_3 during the thermophilic period (Fig. 3b). However, in urea amended treatments, the reduction was drastic during first week and moderate during the second week mainly due to the loss of NH_4^+-N during this thermophilic period. After 2 weeks, TKN contents in all the treatments gradually increased which could be attributed to the degradation of nitrogenous organic compounds and the related concentration effect (Wong et al., 2009). After 42 days, maximum TKN content was observed in FW+NC30+UR3 treatment, followed by FW+NC30+UR1.5, FW+NC30, FW (control) treatments; and the differences among the treatments are significant at $p<0.05$.

The loss of nitrogen was estimated to be 54.07% in control (FW), 55.6% in FW+NC30, 63.5% in FW+NC30+UR1.5, and 68.1% in FW+NC30+UR3 treatments after 42 days. He et al. (2018) reported that the addition of 10% vermiculite was most efficient for nitrogen conservation during food waste composting. The addition of struvite salts reduced the nitrogen loss up to 23.3- 40.8% during food waste composting (Wang X et al., 2016). Similarly, addition of 10% medical stone and 10% biochar was also shown to reduce the N loss significantly (Wang Q et al., 2016). Considering the urea addition scenario, neem cake was also effective in reducing the N loss during food waste composting.

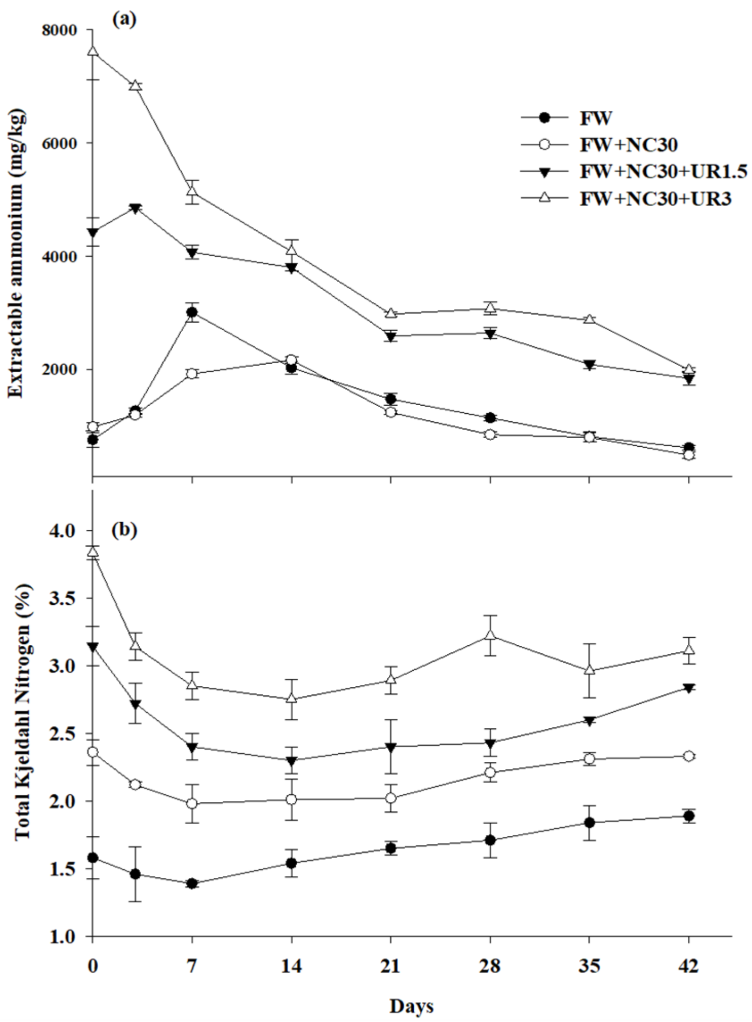

Figure 3. The changes in extractable ammonium nitrogen (NH_4^+-N) (a) and total Kjeldahl nitrogen (TKN) (b) during composting of food waste (FW) with 30% neem cake (NC) and 1.5% and 3% urea (UR).

3.5 Changes in Total Organic Carbon

The total organic carbon (TOC) content during the composting process decreased since the microorganisms mineralized the organic carbon as their energy source. The reduction in TOC content was rapid during the first week coinciding with the thermophilic period. The TOC contents in all the treatments decreased along the composting process as shown in Fig 4a. Among the treatments, carbon loss was the highest in the FW+NC30 treatment (72%), followed by FW control (67.5%), FW+NC30+UR1.5 (65.3%) treatments while the lowest carbon loss was observed in FW+NC30+UR3 (57.4%) treatment. Results indicate that 3% urea addition causes some inhibition when compared with 1.5% urea treatment. A higher carbon utilization in FW+NC30 treatment indicates that the neem cake positively influenced the composting probably providing a good physical environment.

