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Research Article

Agronomic and metabolite profile of *Cymbopogon citratus* utilizing the black soldier fly (*Hermetia illucens*) bioconverted compost

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ABSTRACT

The black soldier fly (BSF) maggot, a bioconversion agent for organic waste, can generate stable materials like compost. Lemongrass (Cymbopogon citratus), recognized for its numerous health benefits, is the subject of this research. The primary objective of this study was to assess the impact of applying BSF maggot bioconversion compost on the bioactive compound profile in the ethanol extract of lemongrass plants. Lemongrass cultivation was conducted in Sindangjaya Village, Cipanas, West Java, Indonesia, employing a randomized complete block design with a single factor. The single factor was the type of fertilizer, namely: control (P1), organic manure fertilizer (P2), and maggot fertilizer (P3). The introduction of BSF maggot bioconversion compost to the growth medium significantly affected the plant height (at 4, 6, 8, 10, and 12 weeks after planting) and wet weight (including stems, leaves, roots, and shoots). Ethanol extraction and identification with LCMS/MS (Liquid Chromatography–Mass Spectrometry/Mass Spectrometry) instruments revealed 48 compounds. Each treatment group (P1, P2, and P3) contained 37, 30, and 35 compounds, respectively. These compounds consisted of various groups, including amino acids, terpenoids, alkaloids, quinolines, carbohydrates, methoxyphenol, benzodioxole, diphenylmethane, and steroids.

Keywords: bioactive; BSF frass; extraction; lemongrass

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INTRODUCTION

Lemongrass (*Cymbopogon citratus*) is a herb widely used in Indonesian cuisine and traditional beverages. Empirically, lemongrass can be utilized as a remedy for headaches, coughs, stomach pain, diarrhea, fever, mosquito repellent (Nuryadin et al., 2018), rheumatism, digestive system disorders, nervous system disorders, and diabetes mellitus (Silalahi, 2020). The bioactive compounds found in lemongrass include alkaloids, saponins, tannins, flavonoids (Suradi et al., 2017), and essential oils composed of monoterpenes, such as citral (Adiguna & Santoso, 2017). These bioactive compounds indicate antibacterial, antiprotozoal, anti-inflammatory, antimicrobial, antidiabetic, anticholinesterase, molluscicidal, and antifungal activities (Silalahi, 2020).

The black soldier fly (BSF) (*Hermetia illucens*) is an insect from the Diptera order. BSF is a synanthropic polyphagous fly originating from the Neotropics; however, it has a cosmopolitan distribution that can be found in tropical regions due to human activities and trade (Soares et al., 2020). BSF maggots can thrive under extreme environmental conditions, such as in compost and organic waste containing various bacteria and fungi. Therefore, BSF maggots possess a well-developed innate immune system and are typically used to degrade organic household, restaurant, and hospital waste (Park et al., 2014).

BSF maggots have been propagated as agents for the biological conversion of organic waste due to their consumption of various decaying organic materials. Another advantage of this species of larvae is that it is not pathogenic and poses no threat to human health. In addition, the presence of BSF fly populations is also known to reduce the population of houseflies. Organic waste that BSF flies have dominated can prevent houseflies from breeding in the same location because BSF larvae are capable of releasing distinctive chemical compounds that are disliked by houseflies (Wardhana, 2016). BSF maggots can rapidly and efficiently consume large amounts of food waste (Bokau & Basuki, 2018). This efficiency is due to the cellulolytic activity present in the digestive tract of the larvae, particularly in the stomach and intestines. According to Supriyatna & Ukit (2016), the intestines of BSF maggots contain various types of bacteria with high cellulolytic capabilities, such as *Bacillus* sp., *Proteus*, and *Ruminococcus* sp. The presence of these bacteria enables BSF to break down the organic waste they consume, converting it into fats and proteins (Supriyatna & Putra, 2017).

The end product of the bioconversion process is a change in the composition of the organic materials resulting from their breakdown into simpler compounds. This bioconversion process yields stable materials such as compost (Pathiassana et al., 2020). Compost is an organic material that has undergone decomposition due to the activity of decomposing microorganisms within it. Compost is beneficial for use as a fertilizer because it is environmentally friendly and easy to produce, and raw materials are readily available. Organic matter in compost can enhance soil fertility and productivity, improve the physical properties of the soil (formation of soil aggregates or granulation), and increase soil permeability and porosity (Bachtiar & Ahmad, 2019).

The presence of macro-and micronutrients in soil can be enhanced by applying organic matter as a source of nutrients for plants, leading to increased plant production (Dewi et al., 2019). Soil nutrient content can also influence the production of secondary metabolites in plants. Secondary metabolites are bioactive compounds synthesized in cells and specific taxonomic groups at certain growth stages or under specific stress conditions related to plants' chemical content. Precursors for the biosynthesis of secondary metabolites are obtained from primary metabolic processes (Salim et al., 2016). This study aimed to analyze the impact of compost fertilizer derived from black soldier fly (BSF) maggots' bioconversion on the agronomic and metabolite profile of lemongrass ethanol extract.

