Applied Environmental Research
- RESEARCH FOR SUSTAINABLE PLANET -

Research Article

Exploring The Co-composting Potentials of Raw Grease Trap and Grease Trap-Derived Soaps: Insights into Grease Trap Modification, Calcium Supplementation, and Microbial Community Analysis

Pokchat Chutivisut[1], Panaya Kotchaplai[2], Bualuang Faiyue[1], Nattapong Tuntiwiwattanapun[1,*]

[1] *Sustainable Environment Research Institute, Chulalongkorn University, Bangkok 10330, Thailand*
[2] *The Institute of Biotechnology and Genetic Engineering, Chulalongkorn University, Bangkok 10330, Thailand*

*Corresponding Email: nattapong.t@chula.ac.th

Abstract

Managing waste with grease traps poses a challenge because of the potential environmental issues associated with its disposal. In this study, two approaches were investigated to increase the biodegradability of grease trap waste: 1) converting raw grease trap waste into soap and 2) supplementing grease trap soap as inoculum with calcium material. The preparation of grease trap soap was optimized to attain a soap yield of 103% by utilizing a water-to-ethanol ratio of 9:1 at 80 °C for a processing time of 3 hours. A comparison of the composting results revealed higher nitrate yields with increased ratios of grease trap soap. Specifically, composting with 100% raw grease traps yielded 523.4 mg kg^{-1} nitrate, whereas composting with 100% grease trap soap produced 1,331.0 mg kg^{-1} nitrate. This indicated greater biodegradability of the modified grease trap, as evidenced by the BOD values, which were 3.81 times greater in the grease trap soap than in the raw grease trap waste. Microbial community analysis revealed distinct patterns between the compost mixed with 100% raw grease traps and that mixed with 100% grease traps. While both compost types contained predominant microorganisms linked to oil-degrading bacteria and biosurfactant producers, notable differences in microbial taxa were detected. Despite the high nitrogen content of grease trap soap compost, the germination index of mung bean seeds revealed that increasing grease trap soap loading tended to reduce the germination index. The addition of calcium hydroxide and calcium carbonate to the compost system, which uses grease trap soap as the inoculum and raw grease trap waste as the feedstock, could result in an increased germination index.

ARTICLE HISTORY

Received: 25 Sep. 2024
Accepted: 13 Mar. 2025
Published: 26 Mar. 2025

KEYWORDS

Compost;
Grease trap waste;
Saponification;
Calcium supplementation;
Microbial community analysis

Introduction

The grease trap waste generated from food processing daily presents a significant environmental challenge in terms of its disposal [1]. Grease is a byproduct of cooking and cleaning kitchenware and is primarily composed of saturated fats derived from animal fat or vegetable oils [2], which remain in a liquid state when heated. However, upon cooling, these fats and oils can solidify into a waxy substance known as grease. The accumulation of grease in sewer systems can lead to several problems, including clogged pipes and failures in wastewater treatment systems, as grease can obstruct water flow [1–2]. Additionally, grease can adhere to activated sludge in biological wastewater treatment systems, causing the sludge to float [3], which disrupts the treatment process. To mitigate these issues, the installation of grease traps is essential, particularly in facilities where food is prepared, such as cafeterias.

Nevertheless, the management of waste from grease traps remains a challenge, as current management practices often rely on disposing of such waste in landfills, which is not a sustainable solution. This approach not only accelerates landfill overflow but also contributes to environmental pollution and greenhouse gas emissions [1]. In the United States of America, incineration has been used for grease trap waste management. However, the high moisture, salt and phosphate contents of grease trap waste are major challenges for incineration. Mixing grease trap waste with other solid waste is recommended [4].

As the requirement for effective waste management solutions increases, it is essential to explore innovative methods for handling grease-trap waste. In this context, composting presents a promising alternative for managing grease trap waste, as it facilitates the transformation of organic materials into valuable compost that can enhance soil health. By incorporating grease trap waste into composting systems, the volume of grease trap waste sent to landfills can be reduced while simultaneously producing a nutrient-rich product that supports agricultural practices. The concept of co-composting grease trap waste as a cosubstrate has been explored in previous studies [5–6]; however, the low biodegradability of grease continues to pose challenges for its removal via biological methods.

To further increase the biodegradability of grease trap waste, converting grease into soap via a sodium hydroxide-based saponification process has been proposed as an effective strategy for biogas production [7]. This transformation facilitates the emulsification and dispersion of fats and oils, making them more accessible for microbial degradation during anaerobic digestion. However, the use of sodium hydroxide in soap production may not be advantageous for composting, as sodium soap exists in a solid form, which presents lower bioavailability than does liquid soap. Additionally, the decomposition of sodium soap can increase the sodium level in compost. Therefore, the exploration of alternative alkaline solutions for saponification that could benefit composting should be considered.

Additionally, another approach to enhance the decomposition of grease trap waste is the application of calcium compounds, which aid in the formation of oil–mineral aggregates [8–9] and have been demonstrated to prevent oil from coating microbial cells during biogas production [10]. Thus, supplementation with calcium may increase microbial activity without requiring the conversion of grease into soap. Nevertheless, the application of calcium materials in aerobic systems, such as composting grease trap waste, is rare.

By exploring both grease trap modification into soap and the supplementation of calcium, sustainable management strategies for grease trap waste can be developed with the aim of maximizing its potential benefits for composting systems. Thus, the objectives of this study were to explore two approaches to enhance the decomposition of grease trap waste in a co-composting system:

(1) Development of the saponification process: This process serves as a pretreatment for grease trap waste. The effects of saponified grease trap waste on compost quality were investigated. Potassium hydroxide was utilized as the alkaline agent in saponification, resulting in a liquid form of potassium soap that not only enhances composting but also provides potassium as a macronutrient for plants.

(2) Investigating the effects of two types of calcium supplements on grease decomposition and compost quality were assessed.

The qualities of the compost during composting, including the seed germination index, ammonium content, nitrate content, nitrite content, and microbial communities, were investigated.

Materials and methods

1) Material

The grease trap waste used in this study was collected from the central canteen of our university campus, Chulalongkorn University, Bangkok, Thailand. Generally, this grease trap has not been utilized, and the waste is disposed of as general refuse destined for landfilling. In the initial step, solid particles, primarily small food waste fragments, were separated from the liquid portion via a plastic sieve. The grease layer was subsequently decanted from the water layer via a separating funnel. The resulting grease trap waste was then stored in plastic bottles at 4 °C until experimentation.

The analysis of the fatty acid profile of the collected raw grease traps revealed four primary free fatty acids: palmitic acid (C16:0) at 31.42%, stearic acid (C18:0) at 5.88%, oleic acid (C18:1) at 40.79%, and linoleic acid (C18:2) at 11.44%. These proportions were comparable to those found in palm oil. The saponification value of this grease trap waste was determined to be 0.223 g KOH per one gram of oil, which indicated the amount of potassium hydroxide needed to convert all fatty residues into soap. Other chemicals, including potassium hydroxide (KOH), hydrochloric acid (HCl), calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), phenolphthalein, isopropyl alcohol (IPA), and ethanol, were purchased in analytical grade.

2) Optimizing grease trap soap production

First, 5 g of the stored grease trap waste was placed in a 125 mL Erlenmeyer flask. A KOH solution was subsequently prepared by dissolving 1.2 g of KOH in 10 mL of ethanol, which was subsequently added to the flask. Water-to-ethanol (W/E) volume ratios of 10:0, 9:1, and 8:2, along with processing temperatures of 40, 60, and 80 °C, were tested for the production of liquid soap from grease trap waste after a processing time of 1 hour. The sample was then placed in a water bath shaker set to 125 rpm at the specified temperatures. Next, the selected W/E ratios and temperatures were further evaluated at processing times of 1, 2, and 3 hours. Upon completion of the process, 10 mL of distilled water was added to the sample before the efficiency of liquid soap production, or soap yield (Eq. 1 and Supplementary Material (SM) 1), and the properties of the liquid soap produced from the grease trap waste, including density, pH, critical micelle concentration (CMC) and surface tension at the CMC level, were analyzed.

