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EVALUATING THE VERMICAST PRODUCED FROM ORGANIC MUNICIPAL WASTE OF DUHOK CITY WITH BULKING AGENTS USING *EISENIA FOETIDA* EARTHWORMS

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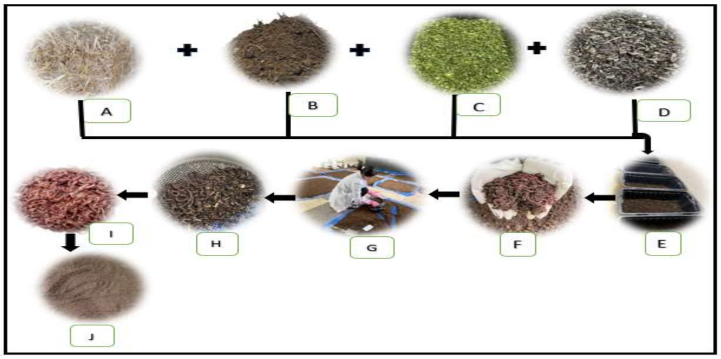
Abstract: This work was took place at the laboratories of the College of Agricultural Engineering Sciences at the University of Duhok, during September 2022 - May 2023, to investigate the compost quality (CQ) produced at Kwashe Recycling Municipal Waste Factory (KRMSWF), and the effect of vermicomposting technique on composting organic municipal solid waste (OMSW), reducing time of composting, and improving the vermicast quality by *Eisenia foetida* earthworms, using different types and rates of bulking agents (Cow dung, wheat straw, vegetable litters and OMSW). The result showed that incorporating bulking agents of vegetable litters with OMSW and their rates in preparation the vermicomposting beds, were significantly influences on the physical traits (color, odor, water holding capacity, bulk density and porosity) of the produced vermicast and reduced the time of vermicomposting by (*Eisenia foetida*) at ($P < 0.05$). Also, significantly influenced on the properties of the produced vermicompost. the pH value of the produced vermicast increased by mixing vegetable litters and OMSW with Cow dung and wheat straw in (T4, T5, and T6) to (8.23 ±0.023, 8.25±0.012, and 8.27±0.000) respectively, in comparing with their values in (T1 and T2), with pH (6.81±0.061, and 5.43±0.057) respectively. In general, the CEC Cmolc. Kg^{-1} %, ash%, TOC%, OM%, TN%, and TP% were increased in comparison with compost and vermicompost produced in (T1, T2 and T3). While the EC value, TK%, and TNa% decreased in comparison with their values in (T1, T2, and T3). The C:N ratio in all treatments decreased with the exception of the % C:N ratio in T6, which increased in comparison with (T2, T3, T4, and T5). The lowest account of total heterotrophic bacteria (THB) in the produced compost and vermicompost were found to be (195×105 ± 0.88) $CFUg^{-1}$ in T3, and (279×104±9.17) $CFUg^{-1}$ inT6, while their higher number was recorded in T5 (298×106±15.7) CFU g^{-1}. The highest and lowest total Coliforms and (E. Coli) bacteria were (≥1600) CFU g^{-1}), exceeded the permissible number (1000 CFU g^{-1}) for all treatments.



Keyword: OMSW, Vermicomposting, Eisenia foetida, bulking agents (feedstock substrates), and vermicast quality.

Introduction:

Soil fertility and plant productivity can be improved by means of inorganic fertilizers, because of their crucial role in providing essential nutrients for plant growth in available forms with adequate amounts (Bhatti *et al*., 2017). Nyberg, (2006) and Edwards and Araya, (2011), reported properly recycling organic solid waste (OSW) into compost, can be used as a soil amendment for achieving environmental sustainability, because it is rich in essential nutrients for plant growth, preserves soil fertility, and maintains soil productivity. The organic municipal solid waste (OMSW) contains harmful toxic materials that threaten mankind's and the environment's safety (Lombrano, 2009 and Soufan, 2012). Leal *et al*., (2020) indicated that lands fertilization with composted organic solid waste (COSW) enhances the physical, chemical, and biological characteristics of the soil, safe environmentally (eco-friendly), economically low-cost, and finally, increases crop productivity.

Relying on the obtained data from the municipality's recycling solid waste factory at Kwashe, which belongs to the General Directorate of Municipalities in Duhok Province. A huge quantity around (1500–1600) tons of solid wastes per day is produced in Duhok Province, around 70% of these solid wastes (1200 tons per day) are received by the Recycling Municipal Solid Waste Factory at Kwashe (RMSWFK). These wastes are a mixture of organic food, inorganic substrates, cardboard, papers, plastic, metals, glass, shredded wood, pharmaceuticals, electronics, petroleum by products, ... etc. After being received by the factory, it is sorted manually. Saeed, (2020), reported that about 50% of the solid wastes which received by (RMSWFK) are organic solid wastes.