MATERIALS AND METHODS

Research site

This study was conducted from February to September 2022 in Sindang Jaya Village, Cipanas, Cianjur Regency, West Java (± 1,100 meters above sea level). Sample preparation was performed at the Department of Biochemistry Laboratory, IPB University, and the Department of Agronomy and Horticulture Laboratory, IPB University. The analysis of bioactive compounds using LC-MS/MS was performed at the Forensic Laboratory Center of the Indonesian National Police, Cipambuan, Sentul, Bogor Regency.

Research materials and equipment

The primary materials utilized in this study were lemongrass seedlings, organic manure, BSF maggot bioconverted compost (BioMagg®), and absolute ethanol (Merck®). The main equipment employed in the study included a rotary evaporator (LabTech, Type: EV400), LC ACQUITY Ultra Performance Liquid Chromatography (UPLC)® H-Class System (UPLC), ACQUITY UPLC® High Strength Silica (HSS) C18 column system (1.8 µm, 2.1×100 mm) (Waters, USA), and the MS Xevo G2-S Two Generation Quadrupole time-of-flight (QTof) Mass Spectrometer system (Waters, USA).

Research design

The planting medium consisted of soil obtained from the fields in Sindangjaya Village, separated from waste and debris, and mixed with rice husk charcoal (1:1). The blended planting medium was then placed in polybags weighing 20 kg each. The polybags were arranged according to a randomized complete block design (RCBD) with a single factor. Planting was carried out in 270 polybags, comprising three treatments: control/without fertilizer (P1), organic manure application treatment (P2), and BSF maggot bioconverted compost treatment (P3), each with three replications (R1, R2, and R3) distributed across three blocks. Each block consisted of 30 individual plants. Lemongrass seedlings were cultivated for 12 weeks after planting (WAP). Lemongrass seedlings (vegetative propagation) aged 2-4 weeks were sourced from local farmers to ensure uniformity.

The lemongrass plant treatments included a control group (without fertilizer application), application of organic manure (100 g/polybag), and application of BSF maggot bioconverted compost (100 g/polybag). Each treatment was replicated three times, and each replicate was carried out once at the beginning of the planting period. Plant maintenance involves several methods, including weed control and applying natural insecticides.

The agronomic profile observation included plant height, number of shoots, and wet and dry weights of all plant parts (stem, leaves, roots, and total clumps). Harvesting was conducted when the plants reached maturity three months after planting. The harvest involved uprooting the entire plant carefully without damaging the roots.

The harvested samples were immediately sorted and thoroughly washed with clean water, dried, and ground before undergoing extraction and moisture content determination, according to Nurcholis et al. (2019) (with modification). The dry stem part of lemongrass was extracted using the maceration method with 96% ethanol as the solvent (1:10 w/v) and replicated three times (technical replication).

The analysis of bioactive compounds was conducted using Liquid Chromatography (LC)-mass spectrometry (MS) under the following conditions: the gradient elution system was performed at 0.2 mL/minute, 50, and 23 min, with a sample injection volume of 5.0 µL. The mobile phase consisted of 5 mM ammonium formate in H_2O and 0.05% formic acid in acetonitrile. Electrospray ionization (ES+) was employed as the ionization source with a mass analysis range of 50-1200 m/z.

Data analysis

Data obtained from observations of lemongrass plants were processed using Microsoft Excel. Analysis of variance was performed at a 95% confidence level or a 5% significance level using the F-test to determine the impact of fertilizer application on the measured parameters. Post hoc tests were conducted in case of significant differences among treatments, utilizing Fisher's least significant difference (LSD) test at a 5% significance level using the Minitab software. The mass values from LC-MS/MS were compared to ChemSpider and PubChem databases.

RESULTS AND DISCUSSION

Agronomic profile of lemongrass

Figures 1 and 2 illustrate the variations in lemongrass growth and shoot production over 12 weeks, highlighting the effects of different fertilizer treatments. The highest mean height of lemongrass plants was observed with the application of BSF compost fertilizer, although differences between BSF compost and organic manure were statistically insignificant. However, significant differences were noted compared to the control. Similarly, the treatment involving compost derived from black soldier fly maggots (P3) resulted in the highest mean number of shoots, though the differences were not statistically significant. In a related study, the application of BSF compost + NPK produced significantly taller tomato plants compared to treatments using conventional compost, NPK, and commercial fertilizers (Anyega et al., 2021).