3) Effects of co-composting a grease trap waste and its soap on the properties of the grease trap compost

The grease trap waste and grease trap soap were applied for co-composting with cow manure, chicken litter, rice husk, and spent coffee grounds in the proportions specified in Table 1. Four co-composting conditions were examined, utilizing different mixtures of raw grease trap waste and grease trap soap to evaluate their biodegradability during composting. The ratios of raw grease trap waste to grease trap soap included 100:0 (100% raw grease trap), 60:40 (60% raw grease trap), 40:60% grease trap soap), and 0:100 (100% grease trap soap). The biodegradability of each mixture was assessed by measuring the biochemical oxygen demand (BOD) prior to mixing with the compost.

Each compost mixture was placed in an 8-L plastic box equipped with ventilation holes for air circulation and moisture evaporation, as illustrated in Figure 1. The compost was incubated alternately at 50 °C and room temperature (30 °C) every 12 hours over a period of four weeks. Humidity was adjusted daily to maintain levels between 50% and 60%, and the compost pile was turned once a day. Samples were collected weekly for analysis of compost properties.

$$\text{Soap Yield (\%)} = \frac{\text{Consumed KOH (g KOH/g Oil)}}{\text{Sponification Value of Grease (g KOH/g Oil)}} \times 100 \quad \text{(Eq. 1)}$$

Table 1 Proportions of the raw materials used in different co-composting conditions

Raw materials	Proportions (g)			
	1	2	3	4
Raw grease trap to grease trap soap ratio	100:0	60:40	40:60	0:100
Cow manure	600	600	600	600
Chicken litter	600	600	600	600
Raw grease trap	400	240	160	0
Grease trap soap	0	160	240	400
Rice husk	400	400	400	400
Spent coffee grounds	200	200	200	200

(A) (B)

Figure 1 An 8-L box used for composting grease trap waste and grease trap soap (A), along with a hot air oven utilized for controlling the composting temperature (B).

For compost sampling, 5 samples were collected from different positions within the compost box. These samples were initially taken from various locations on the top layer of the compost after turning it. Each sample weighed approximately 5 g. The collected samples were pooled together and stored in polypropylene containers at 4 °C for further analysis.

To examine the compatibility of the derived compost with other compost types, grease trap soap compost was mixed with rain tree leaf compost—routinely prepared on the university campus by combining rain tree leaves with decomposed organic food waste—at different ratios. The ratios of grease trap soap compost to rain tree leaf compost were 1:6, 1:8, 1:10, and 1:12. The effects of these mixtures were evaluated by analyzing the germination percentage and the nitrogen, phosphorus, and potassium contents in selected compost samples. The overall experimental steps in this research are illustrated in SM 2.

4) Effects of inoculum and calcium supplement on the properties of grease trap compost

The selected grease trap soap (with a grease-to-soap ratio of 0:100) from the previous section was used as the inoculum in this study. Two types of calcium materials, $Ca(OH)_2$ and $CaCO_3$, were introduced into the compost to improve its properties. The formulation of the grease trap compost used in this study is shown in Table 2.

Five compost formulations were examined for different types of calcium material and their loading. Notably, the calcium material was mixed with the grease trap waste before mixing with the other material. Each compost sample was placed in the compost box as described in the previous section. Samples were collected weekly for analysis of compost properties. Notably, only a single replication was conducted in this section because of the limitation of inoculation in the previous section.

5) Analysis of compost properties

5.1) Nutrient nitrogen content

A 2 M potassium chloride (KCl) solution was used as an extractant for nutrient nitrogen (ammonium, nitrate, and nitrite) in the compost at a ratio of 5 g of compost to 100 mL of KCl solution, which was then incubated at room temperature for 30 minutes. The resulting solution was analyzed for ammonium via the method of Bower and Holm-Hansen [11], as well as for nitrite and nitrate via the method of Strickland [12]; a UV spectrometer was used for measurement.

5.2) Total organic carbon, nitrogen, phosphorous and potassium

The total organic carbon (TOC) content was analyzed via a total organic carbon (TOC) analyzer (Shimadzu TOC-V CPH, model SSM-5000A). The total Kjeldahl nitrogen (TKN) content was analyzed via the Kjeldahl method. The available phosphorous (P) was analyzed via the Bray II method. Ammonium acetate extraction with atomic adsorption was applied for exchangeable potassium (K). Notably, TKN, available P and exchangeable K were determined via the laboratory service of the Sustainable Environment Research Institute, Chulalongkorn University.

5.3) Seed germination index

First, 10 g of compost was extracted with 50 mL of distilled water for 2 hours. The effect of the extracted solution on the germination of mung bean seeds was then tested. Ten mung bean seeds were placed on tissue paper within a Petri dish, and 5 mL of the extracted solution was added. The seeds were incubated in the dark for 5 days, after which germination rates and root lengths were measured and compared to those of a control sample, in which the extracted solution was replaced with distilled water, as shown in Eq. 2.

5.4) Microbial community analysis

The collected compost samples, weighing 5 g, were stored at -20 °C and subjected to microbial community analysis via Illumina MiSeq 16S rRNA sequencing at the Omics Science and Bioinformatics Center at Chulalongkorn University, Bangkok, Thailand. The samples selected for microbial analysis included compost with a 100% raw grease trap (100:0 ratio) and compost with a 100% grease trap soap (0:100 ratio). DNA was extracted via the DNeasy PowerSoil Pro DNA Kit (Qiagen, USA). The 16S rRNA gene marker was amplified with 341F and 805R primers that target the V3–V4 variable regions of the gene, with 2X sparQ HiFi PCR Master Mix (QuantaBio, USA). The PCR conditions were as follows: initial denaturation at 98 °C for 2 minutes; 30 cycles at 98 °C for 20 seconds, 60 °C for 30 seconds, and 72 °C for 1 minute; and a final extension step at 72 °C for 1 minute. The resulting 16S rRNA amplicons were purified via sparQ PureMag Beads (QuantaBio, USA). The amplicons were subsequently indexed with 5 µL of Nextera XT index primer in a 50 µL PCR, followed by 8–10 cycles of the aforementioned PCR conditions. The final PCR products were cleaned, pooled, and diluted to a final loading concentration of 4 pM. Paired-end sequencing of 250-bp reads was performed on an Illumina MiSeq platform.

6) Statistical analysis

The statistical software STATISTICA 10 (StatSoft, Tulsa, OK, USA) was used to conduct ANOVA and multiple mean comparisons at a 95% confidence interval (p value).

Table 2 Proportions of the raw materials used for composting grease traps containing different types and ratios of calcium compounds

Raw material	Weight of material (g)				
	Control	CaOH_100	CaOH_200	$CaCO_3$_100	$CaCO_3$_200
Grease trap soap compost (Inoculum)	200	200	200	200	200
Cow manure	550	550	550	550	550
Chicken litter	550	550	550	550	550
Rice husk	300	300	300	300	300
Grease trap waste	400	400	400	400	400
$Ca(OH)_2$	0	100	200	0	0
$CaCO_3$	0	0	0	100	200
Water	400	400	400	400	400

$$\text{Germination index (\%)} = \frac{\text{Geminated seed}_{\text{Trt.}} \times \text{Avg.root length}_{\text{Trt.}}}{\text{Geminated seed}_{\text{DI}} \times \text{Avg.root length}_{\text{DI}}} \times 100 \quad \text{(Eq. 2)}$$

Results and Discussion

1) Optimization of liquid soap production from grease trap waste

The liquid soap produced from processed grease trap waste is in the form of the potassium salt of fatty acids, which is commonly referred to as potassium soap. As shown in Figure 2, excess KOH and temperature were required to drive this saponification reaction toward potassium soap and glycerol, resulting in a higher soap yield. Moreover, the solubility of triglycerides in alkaline solutions is limited. Thus, ethanol was applied as a co-solvent in this work.

