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Microorganism Formulation in Talcum and Molasses for the Organic Waste Biodrying Process

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ABSTRACT

The growing amount of waste needs the employment of ecologically friendly technologies to reduce the likelihood of environmental hazards. Biodrying is a bioenergy processing technique that uses waste to minimize water content while increasing calorific value and temperature, indicating its potential as a renewable energy source. The purpose of this study was to apply a microbial consortia formulation containing talc and molasses to the biodrying process of organic waste, to assess the effect of carrier materials on biodrying performance, and to identify the ideal period for the process. The microbial consortium used included *Bacillus thuringiensis* SAHA 12.12, *Lactiplantibacillus plantarum* IN05, *Rhizobium* sp. RIKG, *Saccharomyces cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J, all of which were from the IPB Microbiology Laboratory collection. The use of a microbial consortium showed an impact on the measurable results of biodrying organic waste, such as calorific value, water content, and weight reduction. Molasses formulation can boost biodrying efficiency (0.57), calorific value (118−129%), water content (56%), weight loss (34.5%), C/N ratio (32%), and higher temperatures when compared to other carrier materials. Inclusion of talc gives a longer shelf life than molasses. As a result, a molasses-based formulation has the potential to improve biodrying efficiency, while talc can extend the shelf life of the microbial community.

Keywords: biodrying, microbial consortium, molasses, organic waste, talc.

INTRODUCTION

The amount of waste increases year after year, both in Indonesia and around the world. According to UNEP (2024), global trash production in 2020 was at 2.01 billion tons, with municipal solid garbage accounting for the majority. Every person generates an average of 0.74 kg of garbage per day. According to UNEP, roughly 80% of East and Southeast Asia will produce unregulated trash in 2020, with just about 5% being transformed into energy. In Indonesia, spanning 319 regencies and cities, 52.86% of total garbage generation, or 34.27 million t/year (2024), is not properly managed. This is a severe problem since it exacerbates existing environmental issues.

Organic solid waste is a feasible choice for biotechnology-based manufacture of a value-added molecule (Kumar & Jha 2017). This material can be transformed into bioenergy in a variety of ways, including the use of biomass, which is organic material obtained from plant wastes or other forms of organic waste. This biomass has a high potential for usage as a renewable energy source, such as transportation fuel (Begum *et al*. 2024) or briquette (Brunner *et al*. 2021). Biodrying is an important technology for biomass processing (Brunner *et al*. 2021).

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Biodrying is a technique for lowering water content in biodegradable trash using aerobic fermentation, with fungus and bacteria playing important roles (Hao *et al*. 2018). Biodrying reduces water content between 33.7 and 47.1% (Yang *et al*. 2014). Firmicutes, Proteobacteria, Bacteroidetes, and Actinobacteria are frequent microbial groupings found throughout the biodrying process (Wang *et al*. 2020). Abramczyk *et al*. (2014) found that using microorganisms, the method reduced water content by up to 51.7% while increasing temperature. Another study, employing exogenous microorganisms (EM) bacteria, discovered that biodrying with inoculation may rapidly raise temperature and lower water content from 68.35% to 48.52% (Cao *et al*. 2025). These microorganisms can be mixed into a carrier medium, commonly known as formulation. The objective of formulation is to mix the organisms into the carrier, which is reinforced with chemicals to improve storage survival (Jones & Burges 1998).

Microbial packaging has the capacity to retain microbial viability and effectiveness during storage and activity, making it useful as an inoculant (Ariani & Simarmata 2023). Microbial packaging includes both liquid and solid carriers, such as talc (solid) and molasses (liquid). Previous study has focused on the effectiveness of carriers on plant development, such as talc (Swandi *et al*. 2019) and molasses (da Silva *et al*. 2024), but no studies have been conducted for biodrying. Because molasses contains approximately 50% sugar, its use as a carrier stimulates the formation of unbound consortia in liquid medium (Laitila *et al*. 2007), which provides energy to microorganisms. Molasses, in addition to sugar, provide nitrogen, organic acids, and minerals that aid in growth (Palmonari *et al*. 2020). Meanwhile, talc is a good carrier material due to its microbial-friendly qualities, ease of sterilization, and widespread availability (Bahri *et al*. 2014). It can also improve the shelf life of microorganisms like *Trichoderma* (Rahaman *et al*. 2018) and PGP microorganisms (Gopalakrishnan *et al*. 2016). Talc, with its wide pH range and strong chemical stability (Bazar *et al*. 2021), can be an alternative carrier formulation to molasses. The purpose of this study was to employ a microbial consortia formulation using talc and molasses as carrier materials for the biodrying of organic waste, to investigate the effect of carrier materials on biodrying effectiveness, and to identify the ideal period for the process.

METHODS

Time and Location

This study was carried out from June to November 2024 at the Cikabayan Landfill, the Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University (IPB University), and the IPB environment.

Tools and Materials

Petri dishes, loop needles, plastic containers, an autoclave, a microscope, serological pipettes, micropipettes, a pH meter, an oven, a shaker, a 250g heat-resistant plastic bag, a spreader, a biodrying waste bin, a thermometer, a UV-Vis spectrophotometer, a pH meter, a moisture meter, a scale, gauze, knife, cutting board, permanent marker, and a camera were used for documentation.

Organic waste from the Cikabayan Landfill, *Bacillus thuringiensis* SAHA 12.12, *Lactiplantibacillus plantarum* IN05, and *Rhizobium* sp. RIKG, *Saccharomyces cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J from the Microbiology Laboratory collection, Department of Biology, IPB University, were used in the study. Liquid biofertilizer brands include Point Duatani (Commercial 1) and D'Boosterfer (Commercial 2).

Microorganism Purification

B. thuringiensis (BT) SAHA 12.12, *L. plantarum* IN05, *Rhizobium* sp. RIKG, *S. cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J isolates from the Microbiology Laboratory collection were revived as potential biodrying inoculants. Nutrient agar (NA), potato dextrose agar (PDA), yeast mannitol agar (YMA), deMan rogose sharpe agar (MRSA), and the International Streptomyces Project (ISP) medium were used for rejuvenation, with the quadrant streak approach. The samples were cultured at room temperature (± 25°C) for 48−72 h. The isolates were reconfirmed for colony morphology and microscopic features of the bacterial cells and preserved on agar slants as stock cultures.