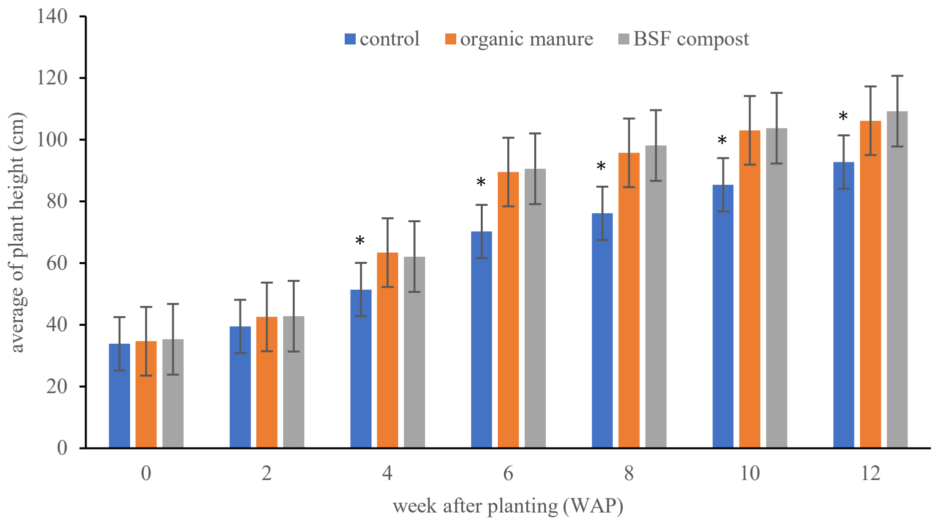

Figure 1. The mean height of lemongrass plants under three treatment conditions over a 12-week planting period. Data followed by (*) were significantly different based on the LSD test at the 5% significance level.

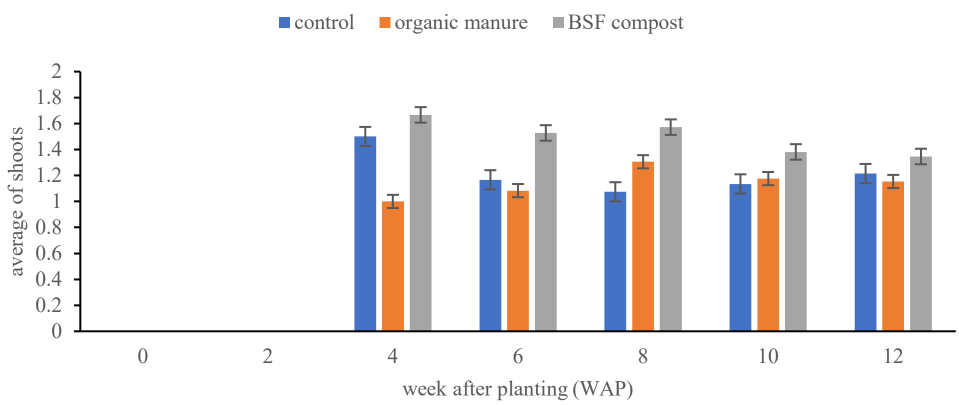

Figure 2. The average number of lemongrass shoots under three treatment conditions over a 12-week planting period. Data followed by (*) were significantly different based on the LSD test at the 5% significance level.

The effects of organic manure and BSF compost fertilizer application on the fresh weights of stems and leaves, roots, and clumps per plant indicated a significant difference, especially compared to the control group (P1) (Table 1). In contrast, no significant difference was observed in dry weight (Table 2). The differences in fertilizer types between variables P2 and P3 indicated statistically insignificant outcomes concerning the fresh weight of stems and leaves, roots, and clumps per lemongrass plant, yet significant differences were evident in variable P1. The fresh weight of the roots in variable P3 showed statistically insignificant outcomes compared to variables P1 and P2. However, the coefficient of variation (CV) values in those data showed more than 30%, which was considered as high. The main source of variation affecting the results came from the quality of the plant seeds, which were likely not uniform, thus influencing plant growth. This was an unavoidable factor in this research since the seeds were supplied by local farmers. Therefore, it is recommended to consider performing extra repetitions or optimizing the planting method to reduce variability.

According to Susanto et al. (2022), the average fresh weight in the Pak Choi plant by using additional doses of BSF frass can produce a greater weight. Field-scale testing to see the effectiveness of using BSF frass on Pak Choi (*Brassica rapa L.)* plants had better yields than using only synthetic fertilizers. The application of compost and BSF frass (BSF compost) also greatly affected the wet weight of the upper plants (canopy) and roots of Pak Choi. The highest wet weight of the plant was in the compost+liquid organic fertilizer (LOB) treatment, followed by 10% BSF frass, compost, 15% BSF frass, and 5% BSF frass, respectively (Agustiyani et al., 2021).

Table 1. Summary of the variance analysis results for the mean fresh weight of post-harvest lemongrass plants.