The common methods for composting organic solid waste are still aerobic and anaerobic composting methods. From these different techniques of composting, vermicomposting is still the superior, attractive, and enhanced technique because it contributes in converting organic solid wastes biologically to a stable soil improver by earthworms through consuming these wastes and changing them into vermicompost (vermicast, wormcast, or manure) in their gut (Mohee and Soobhany, 2014). Ayilara *et al*., (2020), reported that due to organic waste content some resistance substrates which needs more time for decomposition therefore, reducing time of composting is a challenge faces the researchers, to get rid of them in order to reduce its adverse environmental effects.

Many researchers have been studied composting of organic solid wastes using different methods and techniques including vermicomposting, but only few researchers in Iraq and especially Kurdistan Regional have been studied composting the organic solid wastes and their properties, and no one of them has been studied the effectiveness of vermicomposting techniques in improving the quality of Kwashe compost produced from organic municipally solid waste (OMSW) of Duhok city. Therefore, this study came as an attempt to study the compost quality produced at Recycling Municipal Solid Waste Factory of Kwashe at Duhok city, as an attempt to improve its quality through vermicomposting technology with bulking agents (cow dung, wheat straw and vegetable litters), using *Eisenia foetida* earthworms in additional to study their effectiveness in reducing time of composting OMSW.

Material and methods:

This investigation was conducted during September 2022 - May 2023, at the laboratories of the College of Agricultural Engineering Sciences / University of Duhok, 15 kilometers away from the west of Duhok City geographically position 36°51'29.1" N and 42°52'1.6" E at an elevation of 475 m above sea level within Semel district, Kurdistan Region, Iraq.

Laboratory work

A special room with suitable condition for vermicomposting process was prepared. The ambient temperature controlled at (22 ± 2) ºC, and the humidity was adjusted between (50 and 60) % according to (Gajalakshmi et al., 2002). The moisture content of the vermicompost system adjusted between (60–80) % with the temperature (22 ±2) °C (Zigmontienė and Šerevičienė, 2023). Plastic boxes with dimensions (70cm L×50cm W ×40cm H) were used for preparing vermicomposting beds. Six holes were made in the bottom of the boxes, connected with tubes for draining the excess leachate from the vermicomposting boxes. As well, a number of holes were made in the upper sides of the boxes for ventilation. The (*Eisenia foetida*) were fed with a mixture of vegetable litters (lettuce, parsley, celery, and cress) for multiplying their population before starting the experiment.

Bed components collection and preparation

The bed components of the vermicomposting system in this study were prepared from compost produced at Recycling Municipal Solid Waste Factory of Kwashe of Duhok city alone (T1). The organic municipal solid waste (OMSW) of Duhok city collected from the Recycling Municipal Solid Waste Factory at Kwashe, and sorted again from non-desirable foreign materials, which are harmful, and fatal to worms (glass, plastic materials, medical materials, metals, electrical materials, textile materials, paste cans, and other undesirable materials, including organic litter, as mentioned previously) then used in preparing vermicomposting beds alone (T2), also, mixed at different ratios with cow dung and wheat straw collected from Cattle barns of Dolibi village/Semel district (the cow dung and wheat straw used as the main components of the vermicomposting beds of (T3-T6) and the vegetable litters (lettuce, celery, parsley, and cress) collected from the markets of Duhok city used in preparing the mixture components of the vermicomposting beds with different ratios in treatments (T3-T6). It is worthy to mention that vegetable litters (citrus fruits, onion, garlic, and radish) Also, were sorted and excluded from the components of the vermicomposting beds because they are harmful and fatal to the verms, as mentioned by

(Adhikary, 2012). All collected materials were shredded into small particle sizes of (20 – 30) mm before being added to the vermicomposting beds.

The vermicomposting beds were prepared firstly, by placing a transparent cloth sheet at the bottom of the vermicomposting boxes for preventing clogging the holes with drained bed component materials. Secondly, a layer of gravel with a thickness of 2 cm was placed to facilitate draining excessive leachate from the vermicomposting beds, and the third layer was soil with a thickness of 3 cm. Finally, a layer of about 15 cm thickness were placed over the soil layer from a feedstock mixture which prepared for vermicomposting beds for each studied treatment, and each one three times replicated.

The studied treatments were:

T1 = Compost prepared at Kwashe Recycling Municipal Solid Waste Factory
T2 = Organic Municipal Solid Waste before composting (OMSW)
T3 = Cow dung 50% + Wheat straw 50%
T4 = Cow dung 30% + Wheat straw 40% + Vegetable litters 30%
T5 = Cow dung 30% + Wheat straw 40% + OMSW 30%
T6 = Cow dung 20% + Wheat straw 40% + Vegetable litters 20% + OMSW 20%

The selected earthworms, *Eisenia foetida*, were added to each treatment at a rate of 0.5 kg earthworms per kg of waste, according to (Biernbaum, 2014). By completing the vermicomposting process, the vermicompost was separated from the worms through sieving using sieves with 4 and 2 mm in diameter capacity. The vermicompost was preserved in sterilized plastic bags and stored in a refrigerator at 4°C until analysis.