Microorganism Formulation

Microorganism formulation took two forms powder and liquid each with three replicates. It began with the formation of a microbial consortium from purified microbial isolates. Inoculants were created by adding one loop of the isolate to the liquid medium and shaking at room temperature until a particular cell density was reached, as assessed at OD 600 (0.6). The talc powder formulation (Swandi *et al*. 2019) contains talc as the major ingredient, along with carboxymethylcellulose (CMC), yeast extract, peptone, and sucrose. The pH was adjusted to 7.0 with $CaCO_3$. The ingredients were sterilized before the mixed microbial inoculum consortium was added to the talc. The molasses liquid formulation was prepared by combining the microbial consortia with a solution of 5% molasses, 0.1% soybean flour, and sterile distilled water prepared aseptically at a comparable pH. The consortium in both formulations promotes microbial growth and activity in a variety of biodrying applications.

Microorganism Inoculation onto Organic Waste

In the biodrying process, microorganisms were inoculated onto organic waste in two stages: preparation and testing. The preparation stage began with the preparation of fresh leaf litter and organic trash. This trash was weighed at 10 kg per tank and given five treatments: control, commercial 1, commercial 2, molasses, and talc. The consortium formulation inoculum was generated at a 5% (v/v) ratio using organic waste, and the consortium was cultivated for 24 h (Sarkar & Chourasia 2017).

During the test phase, waste from both the treatment and control groups was injected with the microbial community. Samples were placed in small, covered containers (Figure 1) and kept in a composting

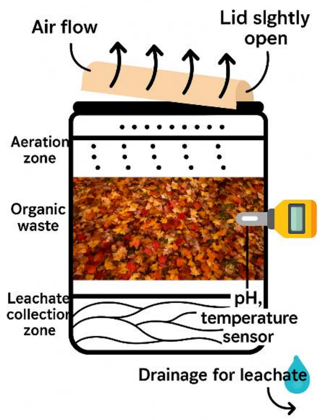

Figure 1 Schematic design of a simple biodrying reactor.

chamber with adequate air movement and protection from direct sunshine. Five treatments were used to inoculate organic waste: molasses (sugar, minerals, vitamins, macro- and micro-nutrients, and laboratory microbial consortium cultures), talc (magnesium silicate, silicon, hydrogen, oxygen), commercial 1 (ZPT hormones, macro- and micronutrients, amino acids, vitamins, microorganisms), *Azospirillium* sp., *Azotobacter* sp., and commercial 2 (ZPT hormones, macro- and micronutrients, organic acids, vitamins, enzymes, local microorganisms from fermentation and synthetic) and control (laboratory microbial consortia cultures in growth media) were used for a 21-day period. Every day for 21 days, measurements were taken of the calorific value, water content, temperature, pH, waste weight, and physical parameters (odor, texture, and color). Biodrying efficiency was determined by comparing the maximum dry weight to the lowest water content. Biodrying efficiency (BI) was calculated as the ratio of organic loss (OL) to water weight loss (WL) (Bhatsada *et al*. 2023):

BI = OL/WL

Formula for calculating OWL (Tchobanoglous *et al.* 1993):

OWL (kg) = initial organic weight (kg) – final organic weight (kg)

Formula for calculating WWL (APHA 1998):

WWL (kg) = initial water weight (kg) – final waterwWeight (kg

Viability and Stability Test

This paper describes the viability and stability studies carried out to determine the survival of microbial populations in carrier materials, specifically molasses and talc, throughout a two-month storage period at ambient temperature (27 °C). The stability of the inoculum within the carrier was assessed by counting the number of live cells at the end of the storage period.

To determine the microbial population, we used the plate method with nutrient agar (NA) medium. Sample of the formulation (1 g) was dissolved in 9 mL of sterile 0.85% NaCl solution, and then serially diluted up to a dilution of 10^{-8}. A 0.1 mL suspension of the last three dilution levels (10^{-6}, 10^{-7}, and 10^{-8}) was then dispersed across NA medium plates and incubated at around 25°C. The total plate count (TPC) method was used to acquire the final colony counts.

Viability and stability tests were performed at baseline (week 0, before to formulation), one month, and two months after formulation. Ida *et al*. (2023) discovered that a two-month (8-week) storage period results in a decrease in viability that is not significantly different from that observed at three months, supporting Swandi *et al*.'s (2019) finding that two months is a suitable duration for a consortium of microorganisms to thrive in carrier materials. After each testing session, TPC calculations were performed, with total microbial populations expressed as colony-forming units per mL (CFU/mL).

RESULTS AND DISCUSSION

Characteristics of Inoculant Microbes

Various studies were performed to define the isolate profiles of *Bacillus thuringiensis* (BT) SAHA 12.12, *Lactiplantibacillus plantarum* IN05, *Rhizobium* sp. RIKG, *Saccharomyces cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J as a requirement for biodrying inoculant application (Figure 2). The goal of selecting microbial isolates in the process was to establish an effective consortium that enhances temperature, calorific value, and minimizes wastewater content while simultaneously improving nutrition and controlling pathogens. Microbial consortia composed of bacteria and fungi exhibit antagonistic pathogen-suppressive capacities, which promote microbial stability during biodrying (Jurado *et al*. 2014). Bacteria like *L. plantarum*, which can eradicate odors and reduce infections, have been demonstrated to boost biodegradation even in small concentrations (Zhang *et al*. 2024). Bacillus, particularly *B. thuringiensis*, is dominant in the biodrying process and has been shown to degrade complex polymers such as protein and starch (Puspasari *et al*. 2013). It also works well in the thermophilic phase alongside Actinobacteria such as *Streptomyces* (Cai *et al*. 2018; Ma *et al*. 2019a). Fungi play a crucial role in decomposition, particularly Trichoderma from the Ascomycota group, which is good in degrading lignocellulose (Zhang *et al*. 2018; Cao *et al*. 2021). Furthermore, *S. cerevisiae*, a yeast group, works as a bioactivator, facilitating the breakdown process (Brunner *et al*. 2021; Septiariva *et al*. 2022).

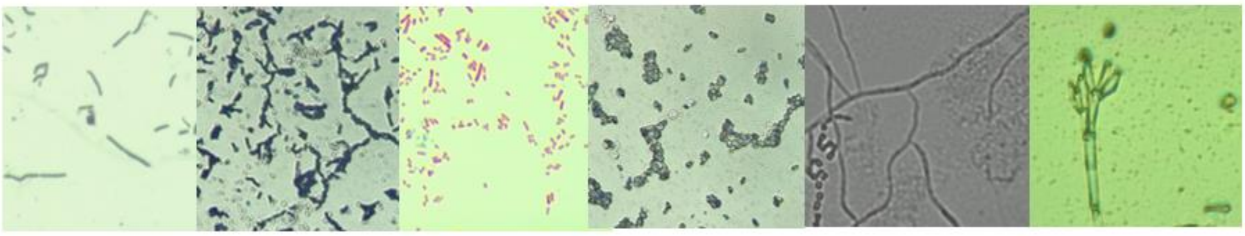

Figure 2 Cell shape of the test microorganisms in this study: (1) *Bacillus thuringiensis* SAHA 12.12, (2) *Lactiplantibacillus plantarum* IN05, (3) *Rhizobium* sp. RIKG, (4) *Saccharomyces cerevisiae* L1, (5) *Streptomyces sp.* A4J, and (6) *Trichoderma* sp. T2J.