Treatment	Fresh weight (g)		
	SL	R	C
P1 (Control)	65.98±24.01a	27.04±11.12a	89.19±37.95a
P2 (Organic manure)	103.77±17.97b	44.85±5.85b	146.30±19.85c
P3 (BSF compost)	99.66±5.00b	38.31±8.50ab	133.98±0.71b
CV (%)	28.81	35.32	28.43
	**	*	**

Note: SL = stem and leaves; R = root; C = clump; The numbers followed by the same letter in the same column were not significantly different based on the LSD test, * = significant at $P < 0.05$; ** = significant at $P < 0.01$.

Table 2. Summary of the variance analysis results for the mean dry weight of post-harvest lemongrass plants.

Treatment	Dry weight (g)		
	SL	R	C
P1 (Control)	39.30±21.89	7.47±3.66	46.80±25.48
P2 (Organic manure)	70.98±11.94	13.63±1.13	84.61±11.72
P3 (BSF compost)	64.79±29.72	11.25±4.30	76.03±34.00
CV (%)	50.40	51.11	48.66
	ns	ns	ns

Note: SL = stem and leaves; R = root; C = clump; tn = not significant

Table 3. Composition of organic manure and BSF compost fertilizer.

Parameter	Unit	Reference value*	Organic manure	BSF compost
C-organic	%	≥ 15	36.43	42.48
C/N ratio	%	15 - 25	16.00	20.84
Water content	%	15 - 25	70.60	25.40
pH		4 - 9	7.90	6.85
Macronutrient: Nitrogen	%	-	2.33	2.04

Note: *according to the Regulation of the Ministry of Agriculture

The agronomic profile of lemongrass, as described above, was greatly influenced by the composition of fertilizer and soil (growing media) used. As shown in Table 3, the nitrogen content in organic manure and BSF maggot compost fertilizer was 2.33% and 2.04%, respectively, whereas the content of soil used in this study was 0.19% (Kjeldahl method) nitrogen (N), 149,5 ppm (P_2O_5/Bray 1 method) phosphorus (P), and 574 ppm (K_2O/Morgan method) potassium (K), respectively (data not shown). Plant growth, particularly in height, is primarily driven by leaf elongation and cell activity in meristematic tissues, which necessitates nitrogen. Nitrogen is essential for forming chlorophyll, enzyme activities, and synthesizing vital macromolecules like proteins and nucleic acids, which are crucial for plant assimilation and respiration. Studies indicate that the type of growing media also influences plant shoot numbers, secondary metabolite production, and overall quality. Key soil nutrients include nitrogen, phosphorus, and potassium, each playing distinct roles in plant growth. Phosphorus aids in cell differentiation and tissue development, especially in apical regions, while potassium is vital for osmotic regulation and enzyme activation (Nurdianti et al., 2019).

Incomplete nutrient absorption and inadequate availability in the growing medium can hinder plant growth. Soil texture, comprising sand (27%), silt (47%), and clay (26%), affects water retention and nutrient availability, essential for optimal plant growth. A good soil texture and structure, with adequate pore spaces, support nutrient uptake and plant development. Soil pH is another fertility indicator, with a neutral pH around 6.6 being ideal for nutrient availability. Adding organic materials like rice husk charcoal to growing media can enhance soil properties, including porosity, moisture retention, and nutrient availability. Fertilization further improves soil structure and promotes microorganism activity, enhancing overall soil fertility and plant growth (Nurdianti et al., 2019; Widia et al., 2022; Bui et al., 2015).

The observation variables of dry weight of stems and leaves, roots, and total shoots per lemongrass plant in the fertilizer application treatments did not exhibit significant differences. According to Gardner et al. (2008), photosynthesis influences plant dry weight. The CO_2 uptake process during photosynthesis can increase dry weight, whereas respiratory catabolism processes lead to reduced dry weight due to CO_2 release. This aligns with Kusumayadi et al. (2013), who indicated that lemongrass plants grown in the highlands (1,500-3,500 masl) experience physiological disturbances, such as suboptimal photosynthesis rates due to insufficient sunlight intensity. In contrast, lemongrass grown in the lowlands thrives better because of adequate sunlight intensity, facilitating optimal photosynthesis rates. The maximum plant height is achieved in lowland planting locations with high sunlight intensity, which is conducive to growth and development.

Metabolite profile of lemongrass

The bioactive compound content of the lemongrass ethanol extract was identified by LC-MS/MS UPLC analysis with an ES+ ionization system. The chromatograms of lemongrass stem extracts from variables P1, P2, and P3 exhibited distinct patterns, revealing the differences in the detected compound compositions in each sample. Interpreting these chromatogram data revealed 48 identified compounds in the ethanol extract of lemongrass stems (Figure 3). The identified compounds comprised amino acids, terpenoids, alkaloids, quinolines, carbohydrates, methoxyphenols, benzodioxoles, diphenylmethanes, steroids, and other compound groups, including indole, tyrosol, piperazines, benzenediol, tetrazole, fatty acyl glycosides, coumarin, methylpyridine, phenylpropane, phenol ether, piperidine, benzonitrile, cumene, naphthalene, diarylheptanoids, phenylpyridine, stilbenes, and purines (data not shown).

