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Allelopathic Sugarcane Leaf Litter and Its Potential Use as Soil Mulching for Weed Management in Sugarcane Cultivation

Ramida Krumsri[1,2] | Thanatsan Poonpaiboonpipat[2,3] | Ukrit Samaksaman[4] | Nitra Nuengchamnong[5] | Chamroon Laosinwattana[6]

[1]Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand | [2]Center of Knowledge and Technology for Cane and Sugar, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand | [3]Department of Agricultural Sciences, Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok, Thailand | [4]Department of Natural Resources and Environment, Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok, Thailand | [5]Science Laboratory Centre, Faculty of Science, Naresuan University, Phitsanulok, Thailand | [6]School of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

Correspondence: Thanatsan Poonpaiboonpipat (thanatchasanhap@nu.ac.th)

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ABSTRACT

Sugarcane leaves, both green and fallen, left after harvest, are agricultural residues containing compounds that inhibit weed germination and seedling growth. This study evaluated their allelopathic effects and mulching potential for weed control. Experimental results using seeds of *Ipomoea pes-tigridis* and *Dactyloctenium aegyptium* suggest that the aqueous extract from sugarcane leaf litter reduces seedling growth. When compared to mulch made from extracted sugarcane leaves, mulch made from nonextracted leaves considerably decreased weed emergence and biomass in the pot experiment. It appears that the weed suppression was not just due to the mulching but also to the allelochemicals that were still present in the unprocessed leaves. Weed germination and seedling rates appeared to be lowered, possibly due to the presence of allelochemicals, especially phenolic compounds. Under sugarcane production conditions, field experiments were conducted to evaluate the effects of soil mulching using sugarcane leaf litter applied at rates of 4, 8 and 12 t ha^{-1}. As a soil mulch, sugarcane leaf litter resulted in reduced weed density and biomass compared to typical agricultural practices, with weed control efficacy improving at higher rates of application. For instance, mulching rates of 8 and 12 t ha^{-1} resulted in respective sugarcane outputs of 104.2 and 111.6 t ha^{-1}, whereas mechanical, manual and no weeding respectively yielded 81.25, 126.88 and 31.25 t ha^{-1}. Based on these findings, the utilisation of sugarcane leaf litter as a soil mulch can reduce weed seed germination and growth, and can therefore be considered as an agroecological practice to be included in sustainable weed management strategies.

1 | Introduction

Sugarcane (*Saccharum officinarum* L.) is a prominent agricultural commodity in Thailand, which ranks second globally in terms of sugar exports, trailing only behind Brazil. In the year 2021, Thailand's cultivated land dedicated to cane production amounted to approximately 1.46 million hectares and the total sugarcane yield was 44.3 million tons, with 66.29 kg ton^{-1} of sugar content (Food and Agriculture Organization of the United Nations (FAO) 2025).

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The presence of weeds poses a significant challenge to sugarcane cultivation, as weeds can impede cane growth and development by competing for essential resources like nutrients, water and sunlight. This competition can ultimately lead to decreases in both the amount and quality of the harvested sugarcane stalks. Losses due to unregulated proliferation of weeds are potentially quite substantial, with numerous studies having documented yield reductions, spanning up to 97% in Nigeria, 70%–84% in Ethiopia (Yirefu et al. 2013) and 42%–78% in the United States (Zimdhal 1980; Farooq et al. 2014). In Thailand, it has been shown that agricultural output may experience a reduction of 50%–70% due to infestation throughout the duration of the crop season (Aekrathok et al. 2021). Implementation of efficient weed management strategies is crucial to minimising these losses and maximising sugarcane harvests.

Agricultural residues inhibit weed growth not only through obstructing sunlight but also by allelopathic action resulting from the release of chemicals. The phenomenon known as allelopathy involves release of chemicals from plants through both direct and indirect means. In mungbean crops, application of sorghum residue as a soil mulch at a rate of 6 t ha^{-1} in combination with sorghum water extract was found to significantly reduce weed density by 65% and weed dry weight by 72%. Simultaneously, the treatment resulted in a 37% increase in yield and improvement of soil quality through increasing soil levels of the enzymes alkaline phosphatase and dehydrogenase (Ullah et al. 2022). Several compounds discharged from sorghum residue, such as dhurrin, p-hydroxybenzaldehyde, sorgoleone, vanillic acid, p-hydroxybenzoic acid, p-hydroxybenzaldehyde, p-coumaric acid and ferulic acid, have been shown to exhibit a diverse range of biological activities, including allelopathy (Won et al. 2013; Ullah et al. 2022). Similarly, soil surface mulching with allelopathic *Parthenium hysterophorus* at the rate of 1–5 t ha^{-1} reduced weed density and weed biomass, achieving a weed control efficiency of 21%–56%. Mulching of soybeans at rates of 1 and 2.5 t ha^{-1} increased shoot dry weight and biological yield when compared with manual weed control (Khalid et al. 2018). Allelochemicals found in *P. hysterophorus* include the sesquiterpene lactone parthenin (Belz 2008); phenolic compounds, viz. gallic, caffeic, 4-hydroxy-3-methoxy benzoic, p-coumaric and m-coumaric acids and ferulic, vanillic and syringic acids (Safdar et al. 2014).