The physical tests of the obtained compost and vermicast

The color of the compost and vermicast samples were determined by the naked eye, while the odor determined, through smelling sense according to (Lekammudiyanse and Gunatilake, 2009), moisture content of the studied samples was measured through the gravimetric method by drying the samples in the oven at 105 ºC for (24 to 72) hours until reaching the fixed weight as mentioned by (Estefan *et al*., 2013), Water holding capacity is determined by saturating the compost and vermicast with distillate water and drying them in the oven at 105 ºC according to (Allen *et al*., 1974), the bulk density and porosity of the studied compost and vermicast were determined using a core method as described by (OCQS, 2021) and (Estefan *et al*., (2013) respectively.

The chemical tests of the obtained compost and vermicast:

The pH and EC values of the studied samples were extracted and measured in an extract (1:10) at 25 ºC by using a pH meter (Trans Instruments model BP3001) and conductivity meter (trans instruments model BC3020), respectively according to (Sarker *et al*., 2020). Cation exchange capacity (CEC) was determined by a flame photometer according to (Richards, 1954), The content of ash percentage determined by ignition of the studied samples of the compost and vermicast in Muffle Furnace at 550 ºC as mentioned by (Bhat, *et al*., 2017), total organic carbon (OC) was determined by the Walkely Black method, as described by (Adams, 1951), and organic matter (OM) content was calculated by multiplying the percentage of total organic carbon by the factor

1.8, as described by (Adams, 1951). Total NPK and TNa were determined by Kjeldahl method according to (Sarker *et al*., 2020), spectrophotometer according to (Sarker *et al*., 2020), and flame photometer as described by (Bhat *et al*., 2017), respectively. C:N ratio was calculated through dividing the total organic carbon by the total nitrogen of the studied samples.

The biological tests the obtained compost and vermicompost:

Total Heterotrophic Bacteria (THB) was determined by using nutrient agar as a culture medium and incubating for (24–48) hours at 30 ºC. The number of the colonies within the range (30–300) was taken into account as described by (Aneja, 2012). Total coliform bacteria were estimated using the most probable number (MPN) method, using MacConkey broth as the growth medium and incubated at (35± 2) ºC for (24–48) hrs., while (*E. coli*) was determined by using the same medium which were inoculated with the positive tubes of the total coliform bacteria using a loop and incubated at 44 ºC for (24–48) hours as described by (Ramnarain *et al*., 2019).

Statistical analysis

For statistical analysis, One-way ANOVA followed GLM procedure were applied to determine the significant differences on studied parameters among different prepared compost and vermicompost. Significant differences between means were tested using post-hoc Tukey Honestly Significant Difference (HSD) Test at P - value < 0.05. All statistical analyses were performed using the Minitab software package 17.

Results and discussion

The OMSW samples, which were collected from the Recycling Municipal Solid Waste Factory at Kwashe, Duhok City, after sorting again from the foreign materials manually their percentage components are shown in figure (1), and used as a representative sample of organic municipal waste (OMSW) of Kwashe Recycling Municipal Solid Waste factory (KRMSWF) in preparing vermicomposting beds in this study. The results indicated that the process of sorting OMSW from non-suitable foreign materials did not well perform at the Kwashe Recycling Municipal Solid Waste Factory, which ultimately affects the compost quality product. This is clear by comparing the differences in the percentage components of the sorting OMSW at (KRMSWF) and segregating these wastes a gain in the laboratory for this study.

The produced compost of Kwashe Recycling Municipal Solid Waste was classified within Class-B non-suitable for the use in agriculture due to the percentage of the foreign materials in compost product should not exceed 2 pieces of greater than 25 mm and should be free from sharp materials (e.g., glass pieces) not more than 3 pieces with 12.5 mm per 500 ml in compost product, when the produced compost of Kwashe was content more these quantities in 500 ml in compost product as suggested by (CCME, 2005), because the results in the figure (1) shows that the Kwashe compost product contains more than these percentages of the mentioned materials in the compost product of Kwashe with (8% plastic and 8% glass pieces), and total foreign materials are more than 21%. These results are matching with those found by (Saeed, 2020) who stated that one of the most barriers and most important factor affecting compost quality produced in Recycling Municipal Solid Waste at Kwashe factory is referred to bad segregation and composting processes which were not performs well. While the compost of quality of (Class-B) can be used as organic conditioner for non - agricultural purposes (e.g., Land reclamation, mining rehabilitation, and reforestation … etc.).

