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Biocatalytic Remediation of PAHs on Crude Oil Polluted Soil By Fruit Garbage Enzymes

E. O. Wellington[1,*] and **I. E. ThankGod**[2]

[1] Department of Chemical Science, Faculty of Basic and Applied Sciences, University of Africa, Toru-Orua, Nigeria

[2] Department of Biochemistry, Faculty of Science, University of Benin, Benin City, Nigeria

*E-mail address: ewellington41@yahoo.com

ABSTRACT

This study investigated the biocatalytic bioremediation of polycyclic aromatic hydrocarbons in crude oil contaminated soil by garbage derived from fermented organic peel wastes. The fruit garbage used were ripened plantain, banana, pineapple, and watermelon peel wastes, which were fermented for 90 days for the derivation of enzymes. Six soil samples were collected and labeled; group 1-6. Group served as positive control, group 2 served as untreated soil sample, while group 3-6 treated with 30, 50, 70, and 100% of fermented garbage enzyme solution for 30, 60, 90, 120, 150, and 180 days. PAHs were determined based on standard methods. GE at 30% from 120 to 180 days elicited mean removal of naphthalene at 65.03±0.03, 78.02±0.02, and 85.62±0.02 % respectively and similar results were observed in treatment with 70 and 100% garbage enzyme solution. Treatment with 30% of garbage for 120 to 180 days elicited mean removal of anthracene at 57.03±0.03, 62.93 ±0.03, and 82.14±0.02 % respectively. GE at 30% from 120 to 180 days elicited mean removal of fluoranthene at 60.82±0.03, 68.26 ±0.02, and 74.52 ±0.03 % respectively. Similar results were obtained on mean percentage removal of pyrene, 1-2-benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benz[a]pyrene, indeno (1-2-3-cd) pyrene, and benzo(g-h-i)perylene after treatment with 30, 70, and 100 % of garbage enzyme ferments. The differences observed in the biocatalytic bioremediation activities of the applied fruit garbage enzymes might be due to the difference in composition of the garbage enzyme mixtures arising from the degree of microbial activities in the solutions.

Keywords: Crude oil, polycyclic aromatic hydrocarbons, garbage enzymes, pineapple, plantain, watermelon, banana peels

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1. INTRODUCTION

The pervasiveness of crude oil pollution has become a very common problem in the Niger Delta region of Nigeria. This is because of the possible harm that it can cause to the environment [1]. Crude oil spilled leads to flow metal and organic contaminants into soil and water and continuous accumulation of these pollutants in oil is of high environmental concern [2].

Although soil is one of the key components of the natural ecosystem that supports environmental sustainability [3] and the severity of the contamination does not stop at the soil surface environment alone but reaches groundwater due to continuous and uncontrollable crude oil spillage [4]. This incidence have attracts public attention because accumulation of hazardous polycyclic aromatic hydrocarbons could lead to chronic endangerment including mutagenicity and carcinogenicity [5, 6].

Meanwhile, the effects of crude oil contamination on the soil characteristics have been the subject of many studies [2]. [7] reported that oil pollution increases carbon and reduces soil nitrates and phosphates. Also, hydrocarbon-based oil pollution prevents oxygen exchange between the soil and the atmosphere due to the hydrophobic properties of the oil. It was further reported that any contact of soil with hydrocarbon-based oil results in damage to the soil microorganisms and plants [8]. Therefore, as the quality of life on earth is inextricably linked to the overall quality of the environment, an essential and appropriate remediation method to deal with crude oil polluted soil that commonly occurs in the Niger Delta Areas is fervently required for managing, preserving, and restoring the quality of soil environment.

There are numerous crude oil spill remediation methods including physical (burning or thermal), chemical, and biological (bioremediation) [9]. The chemical and thermal or burning methods are expensive and has been shown to generate fatal air pollution. This requires the selection of the correct method focusing on efficient, environmentally safe treatment. Accordingly, the biological methods are usually preferred over the physical and chemical methods in decontaminating crude oil pollution [10]. Amongst the biological methods, bioremediation has been considered as the most promising [8]. Consequently, bioremediation has been intensively used to remove crude oil and diesel fuel [11] from the soil, but the removal efficiency is highly variable. This has brought the technique into the limelight of remediation nucleus and thus, bioremediation has been intensively studied over the past two decades, driven by the need for a low-cost, environmentally friendly and in-situ alternative to more expensive engineering-based remediation technology [12].

Despite the merits of bioremediation over the physical and chemical methods in removing water and soil impurities, the method has been limited by nutrients requirement for bolstering the microbial degradation of the metal and organic pollutants and also, the reactions take years to produce desired and substantial results, respectively [5]. Besides, bioremediation goes with its many inherent challenges, such as maintaining the microbial population necessary to degrade a certain compounds, and the necessary growth conditions (i.e., proper temperature, oxygen availability or limitation, moisture levels, pollutant levels, and pH) required by the microbes. In spite of this associated deficiencies in the bioremediation method, more efforts need to be focused towards harnessing modern-day bioremediation process as a suitable alternative

In this respects, it has been documented in literature that microbial extracellular-based enzymes play important function in the decontamination processes of polluted environments. For example, the microbial hydrolytic enzymes have been found promising in reducing the inorganic and organic compounds, removal of pathogenic organisms, and odour in waste sludge

[6]. However, much enough has not been done in the use of enzymes for pollution management, as researchers till now employ commercial hydrolytic enzymes for pollutant degradation and stabilization which is not economical [13]. Therefore, there is a need to find an alternative cheap rich source of such enzymes, as they could serve as powerful instruments to preserve the environment [14]. It is known that enzymes are generally produced from animals, plants, or microorganisms. To this end, enzymes from plant sources are relatively cheaper and have easier extraction and purification steps [15]. For this reason, microbial hydrolytic enzymes, which are readily available can be sourced from plant-based wastes.

It is factual that restaurants, vegetable markets, fruit markets, and food processing industries produce decomposable waste such as fruits, vegetables, and peels in huge quantities. Management of this organic waste is currently another major issue all over the world. The disposal of these decomposable wastes either in the landfill or by composting produces greenhouse gases like methane and nitrous oxides, which are not environment friendly. Hence, the decomposable plant wastes commonly thrown into the environment can be made resourceful stuff for production of value-added bio-product (s), which in turn reduces the production of greenhouse gas from the wastes.

Also, studies show that garbage enzymes are complex organic substance of protein chains, organic acids, and mineral salts produced easily by simple fermentation of fruit and vegetable wastes in water mixed with brown sugar or molasses sugar [16]. The organic solution harvested after the fermentation is a crude enzyme solution, which possesses different extracellular enzymes. Extracellular enzymes refer to those enzymes that are secreted by microbes that enter the aqueous phase during an aerobic submerged fermentation process [17]. Extracellular enzymes such as proteases, amylases, and lipases are produced and harvested during aerobic fermentation of organic matter [18]. Consequently, the garbage enzyme functions in a similar way to enzymes in achieving a high degree of degradation within a short time.

Therefore, this present study aims to explore the potential of fruit garbage enzyme solutions in the remediation of crude contaminated soil, as the advantage of fruit garbage enzyme solution has not been fully explored in soil decontamination. Consequently, this study was initiated and limited to a bench-scale bio-simulative process that includes the production of fruit garbage enzyme solution from ripen plantain, banana, pineapple, and watermelon peels separately and subsequently applied for the remediation of the artificially induced waste oil contamination in crude oil polluted soil.

2. MATERIALS AND METHODS

2. 1. Studied Area and Sample Collection

Agbura community was selected in this study due to the recent crude oil spill that occurred in 2022. The city is located very close to the capital city of Bayelsa State. The population of the city is 1200. Agbura is one of the communities under Yenagoa Local Government Area of Bayelsa state. It rains most in winter and is moderately warm in summer. Its annual precipitation is 217.7 mm, mean annual temperature is 11.8 °C and 46% humidity.

Soil characters of the area was evaluated as sandy loam containing 80% sand, 12% loam, 6% sludge and 2% organic material with pH 6.8. The identification of soil contamination was also possible based on a visual examination of the soil. The crude oil contaminated soil was collected from the soil, which has a characteristic of black colors due to oil spillage and the soil surface was hardened. The sample was packaged into a sterile polytene bag and was brought to the Science Laboratory Technology Department, at University of Africa Toru-Orua for evaluation. The sample was stored at adequate temperature before experimental work.

2. 2. Preparation of Soil Samples

Exactly, 200g of the selected soil samples (crude oil contaminated soil, crude oil contaminated sample was mixed with loamy/black soil at 50:50) was weighed using analytical balance into three different containers. Exactly, 500 ml of distilled water was measured and added into the different container containing the polluted soil and it was mixed vigorously.

2. 3. Garbage Enzyme (GE) Preparation

GE was produced from three organic substances such as ripened pineapple (PA), watermelon (WA), plantain (PL), banana (BN) peels and brown sugar in ratio 10: 3: 1 respectively. The organic substances were subjected to fermentation for the period of 90 Days. The three organic substances (pineapple peels, watermelon and banana peels) were obtained from Swali market Yenagoa. Twelve liters which is equivalent to 12kg of water were measured using measuring cylinder into an empty clean paint rubber bucket, 1.2kg of brown sugar was weighed using analytical Dial Spring Scale and was dissolved in the water to form sugar solution while 3.6kg of the pineapple, watermelon and banana peels were weighed and poured into the sugar solution. The mixture were thoroughly stirred together for proper mixing and were covered. The mixtures were then labeled with the starting and end of the reaction dates (fermentation was allowed for 90 days). The preparation was set-up using three (3) empty clean paint rubber buckets.