The yields of the grease trap-derived soap for each condition, including W/E volume ratios of 10:0, 9:1, and 8:2, as well as processing temperatures of 40, 60, and 80 °C, were compared via ANOVA (Figure 3). The ANOVA results indicated that both the W/E ratio and temperature had statistically significant effects on grease trap soap yield (p value<0.05). Specifically, the W/E ratio of 8:2 produced significantly more grease trap soap at all the processing temperatures tested than the other ratios did. Additionally, increasing the temperature also contributed to higher yields of grease trap soap. On the basis of these results, two production conditions for grease trap soap were selected for further investigation of the effect of processing time on soap yield in the next phase: 1) a W/E ratio of 9:1 at 80 °C (Optimal A) and 2) a W/E ratio of 8:2 at 60 °C (Optimal B).

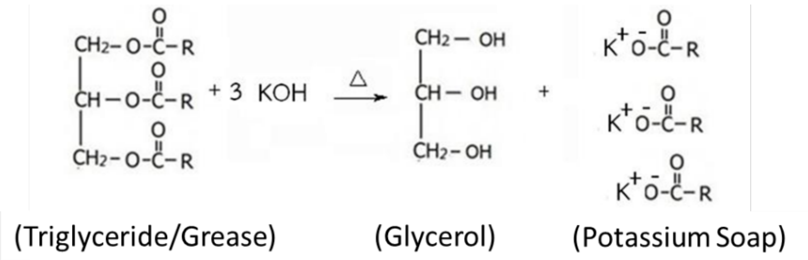

Figure 2 Saponification reaction for producing potassium soap from oil/grease (triglyceride).

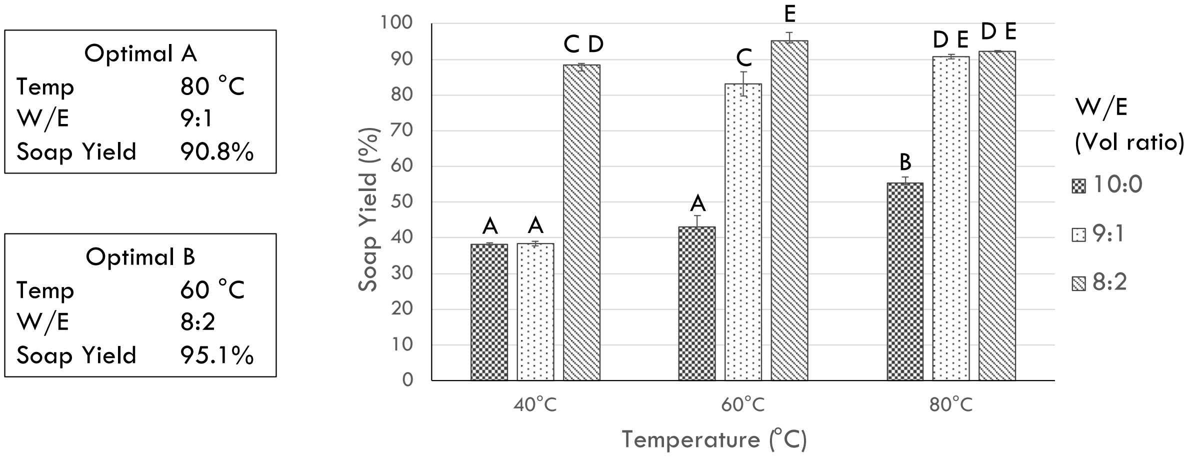

Figure 3 Effect of the W/E ratio and processing temperature on grease trap soap yield with an operation time of 1 hour.

The conditions for the production of soap derived from grease trap waste, referred to as Optimal A and Optimal B, were evaluated to determine the effect of processing time on soap yield for durations of 1, 2, and 3 hours. The experimental results demonstrated that extending the processing time increased the yield of grease trap soap, particularly under Optimal A conditions, which employed a higher W/E ratio of 9:1 than did Optimal B at 8:2. Consequently, the Optimal A condition, which achieved a soap yield of 103% with a processing time of 3 hours, was determined to be the optimal condition for soap production from grease trap waste and was used in the composting experiment. The properties of this trap grease soap are shown in the SM3. Notably, the final pH of the potassium soap was greater than the pH 9. The effect of soap pH on compost quality should be further investigated.

2) Effects of grease trap soap on the properties of compost

The potential of utilizing grease trap soap as a compost substrate was investigated by combining the prepared grease trap soap with raw grease trap waste. This approach aimed to assess both the enhancement of grease biodegradability and the necessity of fully transforming grease trap waste into soap. The ratios of raw grease traps applied to grease trap soap (grease: soap ratio) were as follows: 100:0, 60:40, 40:60, and 0:100. Other co-substrates included cow and chicken manure, rice husk, and spent coffee grounds, which were mixed at the ratios specified in Table 1. Rice husks were selected to improve compost ventilation, whereas spent coffee grounds were chosen as a co-substrate to provide polysaccharides and minerals, thereby increasing compost quality [13]. The efficiency of composting was monitored by tracking the nitrogen nutrient content—specifically ammonium, nitrite, and nitrate—over a period of nine weeks. The effects of the compost produced under each condition on the germination index were subsequently tested, with mung beans used as a model plant.

Typically, the decomposition of organic matter in compost initially results in the release of ammonium, which is then transformed into nitrite and subsequently into nitrate through nitrification [14]. The analysis of nutrient nitrogen during the co-composting of grease trap soap revealed a slight increase, albeit with some fluctuations, in ammonium levels, along with a rise in nitrate concentrations to over 20 mg L^{-1} under all experimental conditions (Figure 4). The absence of nitrite accumulation indicates effective nitrite oxidation during the co-composting process. These findings suggest that these conditions provided sufficient moisture and good ventilation to facilitate nitrification during composting.

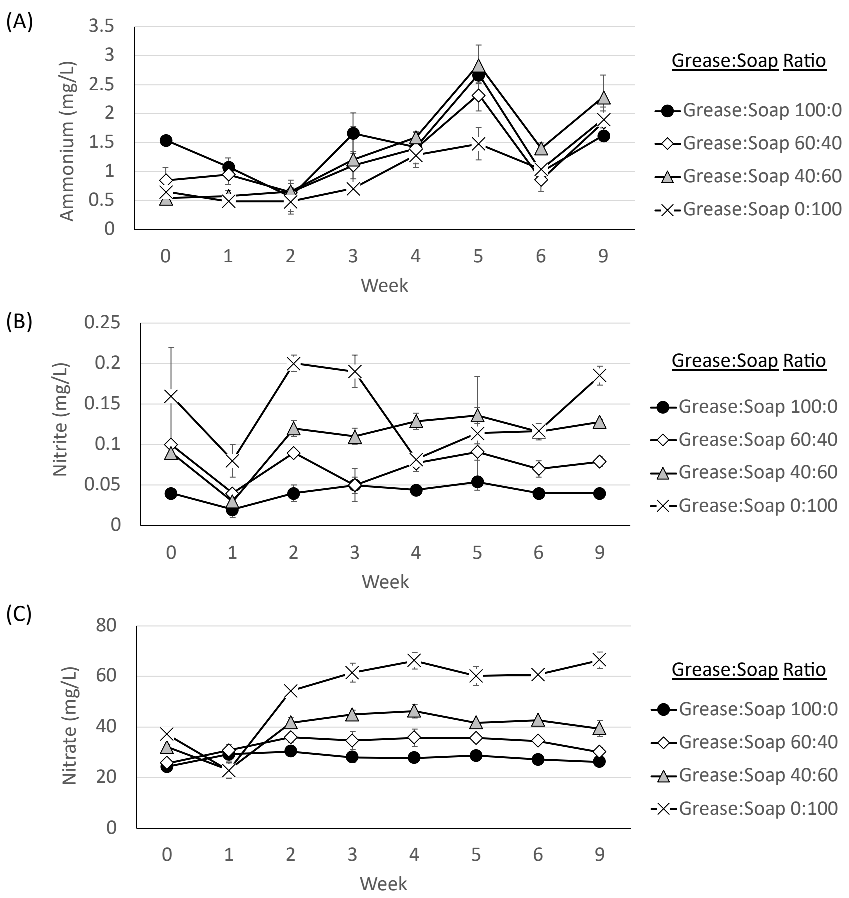

Figure 4 Concentrations of ammonium (A), nitrite (B), and nitrate (C) in KCl solutions extracted from different grease:soap ratios of co-composting samples collected at different time points.