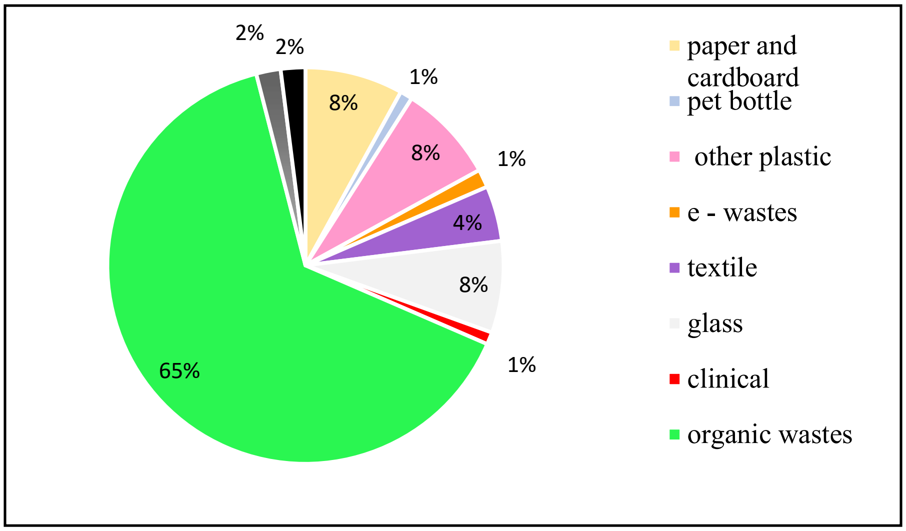


Figure (1): The percentages components of the Municipal Solid Waste (MSW) of Kwashe after sorting again manually for this study.

Effect of feedstock substrates on the duration time of the vermicomposting

The effect of raw material on the duration time of vermicomposting beds is shown in figure (2). The composting process by *Eisenia foetida* earthworms was not progressed forward for composting the OMSW used in (T1 and T2) alone, and all the added earthworms (*Eisenia foetida*) were dead. This may refer to the existence of toxic materials such as petroleum, Agri toxic materials, glass pieces, pharmaceuticals, and other hazardous materials in the OMSW that are lethal (fatal) to *Eisenia foetida*. which agreed with the finding of (Brewer and Sullivan, 2003).

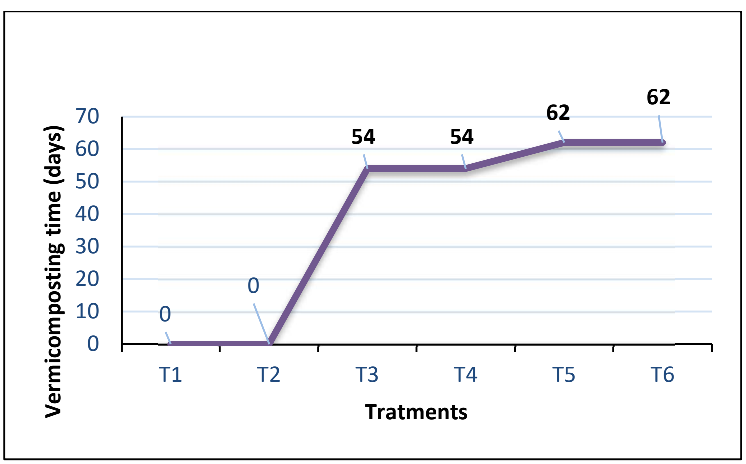


Figure (2): Illustrate the relation between time of vermicomposting and feedstocks used in the preparation of vermicomposting beds.

The duration time of the vermicomposting process varied depending on the raw materials and buking agents used in vermicomposting beds, and the mixed ratio of bulking agents with vermicomposting bed components did not affect the vermicomposting duration time. This may be attributed to the C:N ratio of the feedstock materials mixed with the components of vermicomposting beds, which was less than the preferable ratio of earthworms (25-30:1) and (25-50:1) as suggested by (FAO, 2015 and Biernbaum, 2014), respectively.

In general, it appears from the obtained results that adding feedstock of vegetable wastes as a bulking agent with a high initial C:N ratio reduced the duration time of composting from (62 to 54) days due to *Eisenia foetida* verms preferring materials with high C:N ratio substrates.