2. 4. Sample Treatment

The soil samples collected in each of the groups (group 1-10) were processed and air dried to remove the moisture and water content simultaneously. They were then dried to constant weight in an oven maintained at 105 ºC. Three grams (3.0g) of the soil samples from each group was carefully weighed into clean platinum crucible and ashed at 450-500 ºC then cooled to room temperature in desiccators. The sample was dissolved in 5ml of 20% hydrochloric acid and the solution was carefully transferred into a 100ml volumetric flask. The solution was well rinsed with distilled water and transferred to the flask, made up to the mark with distilled water and shaken to mix well. The resulting sample solution from each group was then taken for the determination of PAHs concentrations using Atomic Absorption Spectrophotometer (AAS) based on the procedures of the Association of Official Analytical Chemist.

2. 5. Experimental Design

Soil samples were collected from Agbura community, recently polluted by crude oil spill. The soil sample were prepared and grouped into six (6). Group 3 to 6 were treated with were treated with garbage enzymes as shown below.

GROUP 1: Non-polluted soil sample, serving as control

GROUP 2: Polluted and untreated soil sample, serving as untreated soil

GROUP 3: Polluted and treated with GE 730t/hectare (30%) from WA+PA for 30, 60, 90, 120, 150, and 180 days

GROUP 4: Polluted and treated with GE 730t/hectare (50%) from PL+BN for 30, 60, 90, 120, 150, and 180 days

GROUP 5: Polluted and treated with GE140t/hectare (70%) PL+WA+PA+BN for 30, 60, 90, 120, 150, and 180 days

GROUP 6: Polluted and treated with GE1460t/hectare (100%) PL+WA+PA+BN for 30, 60, 90, 120, 150, and 180 days

At the end of the duration for each group, the soil sample carried to the laboratory and the heavy metal levels in them were analyzed using standard reagents and methods

2. 6. Determination of PAHs Concentrations

The PAHs levels in all the treated samples were analyzed using Gas chromatography-mass spectroscopy. In this method, 10 g mass of each sample was spiked with 200 ng of the surrogate standard solution containing the deuterated PAH compounds and was then mixed with an equal amount of anhydrous Na_2SO_4. A 30 mL mixture of acetone/DCM/*n*-hexane (1:1:1) was added to each sample, and extraction was achieved by ultrasonication at 30 °C for 30 min. The contents of each mixture were filtered, a fresh aliquot of the solvent mixture was added to the residue, and the process was repeated a further two times. The combined extracts were rotary evaporated to 2 mL at 30 °C and 250 mbar. The mixtures were purified on a column packed with 2.0 g of alumina and 2.0 g of silica gel. The PAHs were eluted from the column with 25 mL of a 9:1 *n*-hexane/DCM mixture and the eluates were evaporated to 2 mL under a slow flowing stream of pure nitrogen gas. The PAHs in the cleaned esamples were analyzed with Gas chromatography–mass spectrometr (GC-MS).

2. 7. Digestion and Analytical Procedure

One gram of each sample was weighed into 50-ml beakers, followed by the addition of 10 ml mixture of analytical grade acids HNO_3: $HClO_4$ in the ratio 5:1, and left overnight for complete contact of material. Next day, the digestion was performed at a temperature of about 190 ºC for 1.5 h. After cooling, the samples were transferred into 100 ml volumetric flask and solution was made up to a final volume raised up to the mark with distilled water. The metal concentrations were determined by atomic absorption spectrometry using a VARIAN model AA2407 Atomic Absorption Spectrophotometer (AAS). Analysis of each sample was carried out three times to obtain representative results and the data reported in µg g-1 (on a dry matter basis).

2. 8. Statistical analysis

The experiment was designed in completely randomized (CRD) with 6 treatments and three replications. Treatment effects were determined by analysis of variance with the help of statistical package STATISTIX-10 and mean separation was tested by Tukey HSD.

3. RESULTS AND DISCUSSION

Table 1 shows the mean percentage removal of naphthalene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of naphthalene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 90-180 days (Table 1). The mean percentage removal of naphthalene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90-180 days (Table 1). Also, the mean percentage removal of naphthalene in crude oil polluted soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 1).

More so, the mean percentage removal of naphthalene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30-180 days (Table 1). However, the mean percentage removal of naphthalene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 60-180 days was highest followed by 70% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of naphathalene was those treated with 50% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2. The significantly high percentage removal of naphthalene in crude oil polluted soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes could attributed to increased naphthalene degradation by GE facilitated by optimum microbial activities. [19] in their study on Biostimulation of Petroleum-Contaminated Soil Using Organic and Inorganic Amendments reported that analysis of residual polycyclic aromatic hydrocarbons (PAHs) showed that the 16 PAHs pollutants were either completely or highly degraded in the combined organic waste treatments, indicating the potential of this amendment for the environmental remediation of soils contaminated with recalcitrant organic pollutants, which were similar to the result of this study.

Table 1. Mean percentage removal of naphthalene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	14.74±0.04^b	22.52±0.01^b	25.72±0.02^b	28.03±0.02^b	23.94±0.04^b	16.01±0.02^b
GE WA+PA (30%)	9.75 ±0.04^c	14.25±0.04^c	37.04±0.03^c	65.03±0.03^c	78.02±0.02^c	85.62±0.02^c
GE PL+BN (50%)	7.24 ±0.03^f	14.82±0.03^f	26.14±0.01^f	35.04±0.03^f	41.73±0.03^f	54.04±0.03^f

GE PL+WA+PA+BN (70%)	20.02±0.02^{f}	25.83±0.05^{f}	46.24±0.03^{f}	68.04±0.05^{f}	82.02±0.01^{f}	87.35±0.02^{f}
GE PL+WA+PA+BN (100%)	18.04±0.03^{f}	39.73±0.03^{f}	52.82±0.03^{f}	71.03±0.03^{f}	80.14±0.03^{f}	93.01±0.03^{f}

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at (P < 0.05) down the treatments. Values with superscript c are statistically different from group 1 and 2 at (P < 0.05) down the treatments. Values with superscript f are statistically different from group 1 and 2 at (P < 0.05) across the treatments.

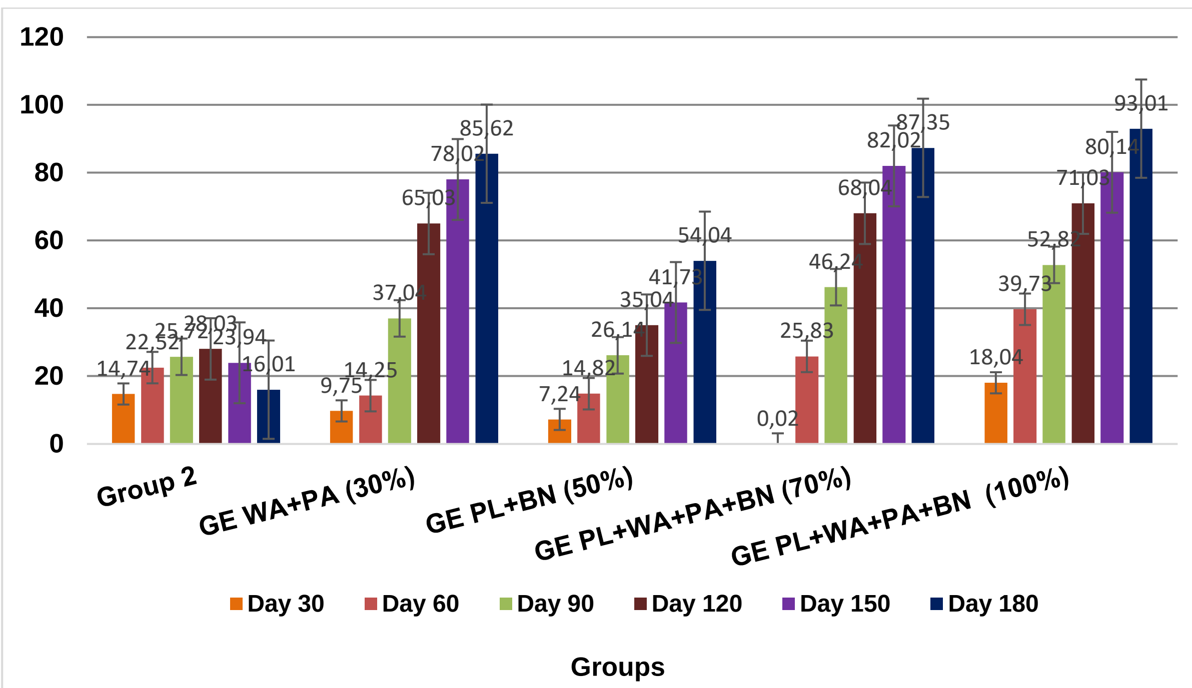

Figure 1. Mean and standard deviation of naphthalene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE).

Table 2 shows the mean percentage removal of acenaphthylene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of acenaphthylene in crude oil polluted soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30-180 days (Table 2). The mean percentage removal of acenaphthylene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30-180 days (Table 2). Also, the mean percentage removal of acenaphthylene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 2). More so, the mean percentage removal of acenaphthylene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30-180 days (Table 2). The mean percentage removal of acenaphthylene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30-180 days was highest followed by 70% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 50% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of acenaphthylene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 2). The significantly high percentage removal of acenaphthylene in crude oil polluted soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes is suggestive that organic peel wastes ferments of ripen plantain, banana, watermelon, and pineapple could good means of acenaphthylene remediation in crude polluted soil. The acenaphthylene percentage removal obtained in this present study was higher than that reported by Ugoma *et al.* [20] in their study remediation of crude oil contaminated soil with locally formulated bioremediation agent, where they reported also that polycyclic aromatic hydrocarbons in crude oil extracted soil were remediated after six months of treatments with local bioremediation agents.