Temperature and pH in the Process

The biodrying process is influenced by several vital parameters, including carbon mass reduction, microbial activity, temperature, biomass, calorific value, moisture content, C/N ratio, odor, and texture (Zawadzka *et al*. 2010; Özbay *et al*. 2022; Minarti *et al*. 2023; Tambone *et al*. 2011, Ham *et al*. 2020). Temperature (Figure 3A) is an important element because it provides optimal conditions for microorganisms involved in organic degradation and moisture reduction (Ngamket *et al*. 2021). The biodrying process is also affected by pH conditions (Figure 3B), which influence the availability of microorganisms at a certain pH. Figures 3A and 3B illustrate the temperature and pH profiles obtained during the 21-day process for five treatments: commercial 1, commercial 2, talc, molasses, and the control. Figure 3A shows temperature fluctuations over the 21-day process, indicating three phases: thermophilic, mesophilic, and cooling (Orozco-Álvarez *et al*. 2025). The temperature immediately rose to the thermophilic phase (45−55°C), peaking on the second day. The molasses treatment reached a maximum temperature of 48.4°C. This thermophilic phase enhanced water evaporation and organic matter decomposition (dos Reis *et al*. 2020; Cai *et al*. 2018). The temperature then dropped until it stabilized at roughly 30°C, indicating a decrease in microbial activity and the attainment of biological stability (Fiki *et al*. 2022), which happens during the mesophilic and cooling phases.

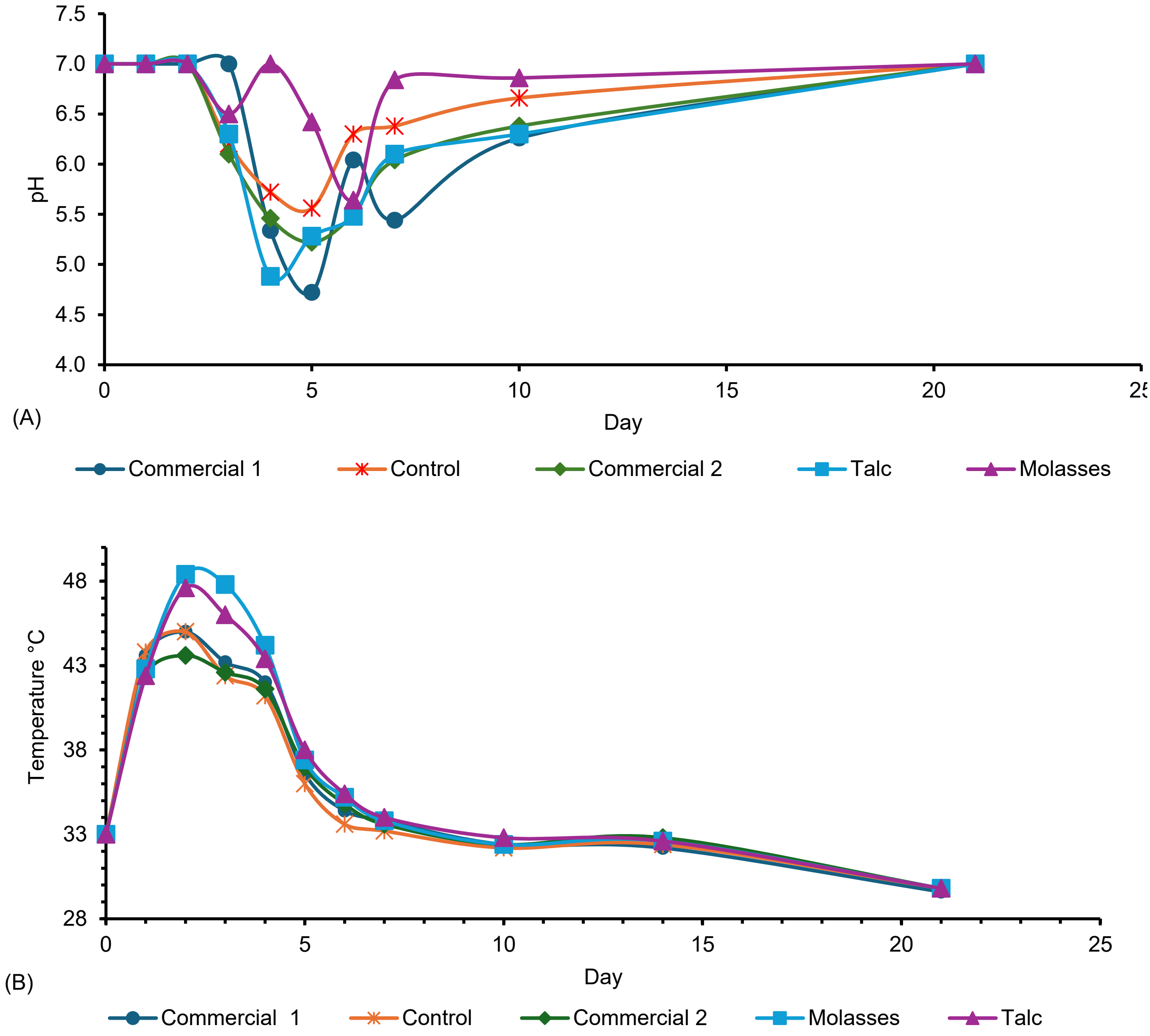

Figure 3 Changes in temperature (A) and pH (B) during the 21-day biodrying process of waste with treatments 1: commercial 1, 2: control, 3: commercial 2, 4: molasses, 5: talc.