The physical properties of the compost and vermicompost

The **color** of the produced compost and vermicompost were black gray, not limited, and dark brown for (T1, T2, and T3 to T6), respectively table (1). When the **odor** of the studied compost (T1) and vermicompost produced in T2 were very nasty, while when mixed with bulking agents and OMSW the compost odor improved from nasty to odorless in (T3 to T6). These results agreed with those found by (El-Nagerabi *et al*., 2011 and Samarasinha *et al*., 2015). Significant variations were found between the **moisture content** of the studied compost and vermicomposts at ($P<0.05$). The higher value of moisture content was (73.34±2.92) % recorded at T4, which significantly deferred from all other studied treatments, and the lower value was (12.52±0.044%) found in treatment T2, when T6 was superior in the moisture content value (56.01±5.180) % to (T2, and T1) which were have values (14.87±0.033 and 12.52±0.044) %, respectively. Also, T5 recorded moisture content (44.11±0.541) % and was significantly higher than its value in T3 (40.09±2.140) %. These finding are similar to those stated by (Gajalakshmi *et al*., 2002; Biernhaum, 2014, and FAO, 2015). Depending on the **water holding capacity** (WHC) of the of produced compost and vermicompost the results in table (1), indicated that WHC of the produced compost and vermicompost were significantly varied at ($P<0.05$). The WHC of the produced compost and vermicompost increased with incorporating bulking agent as feedstocks in vermicomposting beds. The WHC of the studies compost and vermicompost ranged from (145.8% to 183.25) %. The WHC of the vermicompost produced in T3 was (145.8±1.950%) lower of that produced in (T1 and T2) with values (152.1± 0.333 and 158.10.117) % respectively. These results can be demonstrated as a result of using OMSW as a feedstock in preparation the vermicomposting beds in (T1 and T2), which included food by products of the city with a high amount of water content. Additionally, their particles are large in size that reduces their porosity compared shredded feedstocks which increased its porosity, and finally affect the WHC. These results agree with those obtained by (Jadia and Fulekar, 2008). Also, the results show that significant differences were found between porosity of the studied compost and vermicompost at ($P<0.05$). The **porosity** of the produced vermicomposts ranged from (26.78± 0.090 to 56.81± 0.693) %. The higher value of porosity was (56.81± 0.693) % obtained in (T4) treatment, which was significantly superior than (T1-T3) with values (26.78± 0.090, 31.55± 0.278, and 50.58± 2.340) %, respectively. The porosity of the vermicompost produced in T3 was suppressed significantly of that (T1 and T2). These findings are similar to those found by (Saha *et al*., 2010). When, the obtained results indicated that the feedstock type did not significantly affect the **bulk density** of the vermicompost at (P<0.05). The higher values of bulk density were recorded in (T3) (0.644± 0.010,) g cm^{-3}, compared to the lower values found in (T1) (0.326± 0.003) g cm^{-3}, as shown in (Table 1). Generally, the bulk density of the produced vermicomposts increased compared with the bulk density of the feedstock. This illustrates that the initial bulk density of the feedstock is an important factor and affects the final product of compost and vermicompost. These results are compatible with those found by (Bernal *et al*., 2009). There is an inverse relationship between bulk density and porosity; the higher vermicast in the bulk density has lower the porosity. The results are similar to those recorded by (Saha *et al*., 2010).

Table (1): Show some of the studied physical properties of the produced compost and vermicompost in this study

	T1	T2	T3	T4	T5	T6
Color	Black gray	Not limited	Dark brown	Dark brown	Dark brown	Dark brown
Odor	Nasty odor	Nasty odor	Odorless	Odorless	Odorless	Odorless
Moisture %	14.87±0.033^{d}	12.52±0.044^{d}	40.09±2.140^{c}	73.34±2.920^{a}	44.11±0.541^{b}	56.01±5.180^{bc}
WHC %	152.1±0.333^{bc}	158.1± 0.117^{bc}	145.8±1.950^{c}	164.8±2.70^{b}	182.7±4.570^{a}	183.2±3.890^{a}
Porosity %	26.78± 0.090^{c}	31.55± 0.278^{c}	50.58± 2.340^{b}	56.81±0.693^{a}	52.31± 0.249^{ab}	54.26± 0.497^{ab}
Bulk density g cm^{-3}	0.326± 0.003^{b}	0.386± 0.003^{b}	0.644± 0.010^{a}	0.592±0.020^{a}	0.546± 0.053^{a}	0.561± 0.022^{a}

Means in each column that do not share a letter are significantly different at P – Value < 0.05. T1 = Compost prepared in Kwashe recycling factory, T2 = Organic Municipal Solid Waste before Composting (OMSW), T3 = Cow dung 50%+Wheat straw 50%, T4 = Cow dung 30% +Wheat straw 40% + Vegetables 30%, T5 = Cow dung 30% + Wheat straw 40% + OMSW 30%, T6 = Cow dung 20%+ Wheat straw 40% + Vegetables 20% + OMSW 20%