Among the grease:soap ratios applied, the application of 100% soap (0:100 ratio) produced the highest nitrate concentrations, reaching 66.6 ± 3.2 mg L^{-1}. In contrast, the application of 100% grease traps (100:0 ratio) resulted in the lowest nitrate concentration of 26.2 ± 0.6 mg L^{-1} at the end of the composting process. Moreover, the application of 40% and 60% grease trap soap also resulted in an increase in nitrate yield, indicating that pretreatment of raw grease traps waste by converting it into soap could increase the biodegradability of grease waste during composting.

Increases in biodegradability were highlighted by the BOD analysis (Figure 5(A)), which revealed that higher percentages of grease trap soap led to elevated BOD values. Specifically, the BOD level in grease trap soap was 3.81 times greater than that in raw grease trap waste. This increase may be attributed to the significantly larger surface area of the oil droplets in the grease trap soap than in the raw grease trap waste (Figure 5B). In conclusion, the pretreatment of raw grease traps waste through conversion into soap improved the overall efficiency of co-composting with other organic materials, resulting in a nitrate concentration that was 2.54 times higher than that of compost without this pretreatment.

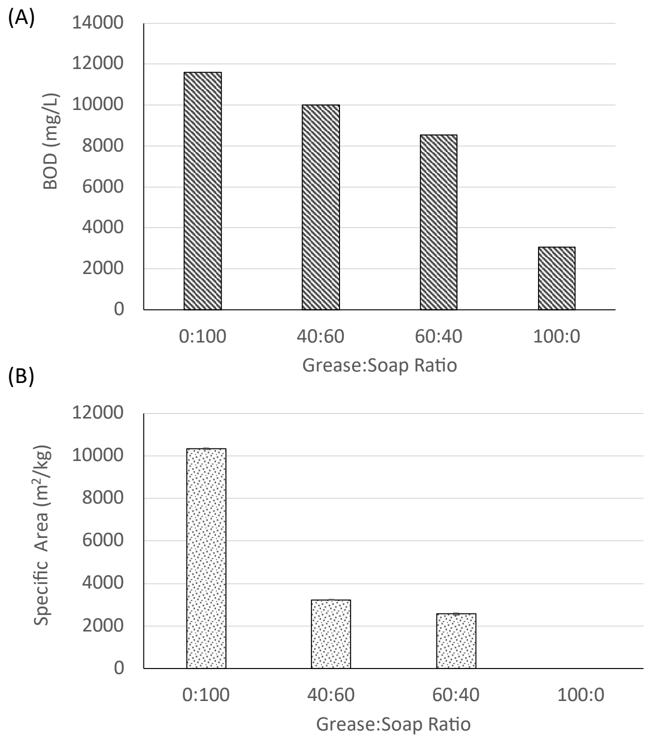

Figure 5 BOD analysis (A) and specific area of oil droplets in the grease trap soap (B) for different ratios of raw grease traps to grease trap soaped at 1% w/v in water.

Although grease trap co-composting has been investigated in previous research [5–6, 15], to the best of the authors' knowledge, the transformation of grease trap waste into soap for composting has not yet been systematically studied. The addition of surfactants to compost can increase organic degradability and improve composting conditions [16]. Surfactants are also reported to assist in the dispersion of organic matter into the water phase of compost, reduce composting duration, increase contact between organic materials and microorganisms, and improve the nutrient properties of the compost [17–19]. The results obtained in this study align with previous findings and highlight a potential strategy for managing grease trap waste by increasing its biodegradability through soap formation, which can then be utilized as a substrate for co-composting.

To compare the characteristics of grease trap soap compost with those of the raw materials used for composting and other compost types, all the raw materials and rain tree leaf compost were included in the analysis (Table 3). The results revealed distinct nitrogen, phosphorus, and potassium properties for each raw material. The chicken litter presented the highest ammonium content, while the cow manure and coffee grounds were rich in nitrate. Notably, co-composting with 100% grease trap soap (0:100 ratio) produced the highest nitrate levels, surpassing those of the raw materials used for co-composting. These findings indicate effective decomposition of the raw materials during the composting fermentation process.

As shown in Figure 4, the amounts of nitrate present at the end of the nine-week composting period were calculated to be 523.4, 601.6, 787.6, and 1,331.0 mg kg^{-1} for the compost mixtures with raw grease trap waste to grease trap soap ratios of 100:0, 60:40, 40:60, and 0:100, respectively. The nitrate content in the rain tree leaf compost was measured to be 158.4 mg kg^{-1}. The application of the grease trap and grease trap soap increased the yield of nitrate in the compost to several times greater than that detected in the rain tree leaf compost, especially the 100% grease trap soap compost (0:100 ratio), which resulted in 8.4 times greater nitrate than that detected in the rain tree leaf compost. Nitrate yields after composting can vary significantly depending on the composting substrate and the proportions applied, which can range from 300 - 1,600 mg kg^{-1} for livestock manure compost [21] to 40 mg kg^{-1} for sewage sludge compost [22]. The amount of nitrate detected in the compost containing 100% grease trap soap (0:100 ratio) highlights the effectiveness of converting grease trap waste into soap as a strategy to improve grease biodegradability. This approach not only adds value to compost produced on university campuses but also emphasizes a decentralized waste management concept by reducing the costs associated with collecting and transporting grease trap waste to landfills. This method thus promotes a circular economy where waste is repurposed as a raw material in other processes.

Table 3 Characterization of the raw materials used for co-composting and mixtures of grease trap soap and leaf compost

Materials	Ammonium (mg L^{-1})	Nitrite (mg L^{-1})	Nitrate (mg L^{-1})	Germination (%)	TKN (%)	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	C/N
Cow manure	3.75±0.29	0.06±0.00	27.21±0.00	93.23	1.52	3,804	13,694	-
Chicken litter	11.22±0.56	0.01±0.00	5.94±0.00	152.39	0.70	23,341	3,866	-
Spent coffee grounds	0.56±0.05	0.04±0.00	14.60±0.00	118.82	2.66	1,500	5,431	-
Rain tree leaf compost	1.62±0.19	0.01±0.00	7.92±0.00	120.42	2.49	1,242	1027	-
Grease trap soap compost (0:100)	1.04±0.06	0.117±0.00	60.70±2.05	37.77	1.17	7,334	901	14.5
Mixture between grease trap soap compost and rain tree leaf compost								
1:6	-	-	-	93.27	-	-	-	-
1:8	3.77±0.22	0.041±0.00	27.62±0.39	105.42	2.02	1930	204	15.4*
1:10	3.78±0.23	0.035±0.00	21.84±0.23	101.08	-	-	-	-
1:12	-	-	-	84.42	-	-	-	-
Thai organic fertilizer standard (Department of Agriculture)					>1%	>0.5%	>0.5%	<20

Remark: "-" indicates data not analyzed. "*" represents data calculated from the rain tree leaf compost [20] and our grease trap soap compost.