3.6 C/N ratio

The C/N ratio is often used to assess the maturity of the end product (Zhou et al., 2018). A significant portion of the carbon is discharged as CO_2 during composting and remaining combines with nitrogen to serve as energy sources for microbial growth. So, the carbon content will decrease, whereas nitrogen content is continuously recycled by the microbes. So, the C/N ratio was decreased in the final compost. In this experiment C/N ratio increased during the thermophilic phase due to the loss of nitrogen as ammonia and comparatively reduced decomposition and then gradually decreased at the end of the experiment in all treatments (Fig 4b). The C/N ratio of compost was 20.2±0.2 in FW (control), 15.8±0.25 in FW+NC30, 12.9±0.94 in FW+NC30+UR1.5 and 11.5±0.52 in FW+NC30+UR3 after 42 days. The low C/N ratio with urea added treatments is due to the higher nitrogen content. Chan et al. (2016) reported that the C/N ratio of struvite treatments was less than 21 during food waste composting. Some researchers have suggested that a C/N ratio of less than 20 indicates maturity and stability, which is favourable for plant growth.

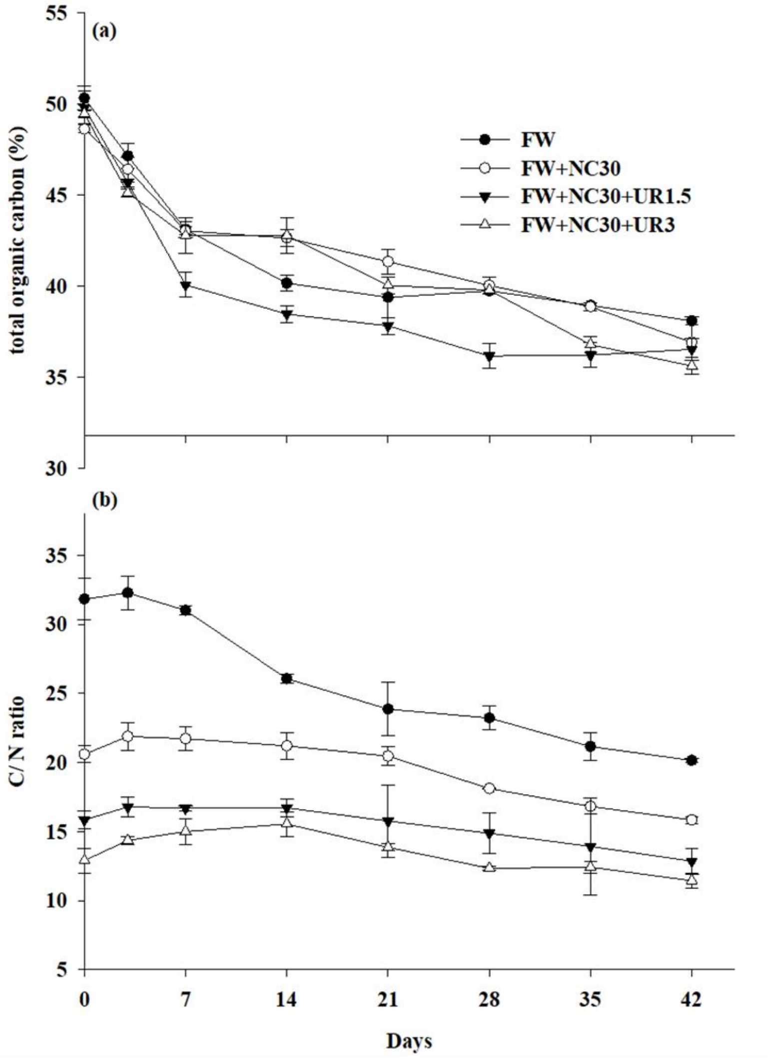

Figure 4. The changes in total organic carbon (TOC) (a) and C/N ratio (b) during composting of food waste (FW) with 30% neem cake (NC) and 1.5% and 3% urea (UR).

3.7 Seed Germination Index

The seed germination index (SGI) is the most commonly used parameter to evaluate the phytotoxicity level of compost and it directly examines the effect on seed germination and seedling growth (Manu et al., 2021). On day 7, SGI was nearly 20% due to phytotoxicity by high of NH_4^+-N and generation of organic acids in the composting mass (Fig. 5). The SGI values continuously increased with the progression of composting due to a reduction in NH_4^+-N contents and organic acids. After 28 days, FW+NC30 treatment showed a SGI value of 98.82±6.03; while the FW control required 42 days to reach the SGI value of 88.0±20.93. However, in the 1.5% urea amended treatment, the SGI value reached 73.9±14.5 after 42 days while the toxicity was severe with 3% urea amended treatment none of the seeds germinated. Results indicate that urea added treatment requires a longer composting period while neem cake contributed to the acceleration of the food waste composting while neem cake addition increased the rate of composting.