The chemical properties of the compost and vermicompost

The statistical analysis of the obtained data showed that composting, vermicomposting processes, and composted feedstock significantly affected all studied chemical properties of the produced compost and vermicast at (P < 0.05), table (2). The results indicated that the **pH** values of the studied compost and vermicompost ranged from (5.43±0.056 to 8.27±0.000). Generally, the pH value of the produced compost increased when compared with the pH value of the feedstocks. This may be due to the activity of microorganisms in the gut of the verms in decomposing organic matter of the mixture components of the vermicomposting bads, lead to the form NH3, which reacts with water to form NH_4^+, and increases the pH value of the final product of the vermicast. These results are similar to those found by (Suthar *et al*., 2015, Bhat *et al*., 2017; Al-Jawaher, 2020, and Wako, 2021). The higher **EC** value of the studied compost and vermicompost was (15.15±0.380 dS cm^{-1}) recorded in (T1), while the lower value was (5.44±0.238 dS cm^{-1}) found in (T3), as mention in table (2). This illustrates that the initial EC value of the feedstock is an important factor influencing the EC value of the final product of compost and vermicompost; these results are compatible with those found by (Bernal *et al*., 2009). It is important to mention that the *Eisenia foetida* worms died in (T1 and T2) treatments. This may be attributed to the existence of toxic materials and to non-well sorting OMSW at Kwashe recycling MSW factory, as reported by (Brewer and Sullivan, 2003), as well as to the high EC value of the feedstocks used in perpetrating the vermicompost. In addition to this the high concentrations of soluble salts (e.g., Na) in the OMSWs, which increases the osmotic pressure of the composting beds and finally influences the decomposing of organic materials by earthworms. The results are well-suited to those found by (Campell *et al*., 1997; Amouei *et al*., 2017, and Bhat *et al*., 2017). The **CEC** values of the vermicomposts produced in (T3-T6) were (34.75±5.530, 44.51±2.720, 45.63±1.260, and 35.45±0.336) cmolc kg^{-1}, respectively. While the obtained values of the CEC in (T1 and T2), were (81.16±0.075 and 18.23±0.111) cmolc kg^{-1} respectively table (2). These differences in the CEC of the studied compost and vermicompost could be attributed to the feedstock substrates used in the vermicomposting beds. Also, may refer to the high percentages of OC and OM in the components of the feedstocks used in the preparation of the vermicomposting beds. This illustrates that the CEC value of the feedstock is an important factor and impacts the CEC value of the final product of compost and vermicompost. These results are similar to those found by (Michel *et al*., 1995; Bernal *et al*., 2009; Edwards and Araya, 2011 and Asio, 2021). The maximum value of the **ash content** was (45.96%) found in Kwashe compost (T1) produced from OMSW in the Recycling Municipal Solid Waste Factory at Kwashe, while the minimum value was (34.91%) recorded in vermicompost produced in (T6), as shown figure (3). Generally, this may be attributed to the existence of many foreign materials (e.g., glasses, soil, small portions of the rocks, and other inorganic sources of the substrates) in the OMSW used in composting that were not sorted well. This conclusion can be supported and clarified through the results of the ash content of (37.96%) obtained from (T2), in which the ash content was significantly reduced after sorting the MSW again and used in the preparation of the vermicomposting beds. These results agree with those observed by (Jalal, 2016).

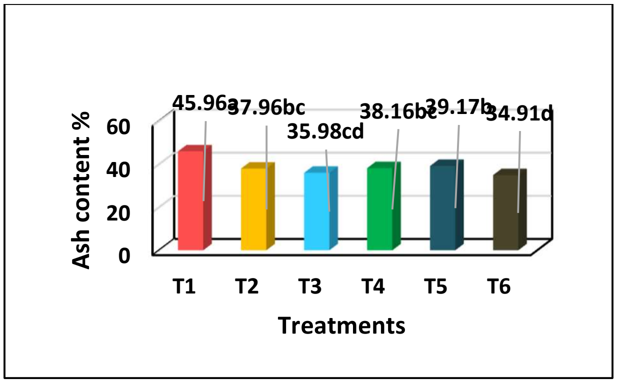


Figure (3): Show the Ash content % of the compost and vermicompost produced from different feedstock treatments.

The highest value of **TOC** was (35.96%) recorded in T6, which was superior to their value in all other treatments (T1 = 29.86 ± 0.012, T2 = 34.27 ± 0.012, T3 = 34.37 ± 0.015, T4 = 33.98 ± 0.211, and T5 = 34.15 ± 0.416) %, table (2). This demonstrates that the total organic carbon value of the feedstock is one of the main factors that affects the quality of compost and vermicompost products. These obtained data are consistent with those documented (Bhat *et al*., 2017, and Sarker *et al*., 2020). The higher value for **OM** content was (65.09±0.508%) recorded at T6, which was significantly superior to all studied treatments. While the lower value (54.04±0.012%) was found in treatment T1, table (2). This may be attributed to the fact that the OMSW which used in vermicomposting beds (T3–T6) was high in organic fraction, which led to increase the OM content in the final products in comparing with those used in in (T1 and T2), although the OMSW used in T2 was segregated again before being incorporated into vermicomposting beds, while the OM content of the produced compost was lower of that in all other treatments, this may refer to the existence of non-compostable foreign material in (T1 and T2). These results are in consistent with those mentioned by (Richards, 1954; Sadeghi *et al*., 2015, and Sarker *et al*., 2020).