The distribution of the identified compounds from the ethanol extracts of lemongrass stems under different fertilizer application treatments is illustrated in a Venn diagram (Figure 4). Based on the Venn diagram, 20 compounds were identified in the ethanol extract of lemongrass stems that were intersected in all three variables. The number of uniquely identified compounds for each variable was seven (P1), four (P2), and three (P3). The intersection of the number of identified compounds for variables P1 and P2 was two; for variables P1 and P3 was eight, and for variables P2 and P3 was four. The total number of compounds generated was highest in P1, with 37 compounds, which did not differ from the other two variables, with 30 compounds in P2 and 35 in P3. The highest number of identified compounds in P1 was caused by some factors.

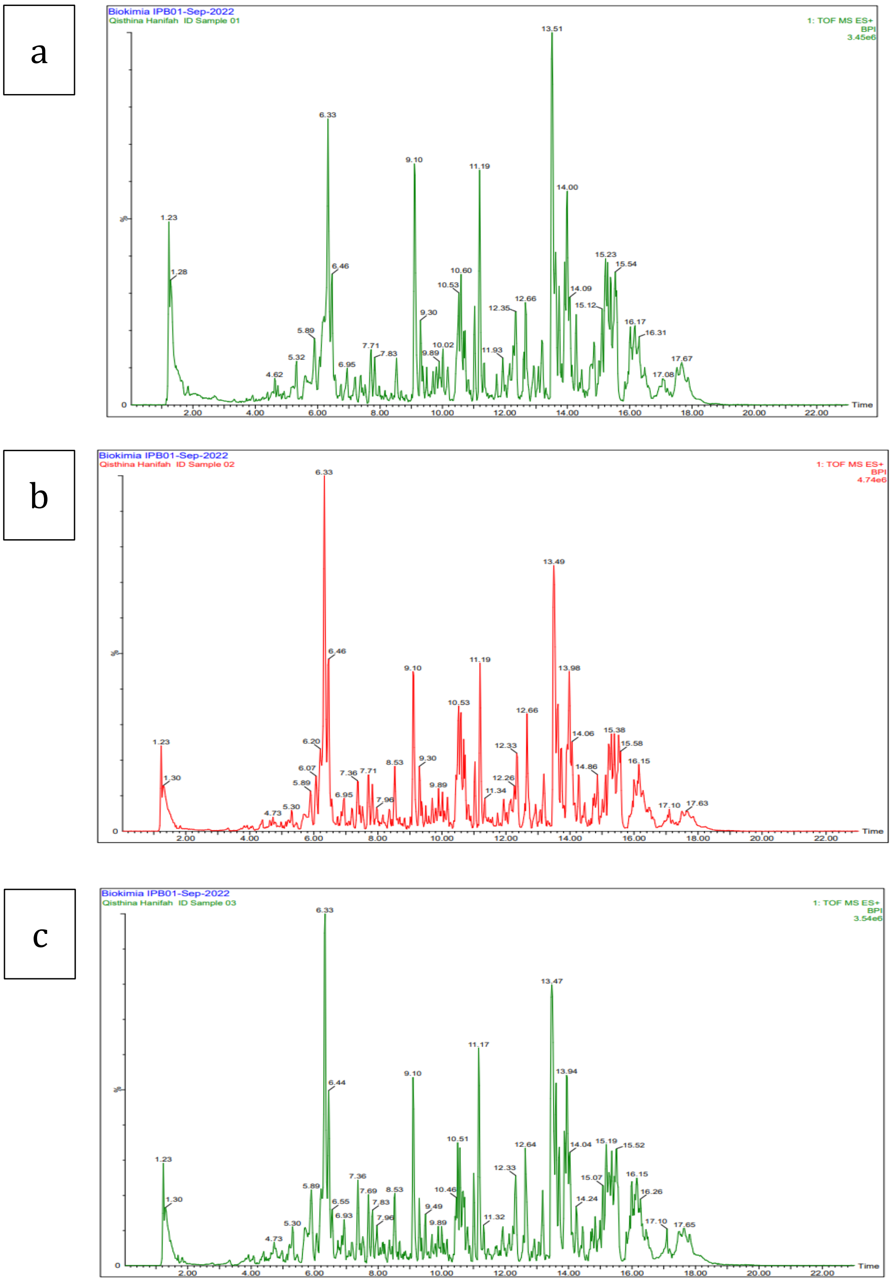

Figure 3. The LC-MS/MS spectrum of ethanol extracts from lemongrass samples: P1 (control), (b) P2 (manure fertilizer), (c) P3 (maggot BSF compost fertilizer).