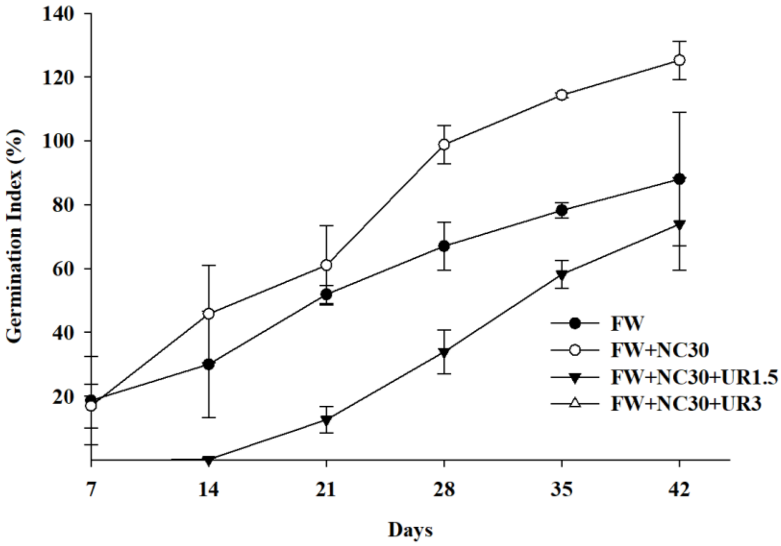

Figure 5. The changes in seed germination index during composting of food waste (FW) with 30% neem cake (NC) and 1.5% and 3% urea (UR).

Table 1. Selected physicochemical properties of the initial composting mix

Parameter	FW	FW+NC30	FW+NC30+ UR1.5	FW+NC30+ UR3
pH	5.32±0.12*	5.34±0.17	5.70±0.15	5.72±0.17
EC (mS/cm)	0.77±0.23	2.60±0.15	4.32±0.35	4.72±0.20
Total organic carbon (%)	50.31±0.68	48.62±0.23	49.80±0.90	49.5±0.23
Total Kjeldahl nitrogen (%)	1.58±0.16	2.36±0.09	3.14±0.15	3.83±0.16
C/N ratio	31.84±1.06	20.60±0.60	15.84±0.67	12.90±0.88
NH_4^+-N (mg/kg)	755±129	981±68	4431±250	7605±495

* - Mean ± SD of three replicates. FW- food waste; NC- neem cake; UR- urea

Table 2. Selected physicochemical properties of compost product after 42 days of composting

Parameter	FW	FW+NC30	FW+NC30+ UR1.5	FW+NC30+ UR3
pH	7.30±0.06*	8.31±0.13	8.25±0.29	8.33±0.37
EC (mS/cm)	1.28±0.20	2.25±0.31	4.56±0.44	4.97±0.56
Total organic carbon (%)	38.09±0.23	36.92±0.98	36.53±0.60	35.62±0.45
Total Kjeldahl nitrogen (%)	1.89±0.01	2.33±0.17	2.84±0.50	3.11±0.30

C/N ratio	20.15±0.25	15.85±0.25	12.90±0.94	11.45±0.52
NH_4^+-N (mg/kg)	610±38	482±53	1842±115	1985±40
SGI (%)	88.02±20.9	125.27±6.0	73.94±7.11	0.0±0.0

* - Mean ± SD of three replicates. FW- food waste; NC- neem cake; UR- urea.

4. Conclusion

Neem cake and urea were used as co-substrate with the food waste composting process was evaluated. Neem cake addition prolonged the high-temperature period for 2 to 4 days when compared with urea added treatments. The addition of 30% of neem cake effectively reduced the EC from 2.60±0.10 mS/cm to 2.25±0.31 mS/cm; nevertheless, the values were within the safe limit of 4 mS/cm. The compost from urea added treatment had a high EC content, so there was no germination of seeds in the 3% urea treatment. TOC contents gradually decreased during the composting process due to the higher carbon utilization in FW+NC30 treatment. TKN contents gradually decreased at the beginning of the composting possibly due to the loss of N during the active/thermophilic phase. Thereafter the TKN contents gradually increased and higher TKN contents were observed in urea-amended treatments. The addition of neem cake treatment achieved the lowest nitrogen loss compared with other treatments. The addition of neem cake resulted in the highest GI value followed by control and 1.5% urea treatment. The overall result revealed that the addition of 1.5% urea amended treatment produced a stable and high N content and the addition of 30% neem cake has controlled the nitrogen loss during the food waste composting process.

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