The higher value of the **total nitrogen (TN)** was (2.087%) recorded in (T5), while the lower value was (1.053%) registered in (T1). Treatments (T2 - T6) were significantly superior to T1, as shown figure (4). Earthworms consume carbon and nitrogen for metabolic reactions such as growth and propagation. These results are supported by (Edward *et al*., 1976) who stated that the worms consume a large amount of OM that contains considerable quantities of nitrogen. As well, (Atiyeh *et al*., 2000) mentioned that earthworms also have a great impact on nitrogen transformations by enhancing nitrogen mineralization. Similar results were recorded by (Sadeghi *et al*., 2015; Ramnarain *et al*., 2019 and Lastiri-Hernandez *et al*., 2023). **Total phosphorous (TP)** concentration in the vermicompost products varied from the lower value (1.237%) obtained from T2 to the higher value (2.195%) recorded in T4. The recorded TP% in T4 was (2.195%) superior to all other studied vermicomposts obtained in other treatments, as mention figure (4). This may be qualified by the raw material type and the percentages of mixed substrates in the preparation of the vermicomposting beds in T4. These results are roughly consistent with those documented by (Sadeghi *et al*., 2015 and Bhat *et al*., 2017). The **total Na** in the studied compost and vermicompost ranged from (0.095±0.003 to 0.263±0.009) %, table (2). The earthworms *Eisenia foetida* died throughout treatments (T1 and T2), and this supports the obtained results because the OMSW used as feedstock materials in the preparation of the vermicomposting system (T1 and T2) included food byproducts of the city, which were used in the preparation of the food by families, that increased the TNa in the OMSW used in vermicomposting and the compost products produced at Kwashe Recycling MSW Factory. These results are matched with those mentioned by (Nagavallemma *et al*., 2004 and Sadeghi *et al*., 2015). The higher value of the **total potassium (TK)** was (0.856 ± 0.014%) found in (T1) recorded for Kwashe compost product, and the lower value was (0.326 ± 0.0145%) found in (T2) for Municipal Solid Waste (OMSW), which was sorted again in the lab before mixing with other feedstocks in preparation for the vermicomposting beds, as mention figure (4). These results are well-suited to those found by (Sadeghi *et al*., 2015 and Lastiri-Hernandez *et al*., 2023).

The **C/N ratio** of the vermicast varied from the higher value (28.43%) recorded in (T1) to the lower value (16.49%) found in (T5), table (2). It appears that the results of mixing the bulking agents (vegetable litters and OMSW) with (cow dung + wheat straw) which were used as the basic components in preparing vermicomposting beds at different mixing ratios of bulking agents influenced the C:N ratio in the vermicompost products. The results illustrate that the C:N ratio of the feedstock used in vermicomposting is considered an important factor impacting the C:N ratio of the final product of compost and vermicompost. The C:N ratio in T1 was superior to all other treatments because it did not reached maturity and it was not composted by the earthworms due to all the added worms were died. This may be attributed to the same reasons mentioned before due to the existence of fatal materials to worms. Negi and Suthar, (2013), reported that when the C:N ratio in the compost products reached to 20, it indicates that the compost has reached maturity and can be used in agriculture (Bhat *et al*., 2017).

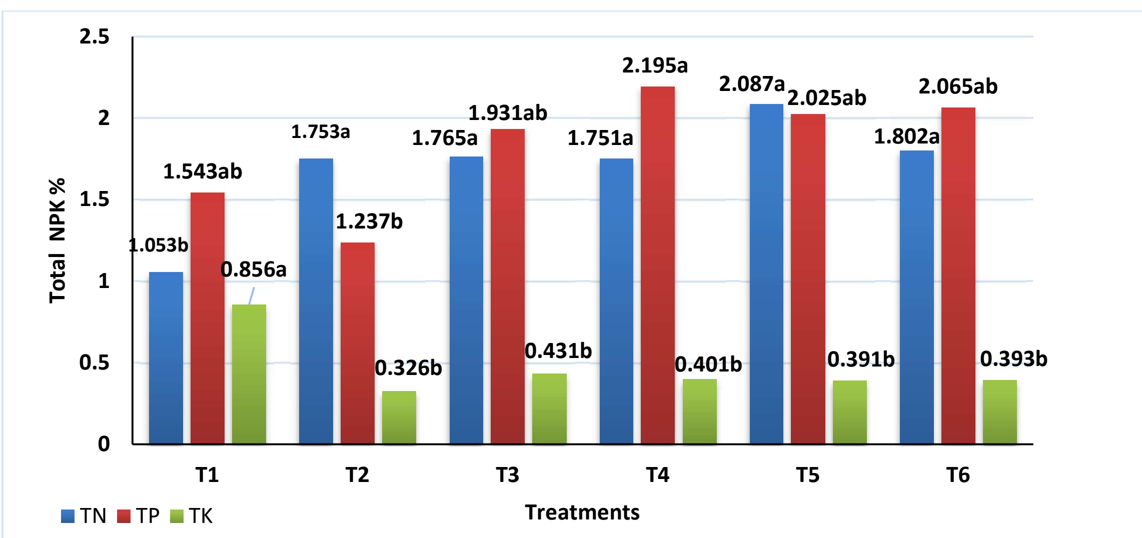


Figure (4): Show the Total NPK of the compost and vermicompost produced from different feedstock treatments.