Soil pH is a major, variable growth factor in natural and agricultural soils. In this study, the pH values of soil were 5.5 (data not shown) or stated as moderate acid. Organic acid metabolism is vital for plant functioning, particularly in phosphorus (P)-deficient soils, where plants modify organic acid exudation to acquire P. Soil pH significantly affects organic acid levels, influencing plant adaptation to varying pH conditions. High pH favors citrate, while low pH increases malate exudation. Acidic soils, often resulting from agricultural or industrial activities, disrupt plant growth through H^+ rhizotoxicity, nutrient deficiencies, and metal toxicity (e.g., Al, Mn, Fe) (Griebenow et al., 2022). The control plants may be better adapted to the original soil conditions, allowing them to allocate resources for the synthesis of metabolites that enhance their stress tolerance. In contrast, fertilized plants may experience physiological stress due to nutrient excess, leading to a reduction in metabolite production (Salam et al., 2023).

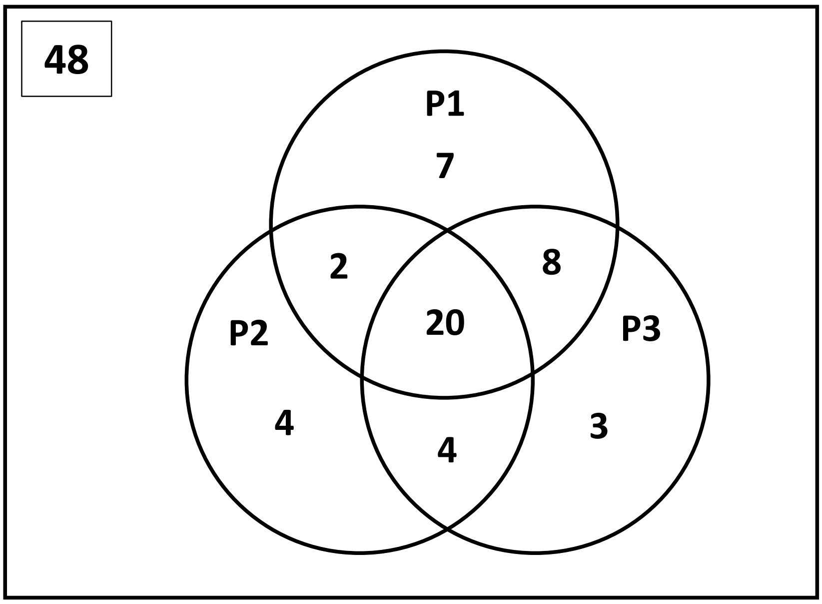

Figure 4. The distribution of compounds varied among the different fertilizer application treatments during the growing period (P1, P2, P3).

Table 4 The metabolite profile of ethanol extract from lemongrass stems based on the highest abundance utilizing LC-MS/MS instrumentation.

No	*Parent ion* $[M+H]^+$ (m/z)	Compound	Group	Retention Time (t_R)	Abundance (%)
		Control (P1)			
1	118.0868 $[C_5H_{12}NO_2]^+$	L-Valine	Amino acid	1.28	10.02
2	418.3476 $[C_{30}H_{44}N]^+$	5-(4-Ethylcyclohexyl)-2-[4-(4-pentyl cyclohexyl)phenyl]pyridine	Phenazopyridine	13.54	11.40
3	202.1596 $[C_{14}H_{20}N]^+$	2,4-Diethyl-2-methyl-1,2-dihydroquinoline	Quinoline	6.33	12.00
4	149.0965 $[C_{10}H_{13}O]^+$	Cuminaldehyde	Monoterpenoid	6.33	12.00
5	524.4226 $[C_{38}H_{54}N]^+$	3-[5-(Benzyloxy)-2-pyridinyl]-N-octadecylalaninamide	Amino acid	15.29	13.02
6	476.4224 $[C_{34}H_{54}N]^+$	N-Benzyl-3,5-cyclocholestan-6-amine	*Cholastane steroids*	15.29	13.02
7	420.3600 $[C_{30}H_{46}N]^+$	6aR,6bS,8aR,9R,11aS,11bS)-6a,8a-Dimethyl-9-[(2R)-6-methyl-2-heptanyl]-6,6a,6b,7,8,8a,9,10,11,11a,11b,12-dodecahydro-5H-cyclopenta[5,6]naphtho[2,1-f]quinoline	*Cholastane steroids*	15.29	13.02