The germination index of mung bean seeds was used to assess the toxicity of compost derived from grease trap soap. The results indicated that the germination index of the seeds in the obtained compost was lower than that of the raw materials used in its production (Table 3). This decrease may be attributed to the decomposition of the raw materials, particularly grease, which traps waste and the derived soap. It is thus possible that the byproducts of organic matter decomposition might contain substances that could inhibit plant growth. To address this issue, rain tree leaf compost, which has a relatively high seed germination rate, was blended with grease trap soap compost at different ratios. This combination resulted in composts with improved characteristics, including increased nitrogen content and reduced toxicity to plants. Seed germination analysis revealed that extracts from the mixed compost at ratios of 1:8 and 1:10 achieved 100% seed germination, comparable to distilled water (Table 3). Additionally, the analysis of ammonium and nitrate contents revealed that the mixed compost had nitrate levels that were more than three times greater than those found in the rain tree compost alone. The combination of grease trap soap compost and rain tree leaf compost thus offers a promising alternative for waste management, resulting in compost with high nitrogen content and good germination potential.

Compared with the Thai organic fertilizer standard set by the Department of Agriculture, the grease trap soap compost did not meet the required exchangeable K or total macronutrient content (NPK) requirements. However, when mixed with rain tree leaf compost at a 1:8 ratio, the resulting compost reached the Thai organic fertilizer standard for TKN and the C/N ratio but did not meet the available P and exchangeable K requirements. Despite this, the mixed compost successfully met the total NPK standard, which mandates a minimum of 2% in total.

3) Effects of grease trap soap on the microbial communities of compost

The analysis of microbial communities in the compost samples was performed via the Illumina MiSeq 16S rRNA sequencing technique (Figure 6), revealing distinct differences in microbial compositions beginning from the second week of composting. Specifically, compared with the compost made from 100% grease trap soap (0:100 ratio), the compost consisting of 100% raw grease trap (100:0 ratio) presented greater microbial diversity. After 4 weeks of composting, the microbial structures in both types of compost maintained their distinctive patterns, suggesting that each group of microorganisms effectively adapted to their respective composting environments.

In the compost containing 100% raw grease, the genus *Tistrella* sp. was the most prevalent microorganism, accounting for 16.6% of the microbial community in the second week and 21.3% in the fourth week. *Tistrella* sp. is known for its oil-degrading ability and has been shown to effectively degrade crude oil [23]. The next most abundant genus in this compost was *Pseudomonas* sp., which was found at proportions of 6.9% and 16.2% in the second and fourth weeks, respectively. Species of *Pseudomonas* have been reported to degrade palm oil [24–25]. Additionally, this genus is known for producing biosurfactants, which increase the solubility of oil, making it more accessible for microbial utilization [26–27].

In the 100% raw grease trap compost, *Pantoea* sp. was also identified at proportions of 12.9% in the second week and 5.2% in the fourth week. This genus is known for its ability to degrade alkane compounds in oil [28] and is also capable of producing biosurfactants [29]. *Isoptericola* sp., which was detected at 5.1% in the second week and 12.7% in the fourth week, has also been reported to produce biosurfactants during oil degradation [30]. Other bacterial genera present in the 100% raw grease trap compost include *Salinicola* sp. and *Streptomyces* sp., both of which are known to degrade polycyclic aromatic hydrocarbons [31]. The analysis of the microbial population in the 100% raw grease trap compost revealed the growth of microorganisms capable of decomposing oil substances. In addition, the ability of several of these bacteria to produce biosurfactants also highlights their potential to access oil as an energy source.

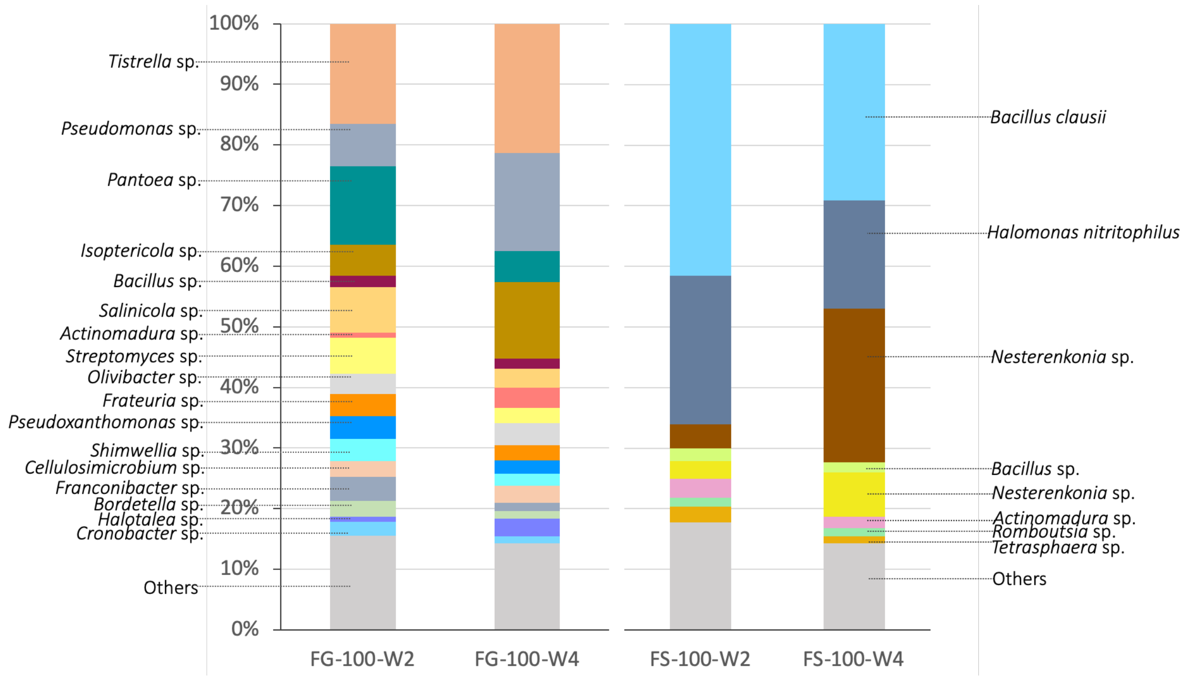

Figure 6 Relative abundances of microbial communities in compost samples from 100% raw grease traps at the second week (FG-100-W2) and fourth week (FG-100-W4) and in those from 100% grease traps at the second week (FS-100-W2) and fourth week (FS-100-W4).

In the 100% grease trap soap compost, three primary taxa with relative abundances greater than 10% were identified: *Bacillus clausii* (41.6% in the second week and 29.1% in the fourth week), *Halomonas nitritophilus* (24.5% in the second week and 17.8% in the fourth week), and *Nesterenkonia* sp. (4% in the second week and 25.4% in the fourth week). Compared with the 100% raw grease trap compost, the compost containing 100% grease trap soap presented less microbial diversity. The dominance of only a few bacterial types in this system highlighted the specificity of this compost environment, which favored the ability of microorganisms capable of thriving on soap as their primary carbon source.

B. clausii is a bacterium known for its ability to decompose cooking oil and produce biosurfactants [32], whereas *H. nitritophilus* has been reported to degrade byproducts from oil decomposition [33]. Both *B. clausii* and *H. nitritophilus*, along with *Nesterenkonia* sp., are classified as halophilic bacteria; hence, they are resistant to saline conditions [34–35]. This saline condition in the compost resulted from the saponification of grease traps into soap through the use of KOH. As soap decomposes, the release of K^+ ions contributes to increased salinity, creating an environment conducive to salt-tolerant bacteria. Interestingly, the analysis of the 100% grease trap soap compost indicated that this condition produced higher nitrate levels than did the 100% raw grease trap compost. Furthermore, the K+ released from potassium soap can serve as a nutrient to promote plant growth. The properties of the compost could thus be improved by incorporating potassium soap, while the established halophilic community could serve as an effective starter material for co-composting with food waste, which typically has a high salt content [36].