Table 2. Mean percentage removal of acenaphthylene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	3.52 ± 0.03^{b}	8.74 ± 0.03^{b}	11.94 ± 0.03^{b}	15.01 ± 0.02^{b}	17.34 ± 0.02^{b}	21.03 ± 0.01^{b}
GE WA+PA (30%)	7.14 ± 0.04^{c}	26.01 ± 0.03^{c}	31.55 ± 0.03^{c}	48.15 ± 0.02^{c}	54.65 ± 0.03^{c}	$67.03 \pm .003^{c}$
GE PL+BN (50%)	19.34 ± 0.03^{f}	27.35 ± 0.04^{f}	41.84 ± 0.04^{f}	53.03 ± 0.01^{f}	73.16 ± 0.03^{f}	83.45 ± 0.04^{f}
GE PL+WA+PA+BN (70%)	17.25 ± 0.03^{f}	36.15 ± 0.03^{f}	51.35 ± 0.04^{f}	60.82 ± 0.02^{f}	74.53 ± 0.03^{f}	87.03 ± 0.03^{f}
GE PL+WA+PA+BN (100%)	26.03 ± 0.03^{f}	46.83 ± 0.02^{f}	58.02 ± 0.04^{f}	68.01 ± 0.06^{f}	83.14 ± 0.03^{f}	92.54 ± 0.04^{f}

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments

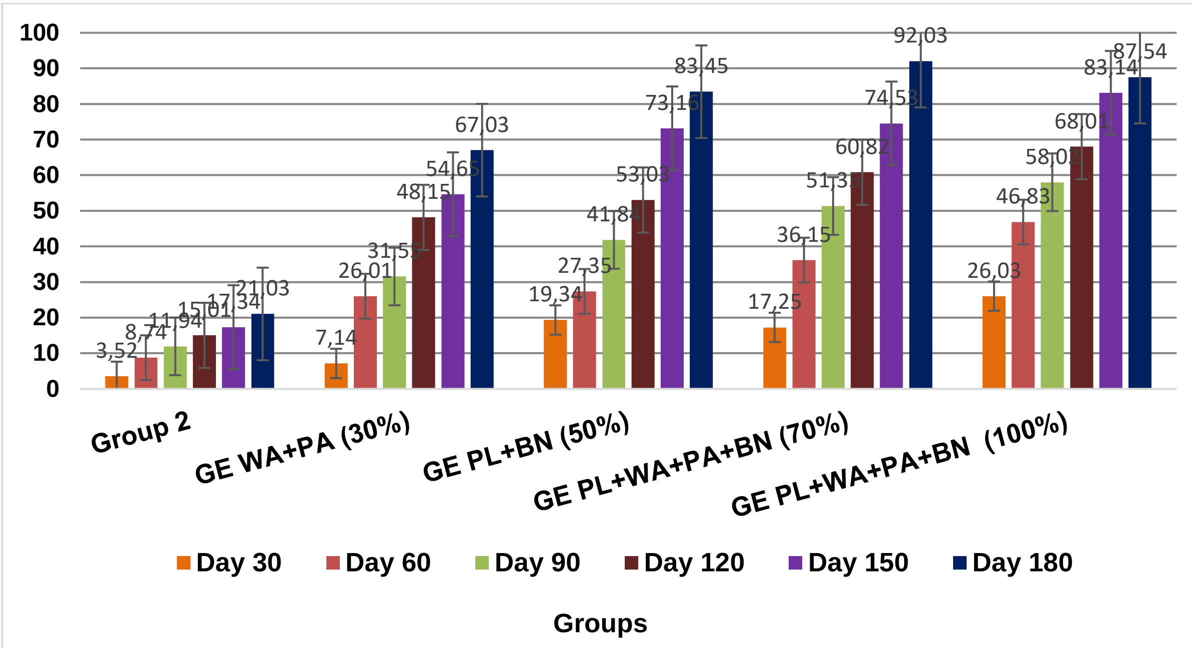

Figure 2. Mean and standard deviation of acenaphthylene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 3 shows the mean percentage removal of acenaphthene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of acenaphthene in crude oil polluted soil treated with 30% of GE ferments from watermelon and pineapple peel wastes were significantly higher than those of group 2, particularly from 30-180 days (Table 3). The mean percentage removal of acenaphthene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30-180 days (Table 3). The mean percentage removal of acenaphthene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 3). More so, the mean percentage removal of acenaphthene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30-180 days (Table 3). The mean percentage removal of acenaphthene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30-180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of acenaphthene was those treated with 100% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 3). GE at 30% is effective degradation of acenaphthene due to increases in microbial activities. Ugoma *et al.* [20] in their study remediation of crude oil contaminated soil with locally formulated bioremediation agent, reported lower values of acenaphthene after treatment with after six months of treatments with local bioremediation agents.

Table 3. Mean percentage removal of acenaphthene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	1.83±0.02^{b}	4.33±0.04^{b}	7.2±0.05^{b}	8.92±0.03^{b}	9.23 ±0.02^{b}	12.01±0.02^{b}
GE WA+PA (30%)	13.73±0.02^{c}	17.52±0.03^{c}	19.84±0.03^{c}	27.45±0.03^{c}	35.04±0.04^{c}	40.15±0.03^{c}
GE PL+BN (50%)	5.23 ±0.04^{f}	11.93±0.03^{f}	13.84±0.03^{f}	19.46±0.04^{f}	37.640±0.04^{f}	47.84±0.04^{f}
GE PL+WA+PA+BN (70%)	3.91 ±0.01^{f}	15.74±0.03^{f}	22.94±0.04^{f}	35.05±0.03^{f}	51.43 ±0.04^{f}	60.01±0.02^{f}
GE PL+WA+PA+BN (100%)	2.84 ±0.04^{f}	5.23 ±0.03^{f}	12.92±0.03^{f}	14.83±0.03^{f}	23.64 ±0.04^{f}	31.02 ±0.03^{f}

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

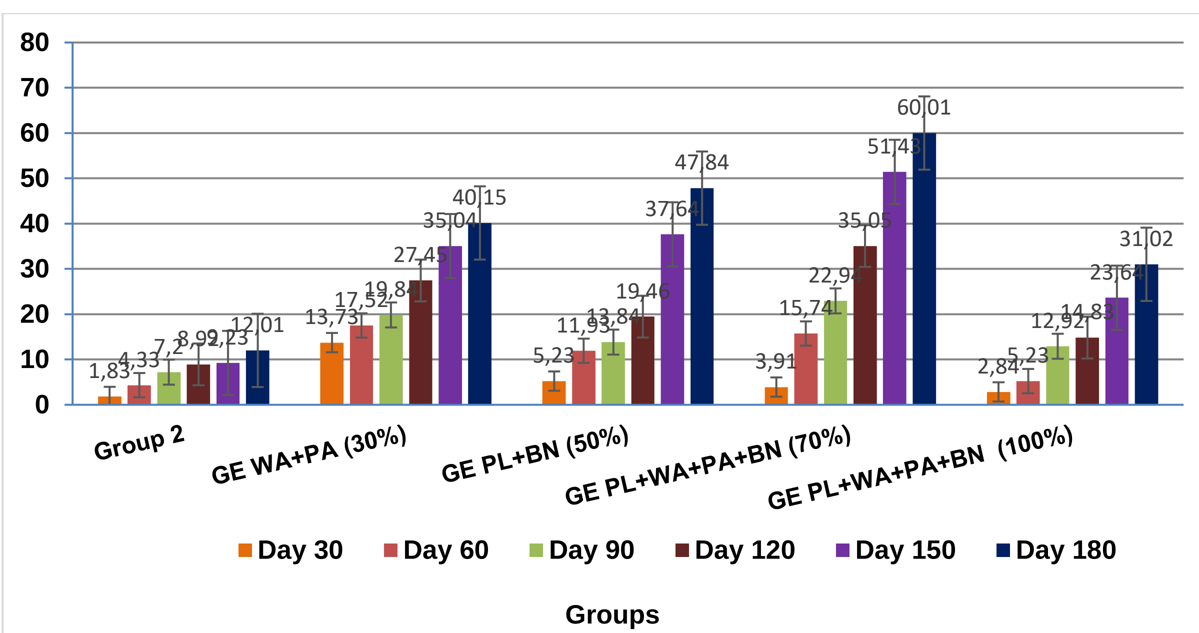

Figure 3. Acenaphthene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE).

Table 4 shows the mean percentage removal of fluorene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of fluorene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 90-180 days (Table 4). The mean percentage removal of fluorene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 4). The mean percentage removal of fluorene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 4). More so, the mean percentage removal of fluorene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90-180 days (Table 4).

The mean percentage removal of fluorene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30-180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of fluorene was those treated with 100% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 4). GE at70% is effective degradation of fluorene due to increases in microbial activities. The high rate of biodegradation fluorene observed in contaminated soil remediated with 30, 50, 70, and 100% garbage enzymes, agrees with the study of Chorom *et al.* [21] who reported that 75% oil degradation was obtained on treatment of crude oil contaminated soil with melon shell.

Table 4. Mean percentage removal of fluorene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	9.84 ±0.04	14.35±0.06	17.23±0.03	18.01 ±0.03	21.33 ±0.03	27.75 ±0.04
GE WA+PA (30%)	2.71 ±0.01	5.02 ±0.03	27.93±0.03	31.64 ±0.04	9.35 ±0.03	14.83 ±0.03
GE PL+BN (50%)	19.84±0.04	25 ±0.01	33.92±0.02	49.64 ±0.04	57.12 ±0.03	63.862±0.02
GE PL+WA+PA+BN (70%)	24.62±0.03	33.74±0.04	41.03±0.04	48.13 ±0.03	58.02 ±0.02	64.84 ±0.04
GE PL+WA+PA+BN (100%)	3.46 ±0.03	11.62±0.02	21.81±0.02	31.03 ±0.03	39.83 ±0.03	51.03 ±0.03

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at (P < 0.05) down the treatments. Values with superscript c are statistically different from group 1 and 2 at (P < 0.05) down the treatments. Values with superscript f are statistically different from group 1 and 2 at (P < 0.05) across the treatments.