Table (2): Show some of the studied chemical properties of the produced compost and vermicompost in this study:

Treatments	pH Mean	EC dS cm^{-1} Mean	CEC Cmol$_c$.kg^{-1} Mean	TOC % Mean	OM% Mean	Total Na % Mean	C: N Ratio Mean
T 1	6.81±0.061^{c}	15.15±0.380^{a}	81.16±0.075^{a}	29.86±0.012^{c}	54.04±0.012^{c}	0.223±0.009^{ab}	28.43±0.0120^{a}
T 2	5.43±0.057^{d}	15.98±0.240^{a}	18.23±0.111^{c}	34.27±0.012^{b}	62.05±0.023^{b}	0.263±0.009^{a}	19.48±0.006^{b}
T 3	8.054±0.043^{b}	5.44±0.238^{d}	34.75±5.530^{b}	34.37±0.015^{b}	62.21±0.023^{b}	0.095±0.003^{d}	19.48±0.602^{b}
T 4	8.23±0.023^{ab}	7.27±0.115^{b}	44.51±2.720^{b}	33.98±0.211^{b}	61.51±0.384^{b}	0.135±0.008^{cd}	19.42±0.263^{b}
T 5	8.25±0.012^{a}	7.62±0.047^{b}	45.63±1.260^{b}	34.15±0.416^{b}	61.82±0.753^{b}	0.151±0.029^{cd}	16.49±0.942^{c}
T 6	8.27±0.000^{a}	7.91±0.032^{c}	35.45±0.336^{b}	35.96±0.280^{a}	65.09±0.508^{a}	0.165±0.003^{bc}	20±0.709^{b}
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Means in each column that do not share a letter are significantly different at P – Value < 0.05. T1 = Compost prepared in Kwashe recycling factory, T2 = Organic Municipal Solid Waste before Composting (OMSW), T3 = Cow dung 50%+Wheat straw 50%, T4 = Cow dung 30% +Wheat straw 40% + Vegetables 30%, T5 = Cow dung 30% + Wheat straw 40% + OMSW 30%, T6 = Cow dung 20%+ Wheat straw 40% + Vegetables 20% + OMSW 20%

The biological properties of the compost and vermicompost

Table (3) show that the highest total number of **heterotrophic bacteria** (298 × 10^6 CFU.g^{-1}) recorded in T5, which did not significantly differ from T3 (P > 0.05). This may be attributed to the mixing OMSW in Duhok City together from different sources of wastes. the lowest number of total heterotrophic bacteria was (195×10^5 CFU.g^{-1}) recorded in T3. These differences may be attributed to the type of the feedstock which incorporated in preparation the vermicomposting beds which affects the activity of the heterotrophic bacteria in decomposition the organic waste. When the existence of the easily decomposable OM provides optimal degrees of temperature in vermicomposting system for growing the heterotrophic bacteria, as well as, provides their requirements from organic carbon, essential nutrients as a source of energy rather than the effect of pH, EC values of the substrates used in preparation the vermicomposting beds which are of critical importance for surviving the heterotrophic bacteria. These results agreed with those found by (Jadia and Fulekar, 2008).

The results of **total Coliforms and Fecal Coliforms (E. Coli) bacteria** showed that the detected numbers of total coliform and E. coli in all produced compost and vermicomposts in this study were (≥1600 $CFU.g^{-1}$) exceeded the suggested number of total coliform and *E. coli* (1000 $CFU.g^{-1}$) by (CCQC, 2002 and CCME, 2005) in the compost quality of the (AA, A, and B) classes. Non-significant differences were found between their numbers in all treatments. This means that the feedstocks used in producing compost and vermicompost are contaminated because these substrates are left behind and collected from city wastes from different contaminated non-pointed sources. As well, the composting and vermicomposting didn't perform in sanitation conditions. Therefore, the workers and farmers should use these products with caution to avoid infection with these pathogens that threaten their health. The present results agree with those found by (Brewer and Sullivan, 2003; Samarasinha *et al*., 2015 and Policastro, and Cesaro, 2022).

Table (3): Show some of the studied biological analysis of the produced compost and vermicompost in this study

Treatments	Total heterotrophic bacteria ($CFU.g^{-1}$)	Total Coliform (MPN) ($CFU.g^{-1}$)	Fecal Coliform (E. Coli) ($CFU.g^{-1}$)
T1	$254\times10^4 \pm 2.52^a$	≥1600	≥1600
T2	$225\times10^5 \pm 3.93^{ab}$	≥1600	≥1600
T3	$195\times10^5 \pm 0.88^{ab}$	≥1600	≥1600
T4	$225\times10^5 \pm 7.86^a$	≥1600	≥1600
T5	$298\times10^6 \pm 15.7^a$	≥1600	≥1600
T6	$279\times10^4 \pm 9.17^a$	≥1600	≥1600
Means in each column that do not share a letter are significantly different at P – Value < 0.05.			

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