In addition to their oil-degrading capabilities, several of the identified bacteria exhibit plant growth-promoting traits. Both *Pseudomonas* sp. and *Bacillus clausii* have been proposed as beneficial biofertilizers, offering an eco-friendly alternative to chemical fertilizers [37–38]. Other dominant taxa in both composts, such as *Halomonas* sp., *Nesterenkonia* sp., *Pantoea* sp., *Isoptericola* sp., *Salinicola* sp., and *Streptomyces* sp., have been previously identified as promoters of plant growth [39–44]. A number of these bacteria have also been reported to support the growth of plants under saline conditions, as many of them, including *Halomonas* sp., *Isoptericola* sp., and *Salinicola* sp., are halotolerant and possess the ability to produce plant hormones [39, 44] as well as solubilize phosphate [43]. Moreover, *Pantoea* sp. and *Streptomyces* sp. have been demonstrated to suppress plant pathogens [41– 42], thereby providing biocontrol during plant cultivation. The traits associated with plant growth promotion in the predominant taxa emphasize the feasibility of these composts for agricultural use, where these beneficial bacteria can thrive on both grease trap waste and grease trap soap during the process of composting. This indicates the potential for the biodegradation of grease-trap waste, regardless of whether it is raw or saponified.

4) Application of calcium as an enhancer for grease trap biodegradation during composting

The potential for degrading raw grease trap waste in compost was further explored through the addition of calcium material as an enhancer of grease biodegradation.

This approach aims to utilize calcium to form oil–mineral aggregates [8–9], which have been shown to prevent oil from coating microorganisms during the oil biodegradation process [10]. The grease trap soap compost from the previous experiment was utilized as the inoculum to introduce beneficial microorganisms that could facilitate the decomposition of the grease trap.

The residual oil extracted from the composts during composting was analyzed for triglycerides through HPLC-ELSD (SM 4). The results indicated that the incorporation of calcium compounds accelerated the decomposition of grease trap waste (Figure 7(A)), especially when $Ca(OH)_2$ was utilized at either concentration applied. However, since grease trap soap compost was used as the starting material, it appears that the presence of mature compost accelerated the composting of raw grease traps, even in the absence of the addition of calcium. This was evidenced by the rapid degradation of residual oil observed after one week of composting.

The results of the germination index revealed a greater germination rate of mung bean seeds when tested with extracts from compost containing either form of calcium after one and two weeks of composting than in the control (Figure 7(D)). This improvement could be attributed to the increased separation of grease within the compost due to oil–mineral aggregation [8, 9]. However, by the fourth week, the compost without added calcium also had an elevated germination index, with results comparable to those of the compost containing 100 g $Ca(OH)_2$. A comparison of the composting results thus indicated that the addition of calcium accelerated the maturation of the compost, leading to effective oil degradation and sufficiently high germinaion indices after just two weeks of composting.

Compost maturation has been shown to reduce phytotoxins within compost [45–46], making phytotoxicity a recommended indicator for assessing compost quality [46]. The germination index, a commonly used parameter for evaluating phytotoxicity, is affected by several factors, including the nitrogen content, type of organic matter, carbon-to-nitrogen ratio, and presence of other metals in the compost [45, 47]. A certain period of time is required for the phytotoxicity of compost to disappear [45, 48]. In the present study, the germination index notably increased when mature compost was used as the starting material compared with that in the previous experiment, especially in the presence of calcium compounds. The addition of calcium has been reported to shorten the time needed to mitigate phytotoxicity during composting [49]. Therefore, the combination of mature starting material and calcium addition should accelerate the composting process, particularly when dealing with low-biodegradable waste such as grease.

However, the concentration of nutrient nitrogen (ammonium and nitrate) decreased during the composting period (Figures 7(B) and (C)), in contrast to the findings regarding grease traps and soap compost in the previous experiment. This reduction may be due to the adsorption of nutrients onto the surface of the calcium material, especially nitrate, which has a negative charge. This could result in lower levels of extractable nitrate from the compost pile. Qin et al. [50] reported that the addition of a calcium solution to soil could increase nitrate adsorption on biochar and the soil matrix, resulting in the retention of nitrogen in the soil. This is due to the formation of $CaNO_3^+$, which is promptly adsorbed on the negative surface charge of the biochar and soil organic carbon. Jantaraksa and Surinkul [51] reported that eggshell water ($CaCO_3$) could be used for ammonium-nitrogen removal from wastewater, with a 20–41% removal efficiency of ammonium sulfate (1–10 g L^{-1}).

Moreover, the decline in nitrate levels over time also suggests that denitrification may have occurred. Nitrate loss due to denitrification has been observed during composting, resulting from the anaerobic microenvironment within the compost pile caused by limited oxygen access [52–53]. In addition, the agglomeration of grease traps might have contributed to the formation of this anaerobic zone during composting. Moreover, the use of mature compost as a starting material or bulking agent can increase nitrous oxide emissions [54]. This phenomenon was attributed to the promotion of the pathway involving nitrous oxide production [54–56], which may explain the reduction in nitrate observed when mature grease trap soap compost was used as the starting material in this study. The results of this study thus suggest that prolonged composting, particularly when mature compost is used as a starting material, could result in a greater degree of nitrate reduction.

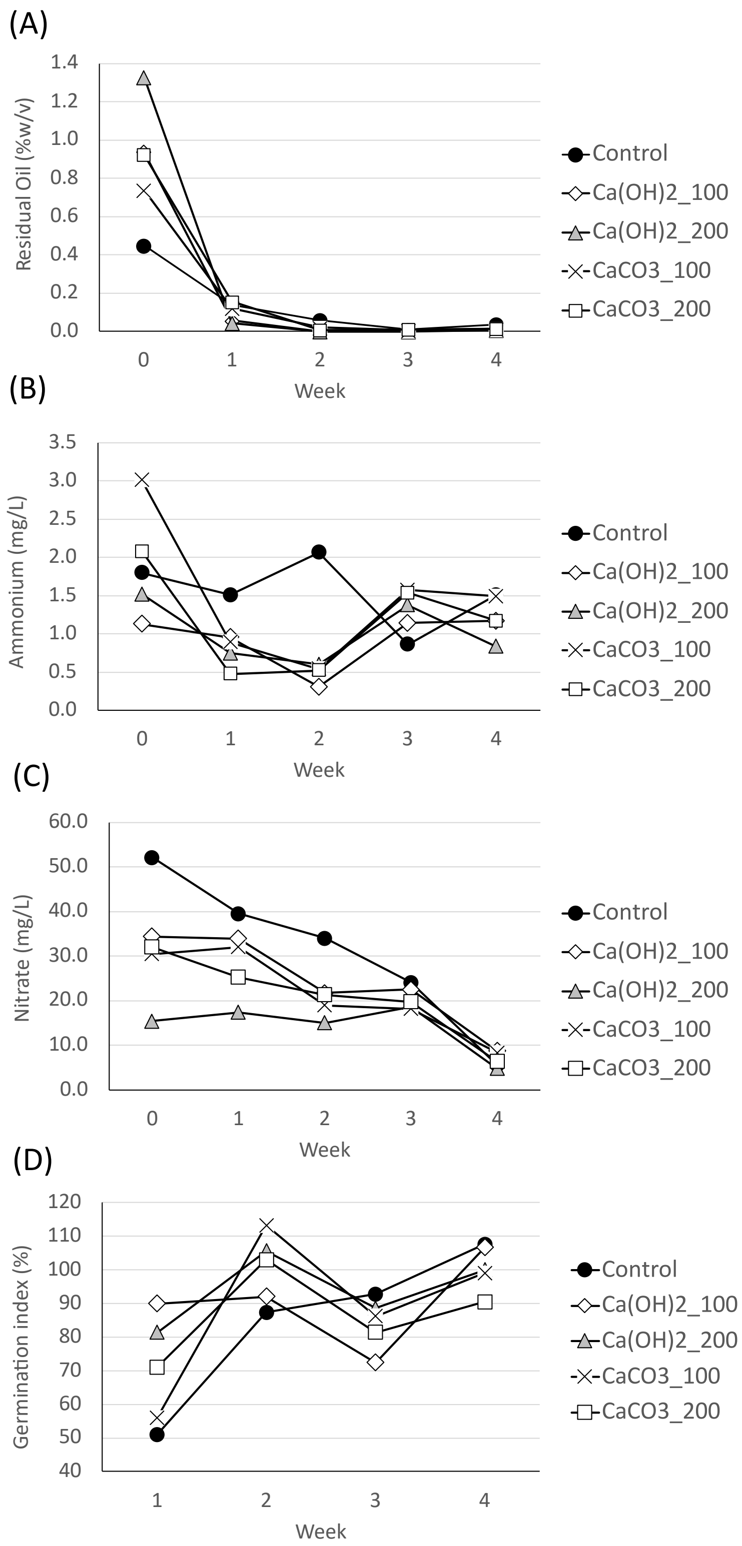

Figure 7 Effects of calcium materials and loading on the residual oil content (A), ammonium content (B), nitrate content (C) and germination index (D) of grease trap compost.