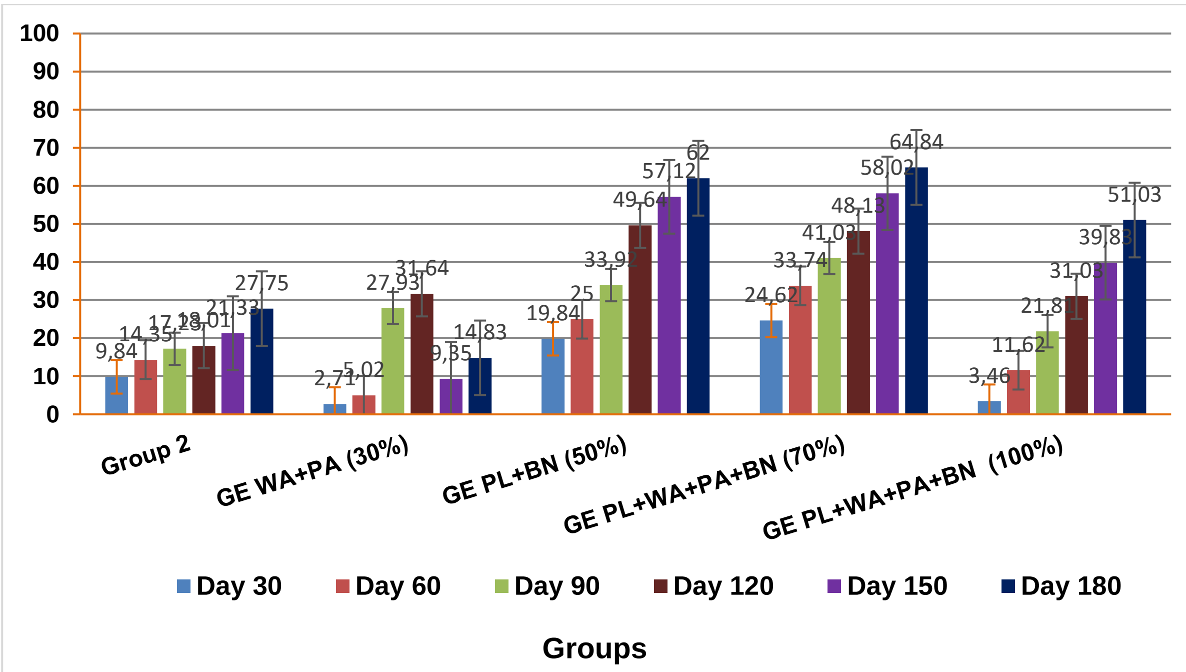

Figure 4. Mean and standard deviation of fluorene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 5 shows the mean percentage removal of phenanthrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of phenanthrene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 90-180 days (Table 4). The mean percentage removal of phenanthrene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 60 to 180 days (Table 5). The mean percentage removal of phenanthrene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 5). More so, the mean percentage removal of phenanthrene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to180 days (Table 5). The mean percentage removal of phenanthrene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 1000% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of phenanthrene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 5). GE at 70% is effective degradation of phenanthrene due to increases in microbial activities.

The percentage removal of phenanthrene observed at 30 to 180 days of treatments in agreement with the findings of Chorom *et al.* [21] who reported that petroleum degradation was decreased with increasing time.

Table 5. Mean percentage removal of phenanthrene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	4.73 ±0.02	8.64±0.03	11.71±0.01	11.94±0.04	12.04±0.03	12.25±0.04
GE WA+PA (30%)	3.6±0.01	8.64±0.04	12.33±0.03	16.03±0.03	16.73±0.03	21.04±0.05
GE PL+BN (50%)	8.93±0.02	16.83±0.03	24.04±0.04	29.94±0.03	36.02±0.04	54.93±0.03
GE PL+WA+PA+BN (70%)	13.75±0.04	33.05±0.04	40.15±0.03	56.04±0.05	61.06±0.02	68.14±0.02
GE PL+WA+PA+BN (100%)	7.05±0.04	16.02±0.04	24.93±0.03	29.72±0.03	31.03±0.03	38.03±0.03

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

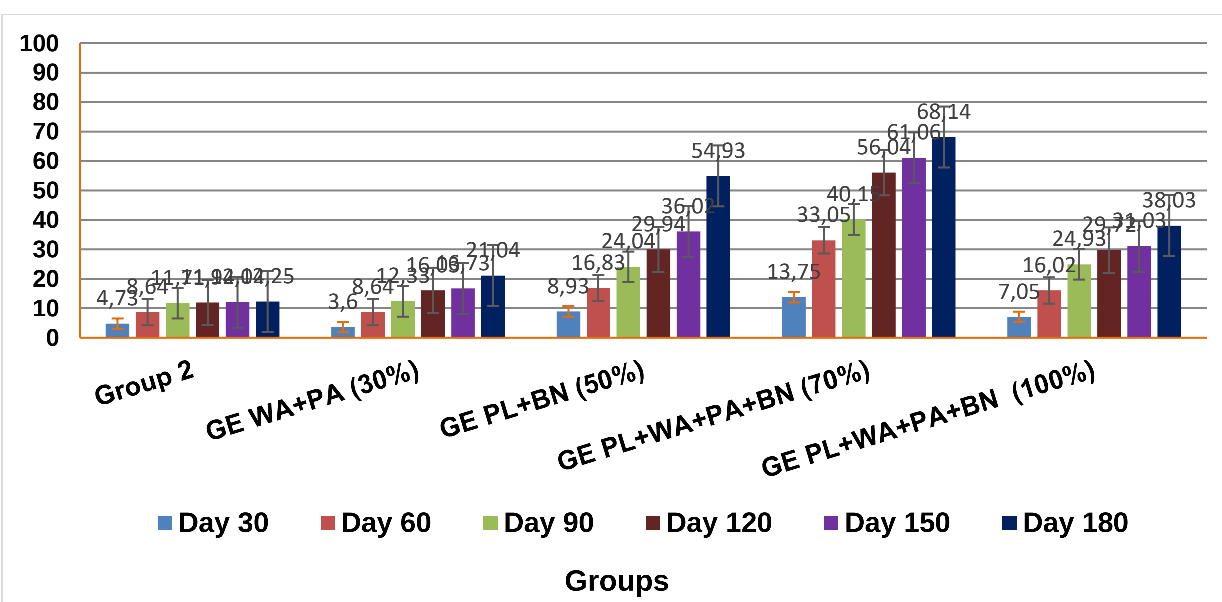

Figure 5. Mean and standard deviation of phenanthrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 6 shows the mean percentage removal of anthracene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of anthracene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 150 to180 days (Table 6). The mean percentage removal of anthracene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 6). The mean percentage removal of anthracene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 6). More so, the mean percentage removal of anthracene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to180 days (Table 6). The mean percentage removal of anthracene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to180 days was highest followed by 50% of GE ferments from ripen plantain and banana peel wastes, 100% of GE ferments from ripen plantain and banana peel wastes, while the least was 30% of GE ferments from watermelon and pineapple peel wastes. GE at 70% is effective degradation of anthracene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon due to increases in microbial activities. This agrees with the report of Yahemba *et al*. [22] where they said that a number and variety of microbial agent influence biodegradation of PAHs in crude oil polluted soil.

Table 6. Mean percentage removal of anthracene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	5.12 ±0.03	11.54±0.06	11.94 ±0.03	12.02±0.02	12.84 ±0.03	13 ±0.01
GE WA+PA (30%)	2.25 ±0.01	6.82 ±0.03	13.05 ±0.03	11.93±0.01	16.04 ±0.04	23.84±0.04
GE PL+BN (50%)	11.53±0.02	17.34±0.01	24.65 ±0.04	29.14±0.01	37.43 ±0.03	43.01±0.02
GE PL+WA+PA+BN (70%)	36.73±0.04	39.94±0.04	46.17 ±0.00	57.03±0.03	62.93 ±0.03	82.14±0.02
GE PL+WA+PA+BN (100%)	10.34±0.03	16.85±0.04	26.02 ±0.03	35.92±0.02	40.01 ±0.02	46.04±0.03

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

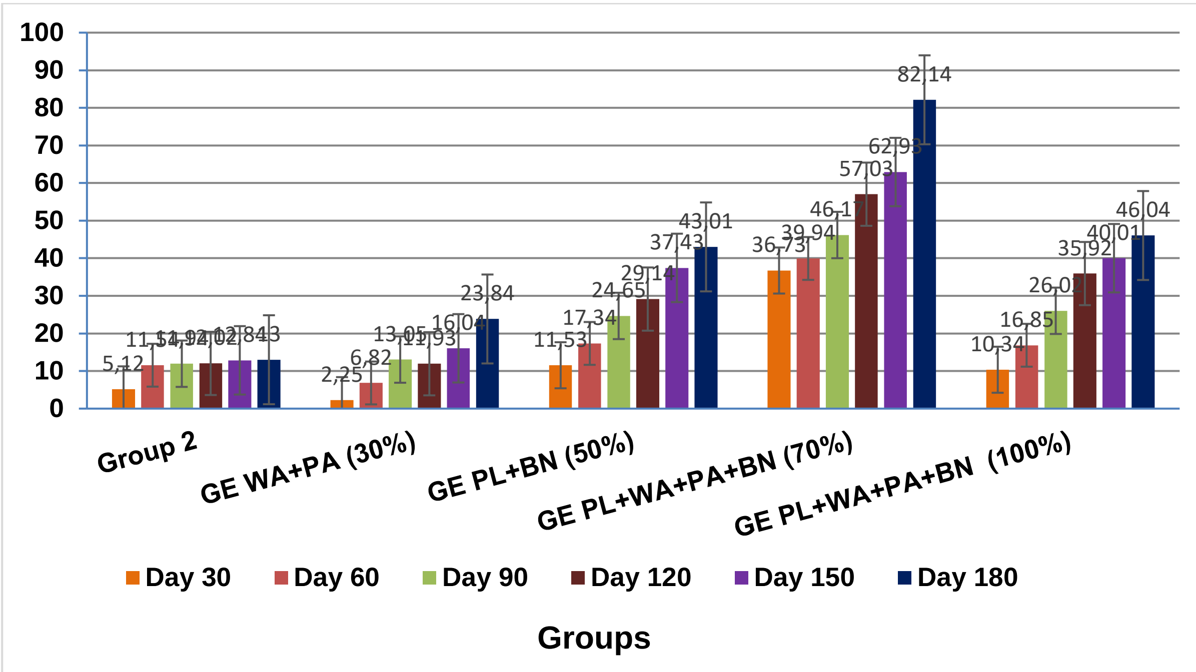

Figure 6. Mean and standard deviation of anthracene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE).