		Organic manure (P2)			
1	524.4226 $[C_{38}H_{54}N]^+$	3-[5-(Benzyloxy)-2-pyridinyl]-N-octadecylalaninamide	Amino acid	15.29	11.34
2	47.,4224 $[C_{34}H_{54}N]^+$	N-Benzyl-3,5-cyclocholestan-6-amine	*Cholastane steroids*	15.29	11.34
3	420.3600 $[C_{30}H_{46}N]^+$	6aR,6bS,8aR,9R,11aS,11bS)-6a,8a-Dimethyl-9-[(2R)-6-methyl-2-heptanyl]-6,6a,6b,7,8,8a,9,10,11,11a,11b,12-dodecahydro-5H-cyclopenta[5,6]naphtho[2,1-f]quinoline	*Cholastane steroids*	15.29	11.34
4	418.3476 $[C_{30}H_{44}N]^+$	5-(4-Ethylcyclohexyl)-2-[4-(4-pentyl cyclohexyl)phenyl]pyridine	Phenylpyridine	13.51	12.66
5	149.0965 $[C_{10}H_{13}O]^+$	Cuminaldehyde	Monoterpenoid	6.33	17.83
		BSF compost (P3)			
1	524.4226 $[C_{38}H_{54}N]^+$	3-[5-(Benzyloxy)-2-pyridinyl]-N-octadecylalaninamide	Amino acid	15.27	12.55
2	476.4224 $[C_{34}H_{54}N]^+$	N-Benzyl-3,5-cyclocholestan-6-amine	*Cholastane steroids*	15.27	12.55
3	418.3476 $[C_{30}H_{44}N]^+$	5-(4-Ethylcyclohexyl)-2-[4-(4-pentyl cyclohexyl)phenyl]pyridine	Phenylpyridine	13.49	12.97
4	149.0965 $[C_{10}H_{13}O]^+$	Cuminaldehyde	Monoterpenoid	6.33	13.13
5	202.1596 $[C_{14}H_{20}N]^+$	2,4-Diethyl-2-methyl-1,2-dihydroquinoline	Quinoline	6.33	13.13

The number of compounds with the highest abundance identified in variable P1 was seven, while five were identified in variables P2 and P3 (Table 4). These compounds belong to amino acids, phenylpyridine, quinoline, monoterpenoids, and cholestane steroids. Some of the identified compounds, such as 3-[5-(benzyloxy)-2-pyridinyl]-N-octadecylalaninamide, N-Benzyl-3,5-cyclocholestan-6-amine, and 6aR,6bS,8aR,9R,11aS, 11bS)-6a,8a-Dimethyl-9-[(2R)-6-methyl-2-heptanyl]-6,6a,6b,7,8,8a,9,10,11,11a,11b,12-dodecahydro-5H-cyclopenta[5,6]naphtho[2,1-f]quinoline, had the highest abundance (13.02%) at a retention time of 15.29. The compound identified in variable P2 with the highest abundance (17.83% at a retention time of 6.33) was cumin aldehyde, which was also identified as having the highest abundance in variable P3. Another compound identified in P3, with an abundance of 13.13% at a retention time of 6.33, was 2,4-Diethyl-2-methyl-1,2-dihydroquinoline.

Amino acids are classified as primary metabolites that serve as fundamental components for biosynthetic processes in plants and are derived from nitrogen assimilation. In the subsequent processes, they are required to form enzymes and proteins. The synthesis of specific amino acids into proteins involves gene expression, transcription, and translation. These proteins form the basis of protoplasm and largely contribute to enzyme production. Enzymes are then integrated into the meristematic tissues of plants, promoting plant growth (Krisdianto et al., 2020). The compounds identified include alanine, a nonpolar amino acid with a glucogenic precursor role, which transports nitrogen from the surface tissues for nitrogen excretion (Lalopua et al., 2022). Alanine is a non-essential amino acid that can be synthesized within the body (Putra et al., 2020).

The most abundant amino acid identified in P1 was l-valine (m/z 118.0868), with 10.02% at a retention time of 1.28. Valine is classified as essential, neutral, nonpolar, and aliphatic (Rahayu et al., 2014). According to Lalopua et al. (2022), valine is a branchedchain amino acid that serves as a glucose precursor. This amino acid is crucial for the growth and maintenance of muscle tissue, facilitating muscle coordination, aiding tissue repair, and maintaining the nitrogen balance in the body. A deficiency in valine can lead to the loss of muscle coordination, making the body highly sensitive to pain and temperature changes.