Temperature fluctuations in biodrying are induced by microbial activity, which creates metabolic heat and is critical to the increase in the temperature of the organic waste pile in this study. In this investigation, the inoculant group *B. thuringiensis* (BT) SAHA 12.12 performed an important role in the thermophilic phase. According to Moustafa *et al*. (2018), BT can live and function in temperatures ranging from 35 to 72°C. In addition to the Bacillus group, Actinomycetes (represented by Streptomyces) contribute to the thermophilic phase by degrading complex substances including cellulose and lignin (Kurniati *et al*. 2016). According to Ma *et al*. (2021), the thermophilic phase reduces microbial diversity as temperatures rise. This shows that the mechanism favors temperature-intolerant microorganisms, especially diseases. However, not all thermophilic-tolerant bacteria are used in the biodrying process, as mesophilic microbes play an important role in the mesophilic and cooling phases. This ensures that different microbial species contribute to the optimization of the process at each phase.

Other groups, such as Lactobacillus, Trichoderma, Saccharomyces, and Rhizobium, thrive at mesophilic temperatures and contribute to the biodrying process. These microorganisms not only degrade simple organic waste, but they also foster the shift to the thermophilic phase, when more degradation occurs. From day 0 (average 33°C) to day 1 (average 43°C), the initial mesophilic phase precedes the thermophilic phase, or maximum temperature rise. On day 5, the second mesophilic phase began, with an average temperature of 37°C for all carriers, followed by a cooling phase (Figure 3A). From day 10 to day 21, the temperature gradually decreases, termed as the cooling phase, peaking on day 21 with an average of 29.76 °C for all carriers. This phase marks a decrease in microbial activity and the attainment of biological stability (Fiki *et al*. 2022). Mesophilic microorganisms can play a role in this phase, and most of them were used in this study, particularly *B. thuringiensis*, which has a powerful defensive system that produces endospores when exposed to extreme environments (heat or cold).

The pH of the organic waste fluctuated between days 0 and 21 during the biodrying process (Figure 3B). On days 0−3, the pH was neutral (pH 6.52−7.0), then it dropped on days 4−6 (pH 5.67−5.96) before rising again on days 7−21 (pH 6.27−7.0). At the end of the process, the pH of all treatments had stabilized (pH 7). Peng *et al*. (2024a) and Orozco-Álvarez *et al.* (2025) showed a similar increase in pH during the cooling step of the biodrying process for stabilization. This increase in pH is caused by the release of ammonia and the mineralization of organic nitrogen, which neutralizes the originally produced organic acids and causes a progressive increase in pH (Ribeiro *et al*. 2017).

The role of microorganisms in rising temperature is determined by carrier material. Molasses as carrier treatment had the highest average temperature (37.95°C), followed by talc (37.73°C). In the molasses treatment, the maximum average temperature was 48.4°C. From day 1 to day 4, it remained in a thermophilic phase, with molasses (45.80°C) and talc (44.85°C) having the highest average (days 1−4) compared to other carrier materials. On the fifth day, the temperature began to drop, with the five carrier materials ranging from 36°C to 38°C (Figure 3A). The temperature continued to fall until day 21 (average 29.76°C). This finding suggests that carrier treatment can improve thermal conditions during biodrying (Hao *et al*. 2018).

Carrier treatment influences pH as well. Overall, according to the Duncan test, all carriers were in the same group, with an average pH of 6. However, on one specific day (day 4), the carrier's molasses, commercial grade 1, and commercial grade 2 caused pH changes. This data contradicts with the temperature data, with day 4 having a higher temperature than the previous days. This is regulated by bacteria with strong metabolic activity, which raise temperatures and create organic acids that lower pH (Afriani 2010). This study used fermentative bacteria that can play a function in waste piles located in the center or bottom of the pile. The presence of LAB bacteria, such as *L. plantarum* and *S. cerevisiae*, can create organic acids (Sandi *et al.* 2023), particularly when provided with a carrier medium high in glucose content (molasses).

The molasses carrier treatment (4.88) can lower the pH level, which becomes noticeable on day 4 (Yunus *et al*. 2000), followed by the control (5.72), commercial 1 (5.34), and commercial 2 (5.46). This decrease has implications for fermentation and organic waste processing. Meanwhile, the talc carrier maintains a steady pH range of 6−7, reaching pH 7 on day 4. Talc treatment preserves a neutral pH because it is inert, has good chemical compound stability, and has a stable surface (Bazar *et al*. 2021), so the pH is maintained. However, for 21 days, the average pH value of all carrier materials remained neutral (6.28−6.7). This finding is similar with Tom *et al*. (2016)'s study, that the average pH during the biodrying process was 6. This study indicates a neutral pH, which is ideal for organic breakdown during biodrying (Orozco-Álvarez *et al*. 2025). Therefore, the carrier material used in this study promotes microbial activity during the process.

Physical Composition Profile

The physical composition profile of biodrying waste, including texture, color, and odor, can be used to control the process (Table 1). During the process, fragrance, color, and texture changes occurred gradually, with considerable increases culminating on day 21. Treatments such as commercial 2, molasses, and talc hastened changes in the physical composition of organic leaf debris, with significant alterations beginning on days 4 to 7, whereas the control had delayed changes. As the decomposition process advanced, the odor became fresher and more earthy,

Table 1 Texture, color, and odor profiles in the biodrying process for five treatments

Treatment	Texture					Color					Odor				
	0	1	4	7	21	0	1	4	7	21	0	1	4	7	21
Commercial 1	+	+	++	+++	++++	+	++	+++	+++	+++++	+	++	+++	+++	+++++
Control	+	+	+	+++	++++	+	+	++	+++	++++	+	+	+++	+++	++++
Commercial 2	+	+	++	++++	+++++	+	++	+++	+++	+++++	+	++	+++	+++	++++
Molasses	+	+	++	++++	+++++	+	++	+++	+++	+++++	+	++	+++	+++	+++++
Talc	+	+	++	++++	+++++	+	++	+++	+++	+++++	+	++	+++	+++	+++++

Description	+	++	+++	++++	+++++
Color	fresh green	brownish green	light brown	dark brown	blackish brown
Texture	very coarse	coarse	medium	fine	very fine
Odor	raw leafy odor	pungent odor	humus odor	fresh earthy odor	very fresh earthy odor

the color darkened to a blackish brown, and the texture smoothed out (Mulyani *et al*. 2022). The smooth texture aids in breakdown, accelerates the degradation process, promotes air circulation, and lowers humidity. According to Colomer-Mendoza *et al*. (2013), external airflow reduces moisture content, which improves biodrying efficiency.