Table 7 shows the mean percentage removal of fluoranthene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of fluoranthene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 7). The mean percentage removal of fluoranthene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 7). The mean percentage removal of fluoranthene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30-180 days (Table 7). More so, the mean percentage removal of fluoranthene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 7). The mean percentage removal of fluoranthene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 60 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 70% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of fluoranthene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 7). GE at70% is effective degradation of fluoranthene due to increases in microbial activities. This results in alignment with the findings of Chorom *et al.* [21] who reported that petroleum degradation was decreased with increasing time.

Table 7. Mean percentage removal of fluoranthene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	3.94 ±0.03	14.01±0.02	14.54±0.02	14.96±0.03	15.45 ±0.03	17.24 ±0.02
GE WA+PA (30%)	7.5 ±0.01	18.14±0.03	21.74±0.02	27.92±0.04	37.03 ±0.02	44.84 ±0.04
GE PL+BN (50%)	36.82±0.04	42.72±0.02	52.65±0.04	60.82±0.03	68.26 ±0.02	74.52 ±0.03
GE PL+WA+PA+BN (70%)	16.84±0.03	23.72±0.02	31.04±0.04	38.53±0.02	47.33 ±0.05	54.83 ±0.06
GE PL+WA+PA+BN (100%)	29.57±0.02	43.82±0.00	56.72±0.03	64.03±0.04	72.83 ±0.03	81.07 ±0.02

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

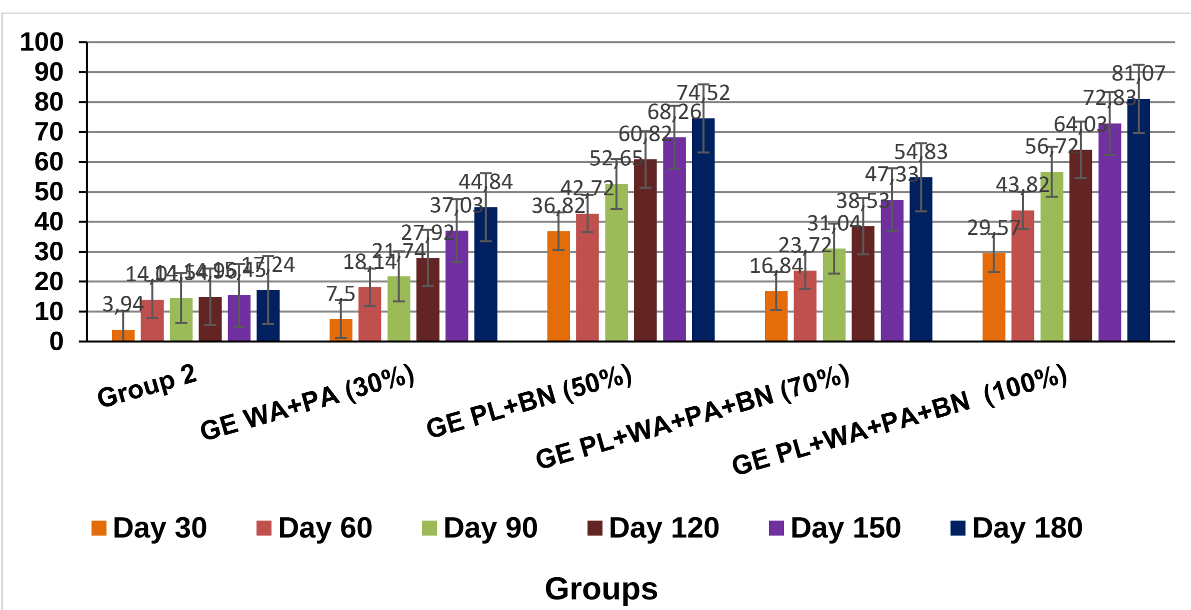

Figure 7. Mean and standard deviation of fluoranthene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE).

Table 8 shows the mean percentage removal of pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of pyrene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 8). The mean percentage removal of pyrene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 8). The mean percentage removal of pyrene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 8). More so, the mean percentage removal of pyrene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 8). The mean percentage removal of pyrene in soil sample treated with 50% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to 180 days was highest followed by 30% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 100% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of pyrene was those treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 8). GE at 50% is effective degradation of pyrene due to increases in microbial activities.

Table 8. Mean percentage removal of pyrene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	32.65 ±0.03	37.03 ±0.04	37.43±0.04	38.02±0.05	40.15 ±0.02	40.56±0.04
GE WA+PA (30%)	40.12 ±0.02	17.82 ±0.03	22.91±0.02	27.17±0.06	33.74 ±0.03	39.04±0.04
GE PL+BN (50%)	57.16 ±0.01	72.53 ±0.03	84.03±0.04	88.73±0.03	94.12 ±0.02	97.03±0.04
GE PL+WA+PA+BN (70%)	14.85 ±0.03	19.63 ±0.04	27.84±0.04	37.53±0.03	44.14 ±0.04	63.03±0.03
GE PL+WA+PA+BN (100%)	34.74 ±0.03	47.03 ±0.03	58.22±0.05	68.04±0.05	74.63 ±0.03	91.03±0.03

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

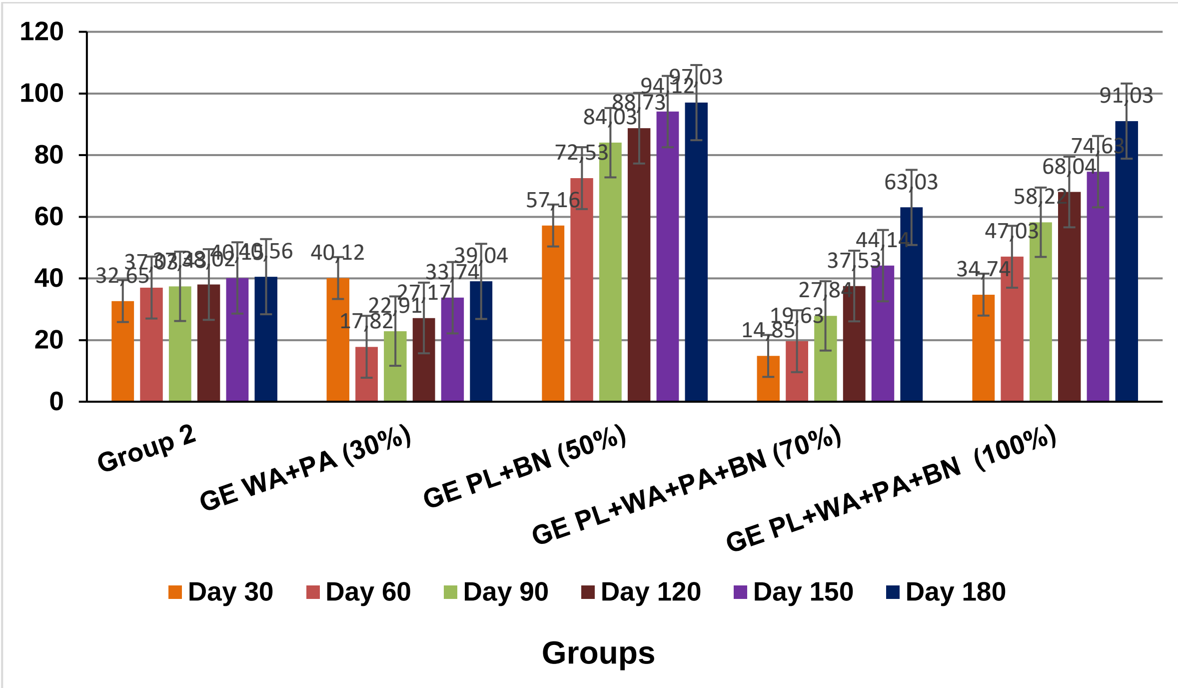

Figure 8. Mean and standard deviation of pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE).

Table 9 shows the mean percentage removal of 1-2-benzanthracene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of 1-2-benzanthracene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 9). The mean percentage removal of 1-2-benzanthracene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 9). The mean percentage removal of 1-2-benzanthracene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 9). More so, the mean percentage removal of 1-2-benzanthracene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 9). The mean percentage removal of 1-2-benzanthracene in soil sample treated with 50% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to 180 days was highest followed by 70% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 100% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of 1-2-benzanthracene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 9). GE at 50% is effective degradation of 1-2-benzanthracene due to increases in microbial activities. Owabor *et al.* [23] in their study on bioremediation of polycyclic aromatic hydrocarbon contaminated aqueous-soil matrix: effect of cocontamination reported similar 1-2-benzanthracene degradation by microbial activities.