In the P1 variable, along with valine, other compounds identified included cholestane steroids, such as n-benzyl-3,5-cyclocholestan-6-amine (m/z 476.4224) and (6aR,6bS,8aR,9R,11aS,11bS)-6a,8a-dimethyl-9-[(2R)-6-methyl-2-heptanyl]-6,6a,6b,7, 8,8a,9,10,11,11a,11b,12-dodecahydro-5H-cyclopenta[5,6]naphtho[2,1-f] quinoline (m/z 420.3600). Steroids (triterpenoids, lipid derivatives) are compounds derived from the hydrocarbon 1,2-cyclopentanoperhydrophenanthrene, which consists of a four-ring integrated carbon skeleton with double bonds in their aliphatic rings. Steroids typically exist in plants as sterols (Suryelita et al., 2017; Nasrudin et al., 2017; Latief et al., 2022). Sterols modulate the properties of plant phospholipid membranes and are involved in the regulation and balance of metabolic processes related to cell membranes. They also serve as substrates for synthesizing secondary metabolites such as glycoalkaloids and saponins (Tahya et al., 2020). Liniawati et al. (2019) noted that steroids exhibit significant pharmacological activities, including antiviral, antibacterial, and anticancer properties, as well as inhibition of cholesterol synthesis.

Lemongrass is known for its high essential oil (EO) content. Essential oils are classified into four groups: aliphatic compounds, terpenes and their derivatives, benzene derivatives, and miscellaneous compounds (Silalahi, 2020). According to Sufyan et al. (2018), the dominant compounds in essential oils often belong to terpenoids and their derivative groups, particularly monoterpenoids (C10) and sesquiterpenoids (C15). Monoterpenoids typically have a main frame of ten carbon atoms and are highly volatile and thermolabile. Some of the identified monoterpenoids included 2,2,4,4-tetramethyl-6-(1-oxopropyl)-1,3,5-cyclohexanetrione (m/z 239.1284), cuminaldehyde (m/z 149.0965), thymol (m/z 151.1122), and fencamfamine (m/z 216.1749). Cuminaldehyde (m/z 149.0965) was the most abundant compound in the P2 variable, with a 17.83% presence at a retention time of 6.33. It was also prominent in the P3 variable, with a 13.13% presence at the same retention time.

Monoterpenoids are secondary metabolites produced during specific growth stages or under certain conditions. Secondary metabolites in plants play a role in attracting other organisms, defending against pathogens, protecting and adapting to environmental stress, shielding from UV radiation, acting as growth regulators, and competing with other plants (allelopathy) (Dalimunthe & Rachmawan, 2017). Heliawati (2018) observed that monoterpenoids exhibit strong aromatic properties that protect plants from predators (herbivores) and undesirable microbial infections.

Another compound with the highest abundance at the same retention time identified in P3 was 2,4-diethyl-2-methyl-1,2-dihydroquinoline (m/z 202.1596), classified as quinolines. Quinolines are alkaloid compounds featuring a nitrogenous heterocyclic ring structure with a double-ring system fused to a pyridine ring and an adjacent benzene ring. These compounds exhibit antiprotozoal, antioxidant, and insecticidal activities, protecting plants from insects. Quinolines demonstrate various activities, including antimalarial, antimicrobial, anticonvulsant, anti-inflammatory, and anticancer properties. Notable antimalarial quinoline compounds include chloroquine, quinine, amodiaquine, primaquine, and hydroxychloroquine (Deswita et al., 2021; Pratama, 2016; Alviani & Purwani, 2021). The other quinoline compounds identified were 2,4-diethyl-2-methyl-1,2-dihydroquinoline (m/z 202.1596) and 2-octadecyl-1H-benzo[de]isoquinoline-1,3(2H)-dione (m/z 450.3383), which are categorized as isoquinolines.

Among the bioactive compounds found in lemongrass is an alkaloid (Sufyan et al., 2018). Alkaloids, characterized by having at least one nitrogen atom in their structure and being basic, play a role in replacing mineral bases to maintain plant ion balance (Siahaan and Sianipar, 2017). In plants, alkaloids serve as storage compounds, supplying nitrogen and other essential elements and acting as growth regulators and toxins that protect against insects and herbivores (Ningrum et al., 2016). According to Amna and Halimatussakdiah (2016), alkaloids can be classified into 14 groups: pyrrolidine, piperidine, quinoline, isoquinoline, pyridine, pyrrolizidine, indole, indolizidine, imidazole, quinolizidine, quinazoline, purine, tropane, and phenethylamine.

CONCLUSIONS

The application of compost derived from the bioconversion of black soldier fly (BSF) larvae influenced the growth of plant height and fresh weight (including stems, leaves, roots, and total clump weight) of lemongrass. Different fertilizer application treatments also affected the composition of bioactive compounds in the plants. Analysis of 96% ethanol extracts from lemongrass using LC-MS/MS revealed 48 compounds identified, with 37 compounds in the control (P1 treatment), 30 in the organic manure (P2 treatment), and 35 in the BSF compost (P3 treatment). These compounds belong to various classes, including amino acids, terpenoids, alkaloids, quinolines, carbohydrates, methoxyphenols, benzodioxoles, diphenylmethanes, steroids, and other compounds.

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