The texture influences its compostability. Biodrying compost with a good texture result in higher physical quality. In this study, texture alterations are trending toward finer textures. A good compost texture has smaller particles (Mulyani *et al*. 2022), showing a shift in texture from coarse to finer because of microorganism activity throughout the biodrying and composting processes, as well as organic matter reduction (Ham *et al*. 2020). As a result, materials with a fine texture breakdown more quickly, reducing process time. Material texture also influences aeration and humidity during the process. Materials with a coarse texture have greater pore spaces, which increase air movement and effectively reduce moisture levels, improving the effectiveness of the process.

C/N Ratio and Waste Weight Profile

The physical composition parameters of biodrying waste can help determine the waste weight and C/N ratio. The C/N ratios in five treatments from day 0 to day 21 (Figure 4A), which are in the optimal composting phase (30), are illustrated in treatments 1, 4, and 5 (commercial 1, molasses, and talc). From day 0 to day 21, the molasses treatment reduced organic waste weight by the most (34.5%) (Figure 4B). According to a one-sample *t*-test, there was insufficient evidence to conclude that the average C/N ratio differs substantially from 30. The talc carrier (29.8) came closest to 30, followed by commercial 1 (31) and molasses (32.4), whereas control and commercial 2 well above 30. An appropriate C/N ratio (about 30) promotes maximum microbial activity, which influences biodrying performance. Larsen and McCartney (2000) found that biodrying failure is influenced by C/N ratios outside the range (<15 or >30). As a result, talc, molasses, and commercial 1 were shown to be more promising for biodrying.

The paired samples *t*-test revealed a significant difference between the initial and final weights. Over the course of 21 days, the average initial weight exceeded the final weight. Molasses and talc had the highest percentage reduction compared to other carrier materials (commercial 1 and 2) or the control (Figure 4B), with weight losses of 34.5% (molasses) and 31.5% (talc), respectively, which are within the typical values reported by Bilgin dan Tulun (2015) of around 30%, while the control and commercial 1 obtained 26% and commercial 2 only 22.5%. This weight loss is due to the action of bacteria found in molasses and talc, which can breakdown organic leaf detritus. High microbial activity can speed the breakdown of organic substances and promote biothermal development (Ma *et al.* 2019).

A consortium of *B. thuringiensis* (BT) SAHA 12.12, *L. plantarum* IN05, *Rhizobium* sp. RIKG, *S. cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J can increase degradation by more than 31% (in talc and molasses carrier materials) compared to other treatments (control and commercial 1 and 2). Microorganisms can create enzymes that aid in the degradation of lignocellulosic biomass in organic waste (Guo *et al*. 2021), expediting the humification process (Xunan *et al*. 2022), and boosting the efficiency of biodrying. These findings suggest that the results can be applied to initial compost processing (Zhang *et al*. 2018).

Moisture Content Profile

Moisture content is an important parameter that influences biogenic carbon levels and the heating value of combustible trash (Chaerul & Wardhani 2020). Overall, all carrier materials demonstrated a decrease in moisture content from day 0 to day 21, with significant results obtained using ANOVA (Figure 5). Molasses and talc, as carrier materials, demonstrated the greatest moisture content drop on day 21, with moisture level below 40%. Meanwhile, other carrier materials, particularly the control and commercial 2, demonstrated a similar pattern of moisture content decline, with moisture content of approximately 45% at day 21. The moisture content decreased significantly

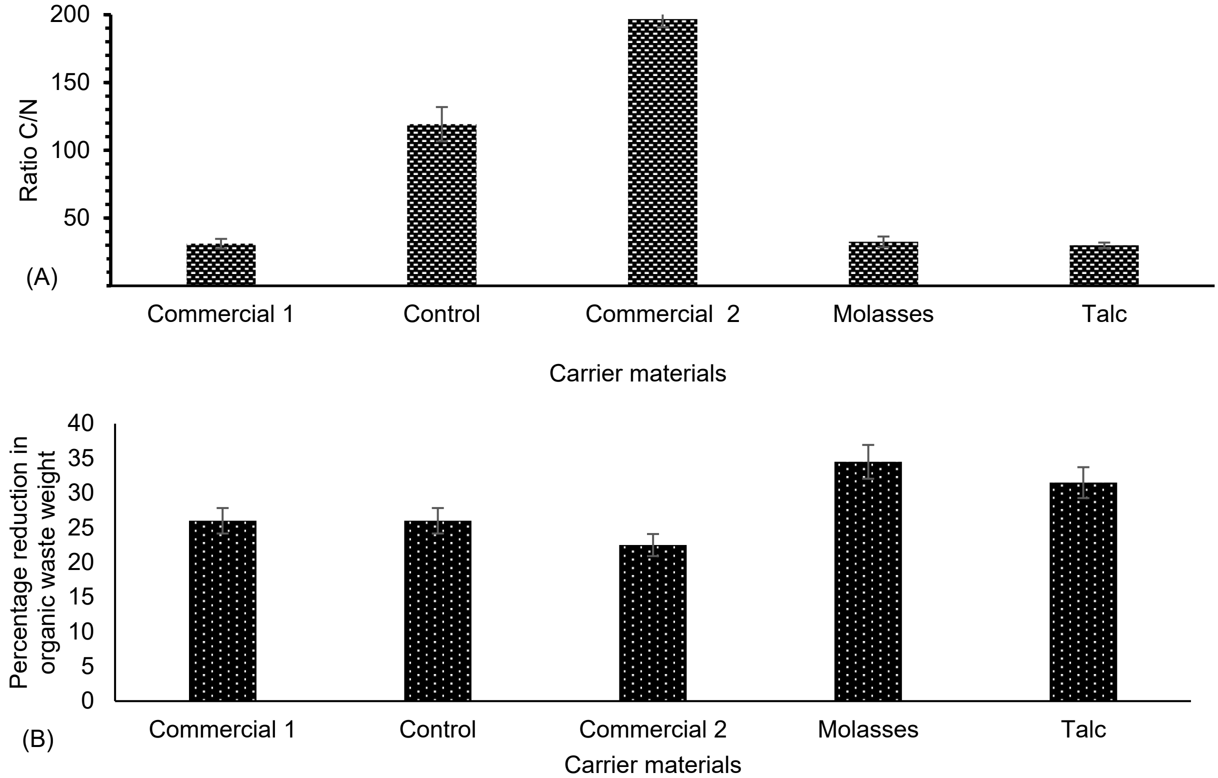

Figure 4 C/N ratio (A) and changes in initial and final weights (B) during the 21-day biodrying process in five treatments (commercial 1, control, commercial 2, molasses, talc).

from day 0 to day 4, with a slower reduction between days 4 and 21. On day 21, all treatments had the lowest moisture level, indicating that moisture reduction will continue throughout the process. Molasses treatment had the lowest moisture content (56.15%), followed by talc (56.26%) and commercial 1 (60.62%). These findings suggest that each treatment has an impact on the rate of moisture reduction. Nakasaki *et al.* (2009) found that the ideal moisture content for microbial activity is 45−65% w/w.