Table 9. Mean percentage removal of 1-2-benzanthracene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	2.01 ±0.00	4.63 ±0.03	12.95±0.05	12.85±0.01	12.94±0.03	13.52 ±0.02
GE WA+PA (30%)	15.06 ±0.02	26.84 ±0.04	24.6 ±0.01	15.14±0.03	72.02±0.05	89.35 ±0.02
GE PL+BN (50%)	46.03 ±0.04	65.24 ±0.02	77.43±0.03	83.74±0.04	97.22±0.02	98.73 ±0.02
GE PL+WA+PA+BN (70%)	25.86 ±0.03	35.92 ±0.05	41.64±0.01	58.01±0.03	63.74±0.04	86.94 ±0.03
GE PL+WA+PA+BN (100%)	13.65 ±0.04	26.56 ±0.02	36.05±0.04	41.74±0.03	61.35±0.03	75.17 ±0.05

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

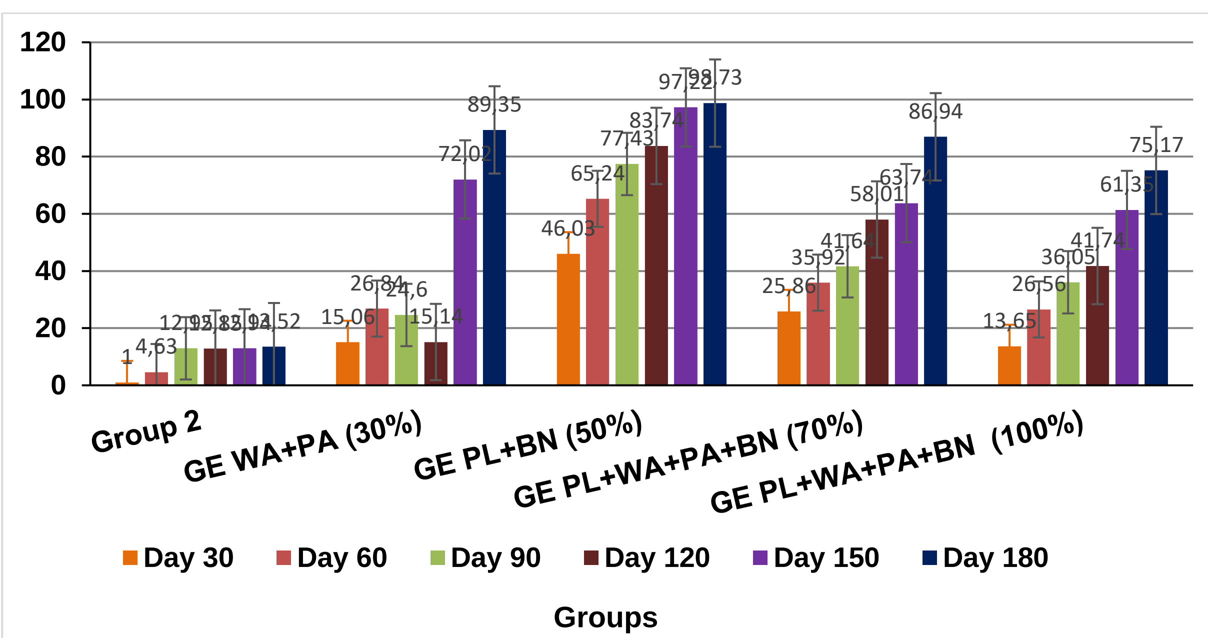

Figure 9. Mean percentage removal of 1-2-benzanthracenepercentageremovalfrom polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 10 shows the mean percentage removal of chrysene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of chrysene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 10). The mean percentage removal of chrysene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 10). The mean percentage removal of chrysene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 10). More so, the mean percentage removal of chrysene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 10).

The mean percentage removal of chrysene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of chrysene was those treated with 100% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 10). GE at 30, 50, 70, and 100% elicited effective degradation of chrysene facilitated by increases in microbial activities, hence they could used as bioremediation tool for chrysene degradation in crude oil contaminated soil.

Table 10. The Mean chrysene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	1.2 ±0.00	4.23±0.03	6.73±0.02	16.03±0.03	19.12±0.05	23.52±0.02
GE WA+PA (30%)	26.85±0.04	31.84±0.03	41.67±0.02	61.83±0.02	74.92±0.05	89.03±0.05
GE PL+BN (50%)	19.24±0.03	36.13±0.04	56.25±0.03	73.85±0.04	83.55±0.03	98.01±0.01
GE PL+WA+PA+BN (70%)	36.74±0.04	53.05±0.04	68.93±0.02	73.83±0.03	85.19±0.00	91.51±0.01
GE PL+WA+PA+BN (100%)	15.72±0.02	27.81±0.01	37.92±0.03	53.14±0.03	72.83±0.02	87.03±0.04

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

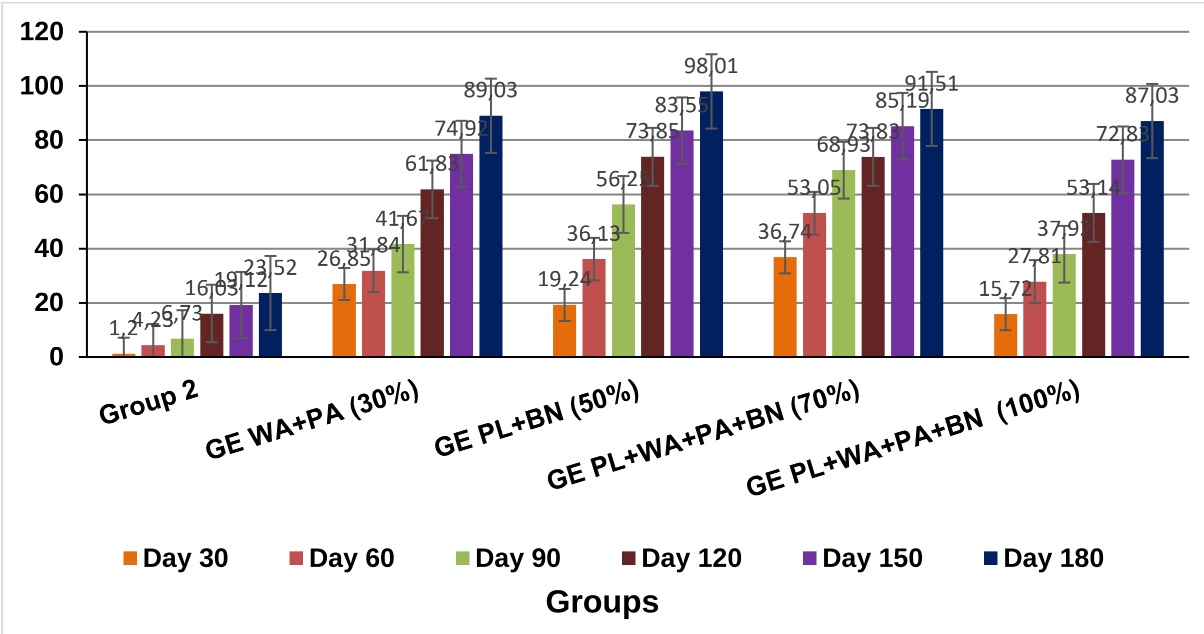

Figure 10. Mean percentage removal of chrysene from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 11 shows the mean percentage removal of benzo(b)fluoranthene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of benzo(b)fluoranthene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 11). The mean percentage removal of chrysene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 11). The mean percentage removal of benzo(b)fluoranthene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 11). More so, the mean percentage removal of benzo(b)fluoranthene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 11). The mean percentage removal of benzo(b)fluoranthene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 30 to 180 days was highest followed by 70% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 50% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of benzo(b)fluoranthene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 11). GE at 100% elicited effective degradation of benzo(b)fluoranthene which could be attributed to in microbial activities. Odukoya and Lambert [24] in their study on Remediation by enhanced natural attenuation (RENA): A beneficial strategy for polyaromatic hydrocarbon degradation and agrifood production reported results that are similar with the finding of this study.

Table 11. The Mean percentage removal of benzo(b)fluoranthene from polluted soil samples treated with different concentration of garbage Enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	0.9 ±0.00	0.72±0.00	26.16±0.03	26.45±0.02	27.72±0.02	26.94±0.02
GE WA+PA (30%)	17.26±0.02	24.73±0.03	33.64±0.04	41.84±0.03	64.01±0.03	83.16±0.03
GE PL+BN (50%)	29.84±0.04	38.32±0.02	47.91±0.01	61.82±0.01	87.12±0.02	94.04±0.02
GE PL+WA+PA+BN (70%)	36.94±0.03	47.33±0.02	59.35±0.02	72.41±0.02	84.42±0.02	94.04±0.04
GE PL+WA+PA+BN (100%)	52.04±0.03	56.83±0.03	68.15±0.04	76.15±0.03	82.43±0.03	98.13±0.02

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

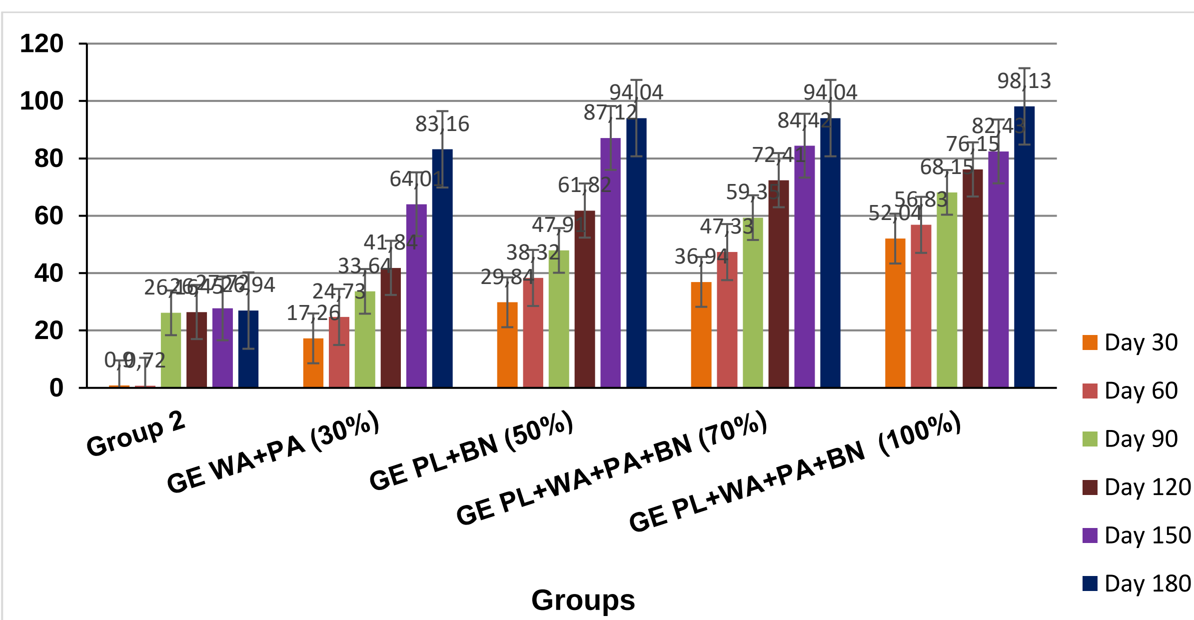

Figure 11. The Mean percentage removal of benzo(b)fluoranthene from polluted soil samples treated with different concentration of garbage Enzyme (GE).