Conclusion

This study demonstrated the potential of applying saponification as a pretreatment step for grease trap waste compositing. The significant increase in nitrate content in the 100% grease trap soap compost highlighted the effectiveness of this grease modification method in enhancing grease biodegradability and compost quality. Interestingly, the addition of calcium supplements further accelerated the composting process, particularly when mature compost from grease trap soap was used as the starting material. Thus, incorporating grease trap waste as a co-substrate in composting is a viable option when combining the strategies of grease trap modification and additive supplementation. By applying simple saponification and calcium supplementation, local governments and communities can manage grease trap waste independently. This approach not only reduces waste management costs but also repurposes grease trap waste into compost, which can serve as a valuable soil amendment for local agricultural use. Future studies on the economic feasibility of this process would provide valuable insights into its broader implementation. Overall, these findings support the implementation of waste management practices that not only improve compost quality but also contribute to the principles of a circular economy by repurposing waste materials into valuable resources. Future research should focus on larger-scale applications of grease trap waste in composting, evaluating the economic feasibility and environmental impact assessment of grease trap saponification and other supplementary materials for practical use.

Acknowledgment

The financial support of this project was funded by the Office of Physical Resources Management, Chulalongkorn University.

References

[1] Wallace, T., Gibbons, D., O'Dwyer, M., Curran, T.P. International evolution of fat, oil and grease (fog) waste management – A review. Journal of Environmental Management, 2017, 187, 424–435.

[2] Del Mundo, D.M.N., Sutheerawattananonda, M. Influence of fat and oil type on the yield, physico-chemical properties, and microstructure of fat, oil, and grease (fog) deposits. Water Research, 2017, 124, 308–319.

[3] Wan, C., Zhou, Q., Fu, G., Li, Y. Semi-continuous anaerobic co-digestion of thickened waste activated sludge and fat, oil and grease. Waste Management, 2011, 31(8), 1752–1758.

[4] Mata, A., Zhang, J., Pridemore, J., Johnson, K., Holliday, N., Helmstetter, A., Lu, M. A review of grease trap waste management in the US and the upcycle as feedstocks for alternative diesel fuels. Environments, 2024, 11, 159.

[5] Belyaeva, O.N., Haynes, R.J. A comparison of the properties of manufactured soils produced from composting municipal green waste alone or with poultry manure or grease trap/septage waste. Biology and Fertility of Soils, 2010, 46(3), 271–281.

[6] Wilkinson, K., Beardsell, D., Hepworth, G., Tee, E., Hood, V., Hudson, C. Effect of maturation of grease trap compost on plant growth. Compost Science & Utilization, 2009, 17(1), 40–47.

[7] Battimelli, A., Carrère, H., Delgenès, J.P. Saponification of fatty slaughterhouse wastes for enhancing anaerobic biodegradability. Bioresource Technology, 2009, 100(15), 3695–3700.

[8] Yu, Y., Qi, Z., Xiong, D., Li, W., Yu, X., Sun, R. Experimental investigations on the vertical distribution and properties of oil-mineral aggregates (omas) formed by different clay minerals. Journal of Environmental Management, 2022, 311, 114844.

[9] Gustitus, S.A., John, G.F., Clement, T.P. Effects of weathering on the dispersion of crude oil through oil-mineral aggregation. Science of the Total Environment, 2017, 587–588, 36–46.

[10] Salama, E.-S., Jeon, B.-H., Kurade, M.B., Patil, S.M., Usman, M., Li, X., Lim, H. Enhanced anaerobic co-digestion of fat, oil, and grease by calcium addition: Boost of biomethane production and microbial community shift. Bioresource Technology, 2020, 296, 122353.

[11] Bower, C.E., Holm-Hansen, T. A salicylate–hypochlorite method for determining ammonia in seawater. Canadian Journal of Fisheries and Aquatic Sciences, 1980, 37(5), 794–798.

[12] Strickland, J. A practical handbook of sea water analysis. Fisheries Research Board of Canada, 1972, 310.

[13] Zhang, L., Sun, X. Using cow dung and spent coffee grounds to enhance the two-stage co-composting of green waste. Bioresource Technology, 2017, 245, 152–161.

[14] Cáceres, R., Malińska, K., Marfà, O. Nitrification within composting: A review. Waste Management, 2018, 72, 119–137.

[15] Rojas-Vargas, J., Mora-Barrantes, J., Herrera-Vargas, P., Arias-Zuñiga, V. Waste management: A study on generating organic fertilizer from oil and grease trap systems. Uniciencia, 2022, 36(1), 1–13.

[16] Li, G., Zhu, Q., Niu, Q., Meng, Q., Yan, H., Wang, S., Li, Q. The degradation of organic matter coupled with the functional characteristics of microbial community during composting with different surfactants. Bioresource Technology, 2021, 321, 124446.

[17] Fu, H., Zeng, G., Zhong, H., Yuan, X., Wang, W., Huang, G., Li, J. Effects of rhamnolipid on degradation of granular organic substrate from kitchen waste by a *pseudomonas aeruginosa* strain. Colloids and Surfaces B: Biointerfaces, 2007, 58(2), 91–97.

[18] Heidarzadeh, M.H., Amani, H., Najafpour Darzi, G. Accurate investigation of the mechanism of rhamnolipid biosurfactant effects on food waste composting: A comparison of in-situ and ex-situ techniques. Journal of Environmental Management, 2022, 322, 116090.

[19] Zhang, L., Sun, X. Effects of rhamnolipid and initial compost particle size on the two-stage composting of green waste. Bioresource Technology, 2014, 163, 112–122.

[20] Klomklang, U., Kulsirilak, N., Intaravicha, N., Supakata, N. Vermicompost from chula zero waste cup and rain tree (samanea saman) leaves. Engineering Journal, 2021, 25(4).

[21] Hao, X. Nitrate accumulation and greenhouse gas emissions during compost storage. Nutrient Cycling in Agroecosystems, 2007, 78(2), 189–195.

[22] Corrêa, R.S., White, R.E., Weatherley, A.J. Effect of compost treatment of sewage sludge on nitrogen behavior in two soils. Waste Management, 2006, 26(6), 614–619.

[23] Wang, W., Wang, L., Shao, Z. Diversity and abundance of oil-degrading bacteria and alkane hydroxylase (alkb) genes in the subtropical seawater of Xiamen island. Microbial ecology, 2010, 60, 429–439.

[24] Marsudi, S., Unno, H., Hori, K. Palm oil utilization for simultaneous production of polyhydroxyalkanoates and rhamnolipids by *pseudomonas aeruginosa*. Applied Microbiology and Biotechnology, 2008, 78, 955–961.

[25] Mohammed Gumel, A., Annuar, M.S., Heidelberg, T. Biosynthesis and characterization of polyhydroxyalkanoates copolymers produced by *pseudomonas putida* bet001 isolated from palm oil mill effluent. PloS one, 2012, 7, e45214.