Day 4 (Figure 5) indicated a higher moisture reduction than the previous days (days 7 and 21), with an average of 42.7%. Molasses (48.23%) and talc (48.22%) had the lowest water content when compared to other carrier materials, especially commercial 1 (54.36%), hence the Duncan Test classified molasses and talc as the same subset. On the seventh day, a modest decline occurred, ranging from 0.8% to 11.9%. The decline over the last 21 days varied from 2.4% to 16. 4% beginning on day 7, indicating that the water content would stabilize until no further decrease occurred. According to Nakasaki *et al.* (2009), the ideal water content for microbial activity is 45–65%. Days 4 (average 49.76%) and 7 (47.80%) still demonstrated appropriate microbial activity, given that the water content ranged from 45 to 65%. However, by day 21, the water content had fallen by an average of 43.54%. These results show that the organic waste material had been dried (Table 1). The large drop in water content seen in this study (particularly on day 4; molasses and talc carrier materials) could have been influenced by the aeration system used, as air treatment in biodrying affects the weight reduction and water content of the biomass feedstock (Darojat *et al*. 2024). The aeration system used in this study entailed depositing garbage in a tank, leaving more space between the top and bottom surfaces of the waste. The tank lid was left slightly open to allow for additional air, which accelerated the drying process.

Furthermore, the air entering the garbage spurred the bacteria within to consume oxygen and organic materials, resulting in the production of CO_2 and O_2. The heat produced by the microorganisms' metabolism dissipated the water vapor (Yang *et al*. 2014). The system controlled by the biodrying reactor employed in this study allowed the water vapor escaping from the pile of organic waste to escape rather than becoming trapped within it. Each tank was lined with a fabric to help absorb water vapor and keep it from rising to the waste's surface. As a result, evaporation accounted for most of the leachate loss. The considerable reduction in water content seen in this study could be impacted by the aeration system used, as air treatment in biodrying affects the weight reduction process and water content of the biomass raw material (Darojat *et al*. 2024). The aeration system used in this study entailed covering the trash with a liner cloth, which helps absorb water vapor and keeps it from returning to the waste's surface. The presence of space between the trash and the bottom of the container allowing for

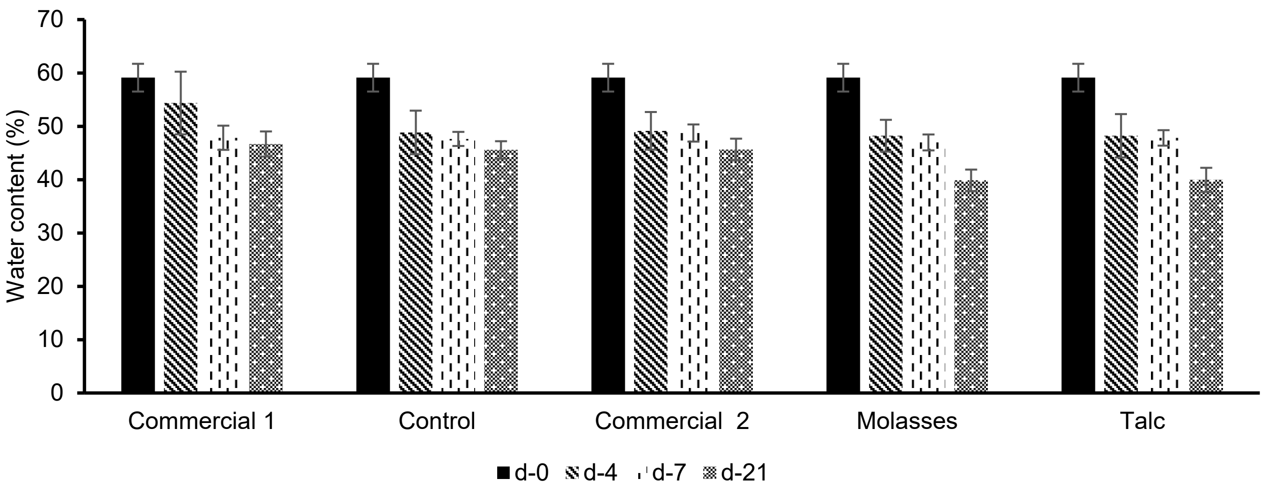

Figure 5 Changes in moisture content in biodrying waste over 21 days on days 0, 4, 7, and 21 across five treatments (commercial 1, control, commercial 2, molasses, and talc).

leachate can speed up the drying process. Unlike previous studies that reported leachate production in the biodrying process, leachate was not produced in large quantities in this study; in fact, most of the water was lost through evaporation, particularly in the treatments with molasses, talc, and control 2, as reported by Yuan *et al*. (2019), that water was significantly lost after passing through a sound aeration system

Calorific Value Profile

The biodrying process seeks to improve the energy content of trash (Tambone *et al*. 2011). Waste can be used as an energy source in the process (Sugni *et al*. 2005), hence the calorific value is an important element in the process. The graph of calorific value changes (Figure 6) shows a considerable increase from day 0 to day 4, with day 4 having the highest calorific value (average 1979.8 cal/g) compared to day 1 (985.72 cal/g). On day 7, the calorific value climbed slightly, to 2021.78 cal/g. On days 4 and 7, the molasses treatment had the greatest increase in calorific value, followed by commercial two and talc, with commercial 1 having the lowest.

Molasses was the most effective treatment for boosting calorific value, closely followed by talc. These findings are consistent with other biodrying characteristics such as temperature, weight, C/N ratio, and physical composition, demonstrating that certain treatments were more effective than others. Temperature, pH, C/N ratio, weight loss, microbial activity, and moisture content all contribute to increased calorific value throughout the process (Yang *et al*. 2014). High temperatures promote water evaporation, lower moisture content, and increase the activity of thermophilic microorganisms, which speed decomposition and produce more energy in the form of heat. Furthermore, an appropriate pH (pH 5.5−8.0) promotes microbial activity, allowing for more efficient decomposition of organic matter such lignocellulose, which increases heat generation (Nakasaki *et al*. 2009). A C/N ratio of roughly 30 is regarded excellent for biodrying because it promotes optimal microbial activity, which accelerates decomposition and boosts energy output (Roy *et al*. 2006). Weight loss also shows the efficiency of microbial decomposition, which releases energy in the form of heat more quickly when organic waste is broken down into simpler chemicals (Ma *et al*. 2019b). Microbial activity, particularly thermophilic bacteria, accelerates the degradation of complex organic matter like lignocellulose, resulting in increased energy yields (Cai *et al*. 2018). Reducing water content increases the concentration of degraded organic matter, which raises calorific value substantially. This is because low moisture content allows more energy to be released during decomposition (Yang *et al*. 2014).