Table 12 shows the mean percentage removal of benzo(k)fluoranthene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of benzo(k)fluoranthene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 12). The mean percentage removal of benzo(k)fluoranthene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 13). The mean percentage removal of benzo(k)fluoranthene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 12). More so, the mean percentage removal of benzo(k)fluoranthene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 12). The mean percentage removal of benzo(k)fluoranthene in soil sample treated with 70% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 120 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 100% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of benzo(k)fluoranthene was those treated with 30% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 12). GE at 70% elicited effective benzo(k)fluoranthene degradation which could be attributed to in microbial activities.

Table 12. The Mean percentage removal of benzo(k)fluoranthene from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	0.5 ±0.00	0.5±0.00	21.53±0.03	21.54±0.03	21.51±0.03	21.63±0.04
GE WA+PA (30%)	6.84±0.03	22.16±0.03	36.74±0.04	47.15±0.04	63.42±0.02	89.31±0.01
GE PL+BN (50%)	43.74±0.03	57.02±0.03	63.16±0.04	69.13±0.02	75.53±0.02	93.64±0.04
GE PL+WA+PA+BN (70%)	17.04±0.04	27.84±0.03	38.93±0.03	71.43±0.03	85.93±0.04	98.11±0.00
GE PL+WA+PA+BN (100%)	26.82±0.02	33.18±0.03	53.18±0.04	65.15±0.04	74.25±0.03	84.93±0.02

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

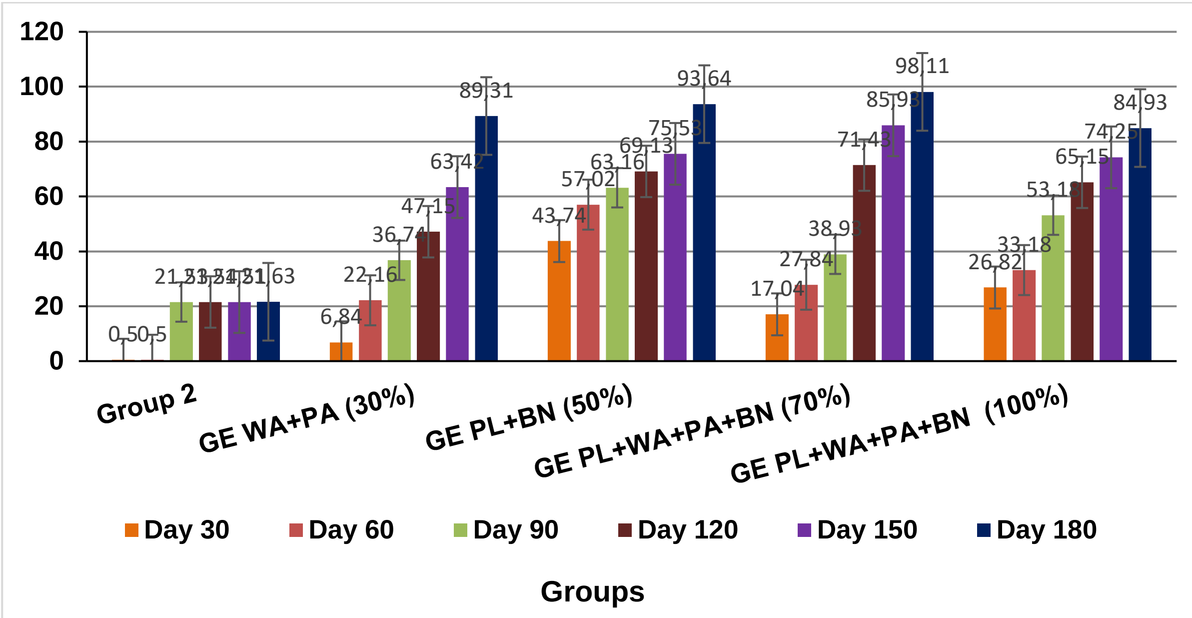

Fig 12. The Mean and standard deviation for benzo (k)fluoranthene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 13 shows the mean percentage removal of benz[a]pyrene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of benz[a]pyrene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, particularly from 30 to 180 days (Table 13). The mean percentage removal of benz[a]pyrene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 13). The mean percentage removal of benz[a]pyrene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 specifically from 90 to 180 days (Table 13). The mean percentage removal of benz[a]pyrene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 13). The mean percentage removal of benz[a]pyrene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 90 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of benz[a]pyrene was those treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 13). The poor percentage removal of benz[a]pyrene in soil sample treated with 70% GE ferments could attributed to decreases in the microbial activities in the solution. GE at 100% elicited effective benz[a]pyrene degradation which could be attributed to increases in the microbial activities of the ferments. This results is also similar to the findings of Lorestani [25] on Bioremediation (natural attenuation) of hydrocarbon contaminated soil.

Table 13. The Mean and standard deviation of benz[a]pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	18.22 ±0.01	25.61±0.02	33.75±0.04	33.85 ±0.04	37.14±0.04	40.04±0.04
GE WA+PA (30%)	19.74±0.03	26.14±0.03	36.14±0.05	47.24±0.03	61.45±0.03	75.93±0.01
GE PL+BN (50%)	27.92±0.02	35.03±0.04	46.16±0.03	57.15±0.03	66.15±0.03	85.23±0.03
GE PL+WA+PA+BN (70%)	18.05±0.04	25.94±0.04	37.14±0.04	51.06±0.02	63.84±0.04	81.35±0.02
GE PL+WA+PA+BN (100%)	42.14±0.03	49.91±0.02	58.23±0.03	69.81±0.01	75.24±0.03	96.04±0.00

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at ($P < 0.05$) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

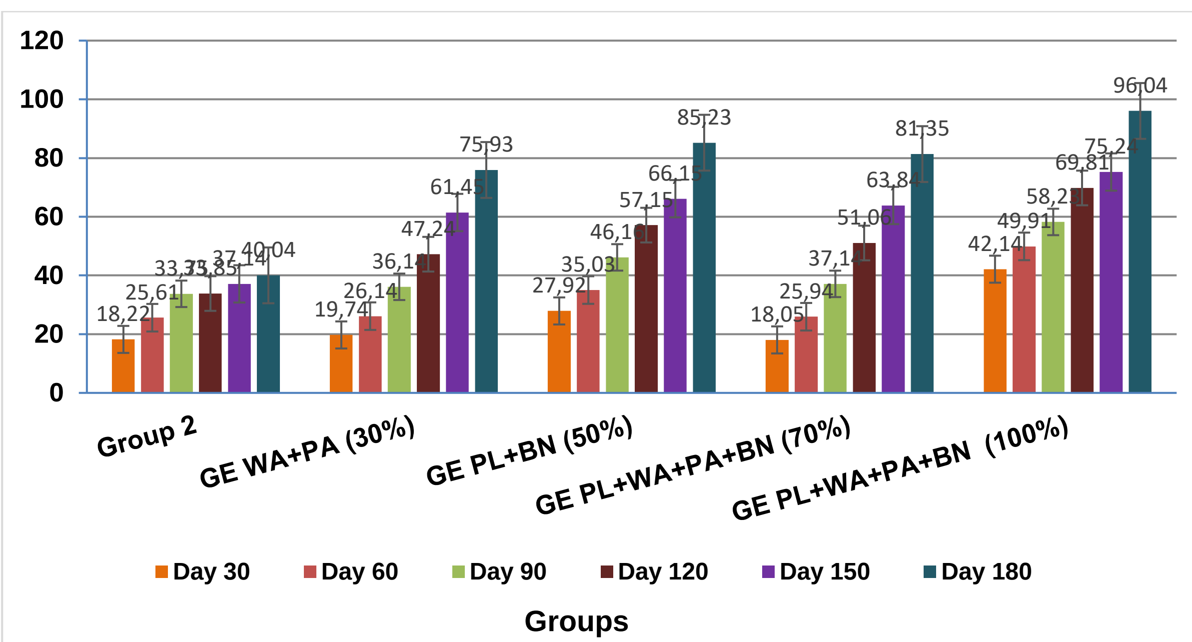

Figure 13. The mean and standard deviation of benz(a)pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 14 shows the mean percentage removal of indeno (1-2-3-cd)pyrene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of indeno (1-2-3-cd) pyrene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 2, from 30 to 180 days (Table 14). The mean percentage removal of indeno (1-2-3-cd) pyrene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 14). The mean percentage removal of indeno (1-2-3-cd) pyrene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 specifically from 60 to 180 days (Table 14). The mean percentage removal of indeno (1-2-3-cd) pyrene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 14). The mean percentage removal of indeno (1-2-3-cd) pyrene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 90 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of indeno (1-2-3-cd) pyrene was those treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 14). Garbage enzymes in organic peel wastes at 30, 50, 70, and 100% demonstrated percentage removal of indeno (1-2-3-cd) pyrene when compared to the untreated.