[26] Janek, T., Łukaszewicz, M., Krasowska, A. Identification and characterization of biosurfactants produced by the arctic bacterium *pseudomonas putida* bd2. Colloids and Surfaces B: Biointerfaces, 2013, 110, 379-386.

[27] Jorfi, S., Mohamadiyan, G., Mobeh-Ali, G.-A., Jaafarzadeh, N. Application of biosurfactants produced by *pseudomonas aeruginosa* sp4 for bioremediation of soils contaminated by pyrene. Soil and Sediment Contamination: An International Journal, 2013, 22.

[28] Afzal, M., Yousaf, S., Reichenauer, T., Sessitsch, A. The inoculation method affects colonization and performance of bacterial inoculant strains in the phytoremediation of soil contaminated with diesel oil. International Jjournal of Phytoremediation, 2012, 14, 35–47.

[29] Almeida, F., Silva, T., Garrard, I., Sarubbo, L., Campos Takaki, G., Tambourgi, E. Optimization and evaluation of biosurfactant produced by pantoea sp. using pineapple peel residue, vegetable fat and corn steep liquor. Journal of Chemistry and Chemical Engineering, 2015, 9, 269–279.

[30] Dong Wan, L., Lee, H., Kwon, B.-O., Yim, U.H., Kim, B., Kim, J.-J. Biosurfactant-assisted bioremediation of crude oil by indigenous bacteria isolated from Taean beach sediment. Environmental Pollution, 2018, 241, 254–264.

[31] Dastgheib, M., Amoozegar, M., Khajeh, K., Shavandi, M., Ventosa, A. Biodegradation of polycyclic aromatic hydrocarbons by a halophilic microbial consortium. Applied Microbiology and Biotechnology, 2011, 95, 789–798.

[32] Hazra, C., Kundu, D., Chaudhari, A. Lipopeptide biosurfactant from *bacillus clausii* bs02 using sunflower oil soapstock: Evaluation of high throughput screening methods, production, purification, characterization and its insecticidal activity. RSC Advances, 2015, 5(4), 2974–2982.

[33] Kawata, Y., Aiba, S.I. Poly(3-hydroxybutyrate) production by isolated halomonas sp. using waste glycerol. Bioscience, Biotechnology, and Biochemistry, 2010, 74(1), 175–177.

[34] Anburajan, L., Meena, B., Sreelatha, T., Vinithkumar, N.V., Kirubagaran, R., Dharani, G. Ectoine biosynthesis genes from the deep sea halophilic eubacteria, *bacillus clausii* niot-dsb04: Its molecular and biochemical characterization. Microb Pathog, 2019, 136, 103693.

[35] Rezaei Somee, M., Dastgheib, M., Shavandi, M., Zolfaghar, M., Zamani, N., Ventosa, A., Amoozegar, M., Halophiles in bioremediation of petroleum contaminants: Challenges and prospects. Bioremediation for Environmental Sustainability, 2021, 251–291.

[36] Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., Sánchez, A. Composting of food wastes: Status and challenges. Bioresource Technology, 2018, 248, 57–67.

[37] Oulebsir-Mohandkaci, H., Benzina-Tihar, F., Hadjouti, R. Exploring biofertilizer potential of plant growth-promoting rhizobacteria *bacillus clausii* strain b8 (mt305787) on brassica napus and medicago sativa. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 2021– 49(4), 12484.

[38] Singh, P., Singh, R.K., Zhou, Y., Wang, J., Jiang, Y., Shen, N., …, Jiang, M. Unlocking the strength of plant growth promoting *pseudomonas* in improving crop productivity in normal and challenging environments: A review. Journal of Plant Interactions, 2022, 17(1), 220–238.

[39] Alghamdi, A.K., Parween, S., Hirt, H., Saad, M.M. Complete genome sequence analysis of plant growth-promoting bacterium, isoptericola sp. Ak164 isolated from the rhizosphere of avicennia marina growing at the Red Sea coast. Archives of Microbiology, 2023, 205, 307.

[40] Etesamia, H., Glick, B.R. Halotolerant plant growth–promoting bacteria: Prospects for alleviating salinity stress in plants. Environmental and Experimental Botany, 2020, 178, 104124.

[41] Itkina, D.L., Suleimanova, A.D., Sharipova, M.R. Pantoea brenneri as3 and *bacillus ginsengihumi* m2.11 as potential biocontrol and plant growth-

promoting agents. Microbiology, 2021, 90(2), 210–218.

[42] Nazari, M.T., Schommer, V.A., Braun, J.C.A., Santos, L.F.d., Lopes, S.T., Simon, V., …, Piccin, J.S. Using *streptomyces* spp. As plant growth promoters and biocontrol agents. Rhizosphere, 2023, 27, 100741.

[43] Nguyen, N.L., Dung, V.V., Tung, N.V., Nguyen, T.K.L., Quan, N.D., Giang, T.T.H., …, Nguyen, H.H. Draft genome sequencing of halotolerant bacterium salinicola sp. Dm10 unravels plant growth-promoting potentials. 3Biotech, 2023, 13, 416.

[44] Orhan, F., Demirci, A. Salt stress mitigating potential of halotolerant/halophilic plant growth promoting. Geomicrobiology Journal, 2020, 37(7), 663–669.

[45] Tiquia, S.M. Reduction of compost phytotoxicity during the process of decomposition. Chemosphere, 2010, 79(5), 506–512.

[46] Selim, S., Zayed, M., Atta, H. Evaluation of phytotoxicity of compost during composting process. Nature and Science, 2011, 10, 469–475.

[47] Siles-Castellano, A.B., López, M.J., López-González, J.A., Suárez-Estrella, F., Jurado, M.M., Estrella-González, M.J., Moreno, J. Comparative analysis of phytotoxicity and compost quality in industrial composting facilities processing different organic wastes. Journal of Cleaner Production, 2020, 252, 119820.

[48] Cui, H.-Y., Zhao, Y., Chen, Y.-N., Zhang, X., Wang, X.-Q., Lu, Q., …, Wei, Z.-M. Assessment of phytotoxicity grade during composting based on eem/parafac combined with projection pursuit regression. Journal of Hazardous Materials, 2017, 326, 10–17.

[49] Himanen, M., Hänninen, K. Effect of commercial mineral-based additives on composting and compost quality. Waste Management, 2009, 29(8), 2265–2273.

[50] Qin, J., Niu, A., Li, Q., Liu, Y., Lin, C. Effect of soluble calcium on enhancing nitrate retention by biochar. Journal of Environmental Management, 2020, 274, 111133.

[51] Jantaraksa, C., Surinkul, N. Ammonium-nitrogen removal in wastewater through adsorption utilizing bio-sorbent matrix. Thai Environmental Engineering Journal, 2020, 34(2), 45–56.

[52] Szanto, G.L., Hamelers, H.V.M., Rulkens, W.H., Veeken, A.H.M. NH_3, N_2O and CH_4 emissions during passively aerated composting of straw-rich pig manure. Bioresource Technology, 2007. 98(14), 2659–2670.

[53] Tsutsui, H., Fujiwara, T., Matsukawa, K., Funamizu, N. Nitrous oxide emission mechanisms during intermittently aerated composting of cattle manure. Bioresource Technology, 2013, 141, 205–211.

[54] Wang, K., Wu, Y., Li, W., Wu, C., Chen, Z. Insight into effects of mature compost recycling on N_2O emission and denitrification genes in sludge composting. Bioresource Technology, 2018, 251, 320–326.

[55] Maeda, K., Hanajima, D., Toyoda, S., Yoshida, N., Morioka, R., Osada, T. Microbiology of nitrogen cycle in animal manure compost. Microbial Biotechnology, 2011, 4(6), 700–709.

[56] Maeda, K., Miyatake, F., Asano, R., Nakajima, K.-i., Maeda, T., Iwabuchi, K. Response of the denitrifier community and its relationship with multiple N_2O emission peaks after mature compost addition into dairy manure compost with forced aeration. Chemosphere, 2018, 206, 310-319.