Calorific value is an important criterion in determining the energy potential of biomass materials produced during the biodrying process. Reductions in moisture content, waste weight, and temperature increases, as well as other characteristics after biodrying, not only boost calorific value but also make biomass more efficient in energy production. This technique has tremendous potential for using biomass as an environmentally friendly and sustainable renewable energy source (Santosa & Soemano 2014). Drier, carbon-rich biomass can be used directly as fuel/biofuel (Bilgin & Tulun 2015), or it can be converted into briquettes (Santosa & Soemano 2014). As a result, biomass produced by biodrying can replace fossil fuels such as coal, oil, and natural gas in a variety of industrial uses, including electricity generation and heating (Zaman *et al*. 2021), where it is known as RDF (refuse derived fuel). In addition to being a fuel, the biomass produced by biodrying can be used to create biochar, which is a carbon storage material that can subsequently be utilized as a fuel (Begum *et al.* 2024).

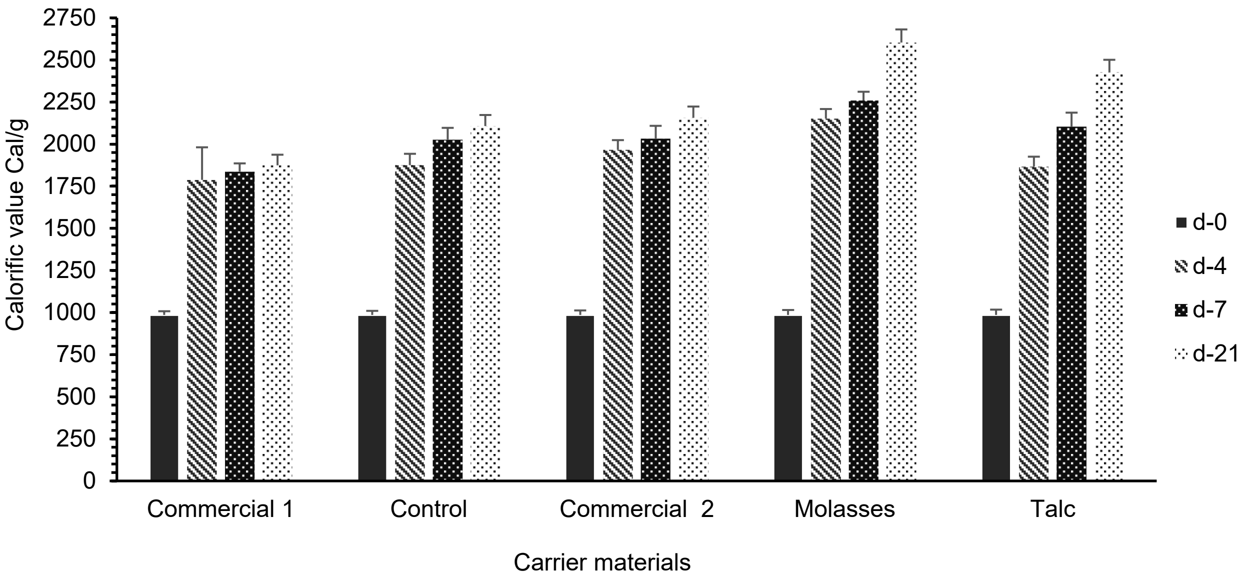

Figure 6 Changes in the calorific value of biodrying waste over 7 days across five treatments (commercial 1, commercial 2, control, molasses, and talc).

Effective Molasses Formulation for Increasing Efficiency

Molasses can improve carbohydrate metabolism and fermentation quality, leading to increased microbial activity (Liu *et al*. 2020). Peng *et al*. (2024) discovered that adding molasses considerably increased the activity of *L. plantarum*, as the water-soluble carbohydrates in molasses can offer a substrate for the growth of lactic acid bacteria, hence boosting fermentation (Xie *et al*. 2021). Molasses, as a potential culture medium, can influence Bacillus growth (de Silva *et al*. 2024). Molasses' pH reduction can inhibit the growth of other pathogenic (non-inoculant) bacteria while also controlling the environment (Liu *et al*. 2020). Molasses can also increase aerobic stability and storage time (Peng *et al*. 2024). Furthermore, increasing microbial activity can affect temperature, moisture content, and calorific value.

The biodrying process works by removing as much water as possible from the system while avoiding organic carbon degradation, resulting in a product with a low water content and a high calorific value (Tambone *et al*. 2011; Ngamket *et al*. 2021; Payomthip *et al*. 2022). The moisture and organic carbon content measurements assess biodrying effectiveness. The optimal rate of water and carbon loss in solid waste drying influences both the system's efficiency and the quality of the biodrying output (Ngamket *et al.* 2021).

The study comparing the biodrying efficiency of molasses to the other four carrier materials found that molasses had the highest efficiency (Table 2). Molasses had the best results, with the highest OL (organic matter loss), WL (water loss), and biodrying index (0.57). This shows that molasses is the most effective carrier for lowering organic matter and water content throughout the process. Talc (0.53) and commercial carrier 1 (0.50) outperformed expectations, with biodrying indices exceeding 0.50. Commercial carrier 2 and the control had the lowest efficiencies, with indices of 0.44 and 0.48, respectively, but molasses and talc had above-average efficiencies (0.51).

Microbial Viability in Carrier Materials

The goal of carrier formulation stability is to determine the influence of carrier formulation on microbiological survival over a given time (in this case, two months). Microbial isolates that have established a consortium are subsequently formulated in both solid (talc) and liquid (molasses) forms. The formulation contains a consortium inoculant made up of isolates of *B. thuringiensis* (BT) SAHA 12.12, *L. plantarum* IN05, *Rhizobium* sp. RIKG, *S. cerevisiae* L1, *Streptomyces* sp. A4J, and *Trichoderma* sp. T2J. Microbial stability and vitality might vary greatly depending on the storage circumstances and the specific microbe in question. Microbial viability diminishes over time, and the rate of decline is regulated by temperature, humidity, and nutrition availability (Visciglia *et al*. 2022). The drop in the number of colonies can also be attributed to a decrease in the nutrients in the formulation. *B. thuringiensis* (BT) SAHA 12.12 exhibited the highest vitality among all microorganisms, followed by *L. plantarum* IN05. *Rhizobium* sp. RIKG and *Streptomyces* sp. A4J exhibited the lowest viability levels (Figure 7).