Table 14. The Mean and standard deviation of indeno (1-2-3-cd) pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	16 .29±0.00	25.34±0.03	29.15±0.03	36.03±0.03	41.55±0.06	47.28±0.00
GEWA+PA (50%)	27.14±0.03	35.45 ±0.03	44.82±0.03	51.33±0.03	66.04±0.04	78.15±0.04
GE PL+BN (50%)	34.72±0.02	45.73±0.01	58.23±0.02	75.02±0.00	86.01±0.02	93.73±0.02
GE PL+WA+PA+BN (70%)	26.82±0.02	38.63±0.03	47.82±0.01	57.23±0.03	68.34±0.03	84.55±0.03
GE PL+WA+PA+BN (100%)	37.53±0.03	45.72±0.03	58.13±0.05	66.13±0.04	72.43±0.04	91.84±0.03

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at (P < 0.05) down the treatments. Values with superscript c are statistically different from group 1 and 2 at ($P < 0.05$) down the treatments. Values with superscript f are statistically different from group 1 and 2 at ($P < 0.05$) across the treatments.

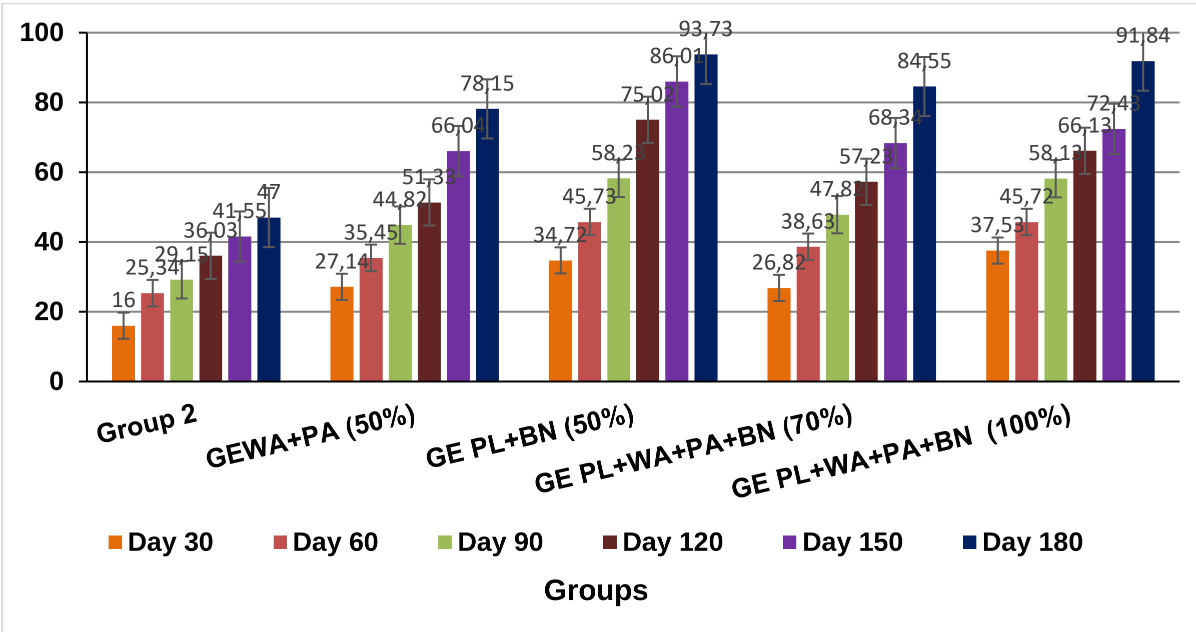

Figure 14. The Mean and standard deviation of indeno (1-2-3-cd) pyrene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

Table 15 shows the mean percentage removal of benzo(g-h-i)perylene from polluted soil samples treated with different concentration of garbage enzyme (GE). The mean percentage removal of benzo(g-h-i)perylene in crude oil contaminated soil treated with 30% of GE ferments from watermelon and pineapple peel wastes in group 3 were significantly higher than those of group 1 and 2, from 30 to 180 days (Table 15). The mean percentage removal of benzo(g-h-i)perylene in crude oil polluted soil, treated with 50% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 30 to 180 days (Table 15). The mean percentage removal of benzo(g-h-i)perylene in crude oil soiled soil, treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes were significantly higher than those of group 2 specifically from 60 to 180 days (Table 15). The mean percentage removal of benzo(g-h-i)perylene in crude oil polluted soil, treated with 100% of GE ferments from ripen plantain and banana peel wastes were significantly higher than those of group 2 from 90 to 180 days (Table 15). The mean percentage removal of benzo(g-h-i) perylene in soil sample treated with 100% GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, from 90 to 180 days was highest followed by 50% treatment with GE ferments from ripen plantain, banana, pineapple, and watermelon peel wastes, 30% treatment with GE ferments from watermelon and pineapple peel wastes, while the least percentage removal of benzo(g-h-i)perylene was those treated with 70% of GE ferments from ripen plantain, banana, watermelon, and pineapple peel wastes when compared to those of group 2 (Table 15). Garbage enzymes in organic peel wastes at 30, 50, 70, and 100% demonstrated percentage removal of benzo(g-h-i)perylene when compared to the untreated.

Table 15. The Mean and standard deviation of benzo(g-h-i)perylene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE) (n=3)

Group	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180
Group 1	0	0	0	0	0	0
Group 2	1.01 ±0.00	1.63±0.01	4.74±0.04	16.06±0.01	24.73±0.03	37.94±0.04
GE WA+PA (30%)	12.93±0.02	26.17±0.02	33.84±0.03	61.45±0.02	76.13±0.03	91.44±0.02
GE PL+BN (50%)	27.14±0.03	31.61±0.02	54.75±0.04	69.02±0.02	78.02±0.03	92.14±0.03
GE PL+WA+PA+ BN (70%)	36.83±0.02	44.74±0.04	57.15±0.04	65.34±0.04	72.52±0.03	95.75±0.04
GE PL+WA+PA+ BN (100%)	47.03±0.05	54.72±0.02	61.85±0.03	79.32±0.02	86.52±0.03	98.24±0.04

GE = garbage enzymes, WA = watermelon, PA = pineapple, PL = plantain, BN = banana. Values are reported in means ± Standard Error of Mean (SEM). Values with superscript b are statistically different from group 1 at (P < 0.05) down the treatments. Values with superscript c are statistically different from group 1 and 2 at (P < 0.05) down the treatments. Values with superscript f are statistically different from group 1 and 2 at (P < 0.05) across the treatments.

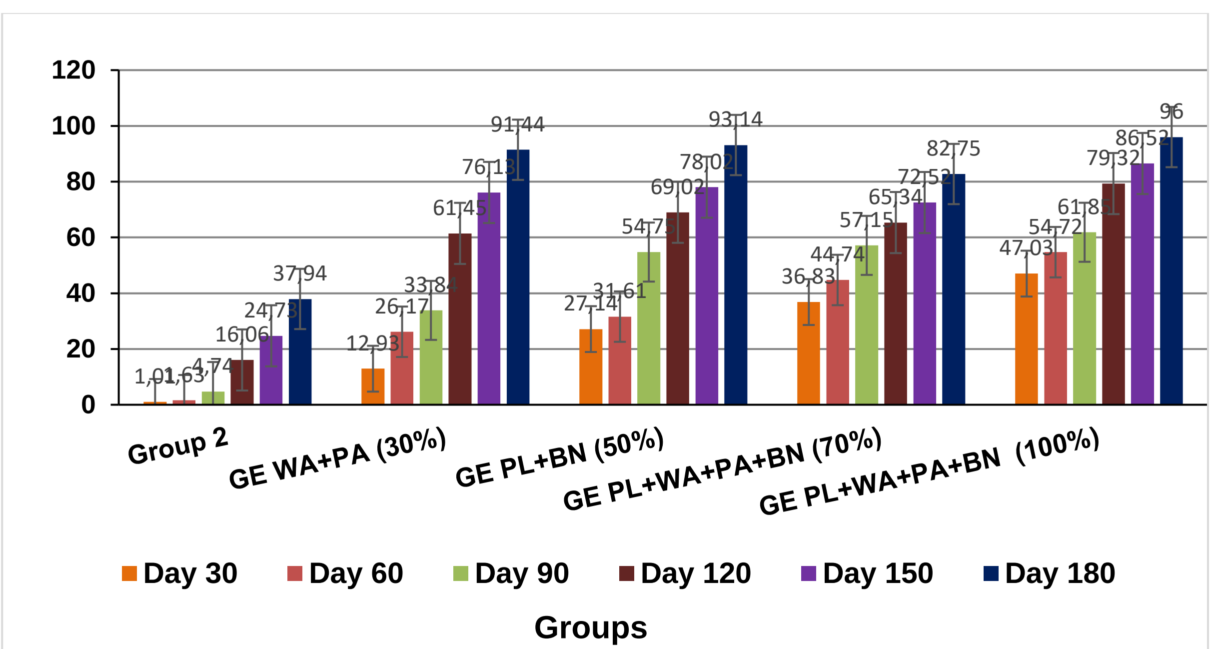

Figure 15. The Mean and standard deviation of benzo(g-h-i)perylene percentage removal from polluted soil samples treated with different concentration of garbage enzyme (GE)

4. CONCLUSION

This study investigated the biocatalytic bioremediation of polycyclic aromatic hydrocarbons in crude oil contaminated soil by garbage derived from fermented organic peel wastes. Garbage enzymes solution at 3, 50, 70, and 100% upon application elicited different and varying significant percentage removal of pyrene, 1-2-benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benz[a]pyrene, indeno (1-2-3-cd) pyrene, and benzo(g-h-i)perylene after treatment with 30, 70, and 100 % of garbage enzyme ferments for 30 to 180 days. The differences observed in the biocatalytic bioremediation activities of the applied fruit garbage enzymes might be due to the difference in composition of the garbage enzyme mixtures arising from the degree of microbial activities in the solutions. Hence, could be adopted as local bioremediation tools against PAHs in soil.

Note

This study demonstrated the effectiveness of garbage enzyme solution from fermented organic wastes in the bioremediation of polycyclic aromatic hydrocarbons in crude oil contaminated soil. This concept should be carefully studied in the light of current bioremediation techniques so that they can be accepted as appropriate bioremediation tools.

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