T[illegible] (A) [illegible]performed molasses as a carrier medium, prom[illegible] microorganism stability and vitality. After two months, the talc could maintain *B. thuringiensis* (BT) SAHA 12.12 viability at 4.6 × 10^8 CFU/mL, but molasses only managed 2.3 × 10^7 CFU/ml. This result is likewise true for other bacteria in both carrier mediums. This finding is consistent with prior research (Arifin *et al*. 2025), that talc is the best carrier material for preserving microbial viability throughout storage. Panjaitan *et al*. (2019) discovered that the talc carrier

Table 2 Biodrying efficiency based on the ratio of organic (OL) and water (WL) weight loss

Carrier material	OL (Organic weight loss) kg	WL (Water weight loss) kg	Biodrying index
Commercial 1	2.60	5.24	0.50
Control	2.60	5.32	0.49
Commercial 2	2.25	5.16	0.44
Molasses	3.45	6.08	0.57
Talc	3.15	5.96	0.53
Average			0.50

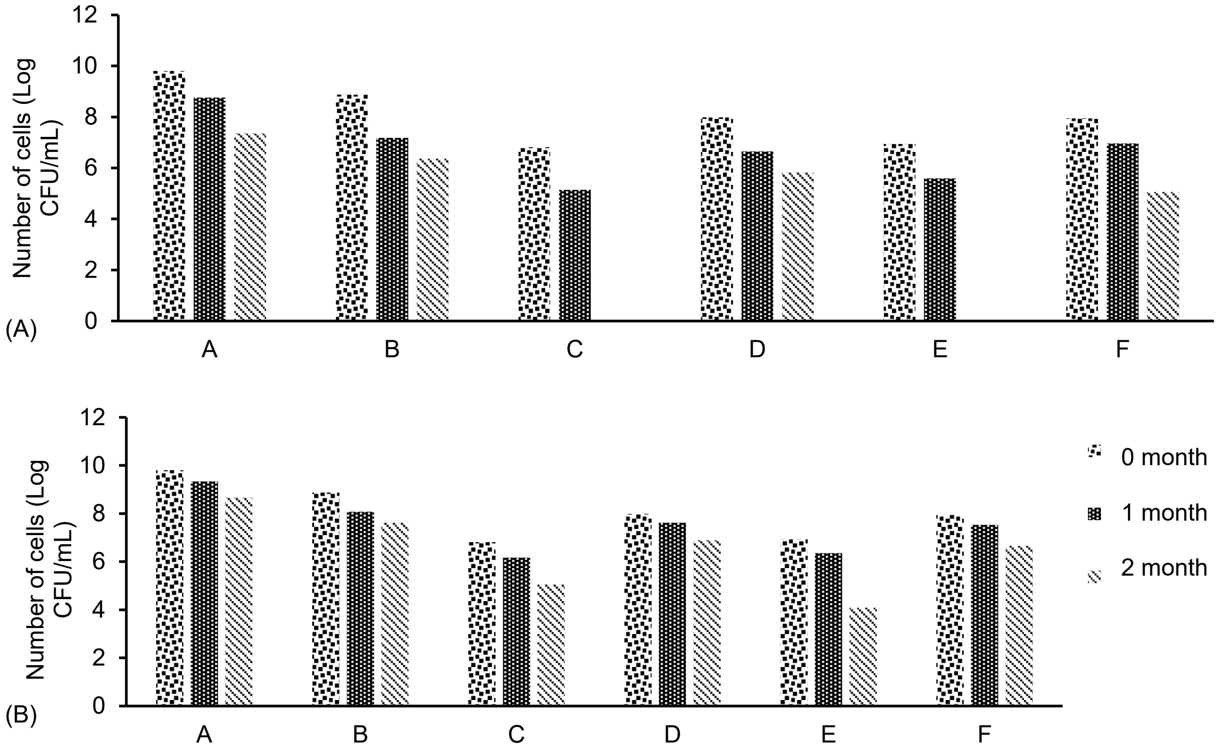

Figure 7 Carrier viability over 2 months: A. Molasses; B. Talc with microbes. (A) *Bacillus thuringiensis* SAHA 12.12; (B) *Lactobacillus plantarum* IN05; (C) *Rhizobium sp.* R1KG; (D) *Saccharomyces cerevisiae;* (E) *Streptomyces* sp. A4J; F. *Trichoderma* sp. *T2J*

formulation outperformed other materials during an 8-week period. Talc's chemical composition, which includes magnesium and silicon, supplies vital nutrients, particularly oxygen and magnesium, which promote microbial viability (Rakian *et al*. 2018). This makes talc a better carrying material than molasses. Talc has a wide pH range (pH 2–12) (Bazar *et al*. 2021), allowing microorganisms (consortia) to thrive in a variety of conditions. Microorganisms can remain stable under a wide range of environments and for long periods of time due to different pH tolerances and transporters.

CONCLUSIONS

Microbial formulation treatment during the biodrying process influences outcomes such as calorific value, water content, weight loss, temperature, and pH. The type of carrier (solid or liquid) has a major impact on efficiency; liquid treatments such as molasses and solid treatments such as talc outperformed other treatments (commercial 1, 2, and control). The microbial consortia in molasses successfully adjusted several parameters. On day 4, the molasses treatment had the greatest increase in calorific value, at 118.32% (2152 cal/g). Meanwhile, the talc carrier prolonged the microbial shelf life, with *B. thuringiensis* (BT) SAHA 12.12 viability reaching 4.6×10^{-8} CFU/mL, outperforming other microbes and carriers. In terms of time, all metrics improved significantly on day 4 compared to days 0, 7, and 21.

To improve the effectiveness of the biodrying, more research is needed. One major focus is on discovering new microbial species or microbial consortia with the potential to expedite organic material decomposition, maintain pH stability, adjust temperature, and improve water reduction efficiency. Additional research should investigate carrier materials other than molasses and talc that can improve efficiency. In addition to carrier materials, long-term microbial stability testing (over two months) is required to ensure ongoing microbial activity throughout the procedure. This study could also focus on a more extensive analysis of additional biodrying factors, such as air flow and volatile analysis (e.g., CH_4), which are required to provide in-depth insight into the link between carrier materials, bacteria, and final process results.

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