When sugarcane is harvested, the plants possess both green leaves and dry mature leaves. The sugarcane harvester sucks the plants up and ejects the leaves, termed sugarcane leaf litter. This agricultural waste is commonly utilised as a primary energy source for electricity generation in power plants; however, cane leaves contain a variety of bioactive substances, including allelochemicals. Singh et al. (2003) identified 2,4-dihydroxy-1, 4-benzoxazin-3-one and benzoxazolin-2-one, while Sampietro et al. (2007) detected ferulic and syringic acids. Gomes et al. (2016) likewise discovered palmitic, linoleic, stearic and 8,11,14-docosatrienoic fatty acids in the dichloromethane fraction of sugarcane leaf extract. These compounds have been reported to inhibit germination and growth of bioassay seeds (Devi and Prasad 1992; Macías et al. 2005; Zhou et al. 2014; Huang et al. 2018). This inhibitory activity is similar to that of an herbicide, and has the potential to be developed into a bioherbicide or utilised in management of weed growth in cane production through the use of litter. Hence, the current investigation was undertaken to assess the allelopathic impact of sugarcane leaf litter on the germination and growth of two weed species, as well as to evaluate the efficacy of soil surface mulch in suppressing weeds during sugarcane cultivation.

2 | Materials and Methods

2.1 | Sugarcane Residue Sampling

The sugarcane variety Khon Kaen 3 was cultivated using ratooning at the agricultural field of Naresuan University, located in Phitsanulok, Thailand, in November 2019. Harvesting took place in December 2020. Pesticide application was prohibited within a period of 6 months prior to the commencement of harvesting. A part of the harvested sugarcane leaves was utilised to extract essential substances for laboratory and greenhouse experiments, while the residual section was desiccated in the shade for field study. The first part, leaves were categorised into two groups: green leaves and fallen leaves. After collection, both types of leaves were subjected to a cleaning and drying process using a hot air oven set at a temperature of 40°C for a duration of 96 h. The dried leaves were then ground to powder using an electric grinder and subsequently stored in a cool and dark environment at a temperature of 14°C until ready for utilisation.

2.2 | Bioassay Weed Species

Dactyloctenium aegyptium (L.) Willd. and *Ipomoea pes-tigridis* L. were used as the weed species in bioassays because they are major weeds observed in the experimental field. *D. aegyptium* is an annual grass generally distributed and observed in crop production areas throughout the world. The seeds are kidney-shaped or round, brown and about 1.1–1.2 mm long. *I. pes-tigridis* is an annual broadleaf species with climbing characteristics. The seeds are oval-shaped capsules, 2 mm wide and about 4 mm long, with scattered grey hairs.

2.3 | Allelopathic Activity of Crude Aqueous Extract Against Germination and Seedling Growth of Bioassay Species

The allelopathic activity of green and fallen leaf powders was assessed in a laboratory setting to determine their effect on the germination and seedling growth of bioassay weeds. A quantity of 100 g of leaf powder was extracted using 1 L of deionised (DI) water, maintained at a temperature of 7°C for a duration of 72 h. The extracts were filtered using No. 1 filter paper, then subjected to evaporation using a rotary evaporator (KNF RC 900) at a temperature of 45°C, vacuum pressure of 0.85 bar, and rotation speed of 100 rpm until complete dryness was achieved, resulting in the production of a crude extract. The crude samples were stored under controlled conditions of 7°C in a dark environment prior to their utilisation.

A factorial design with a $2 \times 4 + 1$ arrangement was applied in a completely randomised design, with four replications. The first factor encompassed extract source (green or fallen leaves), and the second factor comprised four different concentrations

of crude extract: 12.5, 25, 50 and 100 g L^{-1}; additionally, a control group used DI water. Dried crude extracts were diluted with DI water to obtain the required concentrations. To conduct the experiment, a 5 mL aliquot of the appropriate treatment was introduced into a 9 cm petri dish lined with a No. 1 filter paper. To break dormancy, seeds of *D. aegyptium* and *I. pes-tigridis* were incubated in a dark environment at a temperature of 25°C for a duration of 24–48 h. A total of 20 germinating seeds of *D. aegyptium* or *I. pes-tigridis* were then carefully positioned on the filter paper. The petri dishes were securely covered, sealed using Parafilm and subsequently placed in a growth chamber set to provide a temperature of 32°C/25°C and a simulated 12/12 h day/night cycle with an approximate light intensity of 300 μmol m^{-2} s^{-1}. Germination, shoot length, and root length were measured after a period of 7 days and the proportion of germinated seeds was calculated.

2.4 | Allelopathic Effect of Litter Used as Soil Mulching on Emergence and Growth of Bioassay Species

The objective of this experiment was to examine the effects of mulching with extracted and nonextracted sugarcane leaf litter and validate weed control resulting from the allelopathic effect of the litter, as described in the research of Laosinwattana et al. (2007) and Krumsri et al. (2020). Nonextracted litter was stored under dark and dry conditions as described above, and otherwise untreated. Extracted litter was subjected to three extractions using 95% methanol to eliminate metabolites present in the plant cells, then dried in a hot air oven maintained at a temperature of 60°C.

A soil sample was obtained from a depth of 30 cm in the nearby experimental field, the qualities of which are outlined in Table 1. To eradicate weed seeds, the soil was treated with boiling water at a temperature of 100°C for 30 min. To eliminate contamination from weed seeds in the soil, boiling water was applied before sowing. This heat treatment helped reduce seed bank interference, ensuring clearer allelopathic results (Hall et al. 2024). Subsequently, the material was subjected to solar drying and subsequently pulverised into diminutive fragments measuring less than 1 cm in size.

The experiment employed a 2 × 3 + 1 factorial system in a completely randomised design, with four replications. One of the primary factors under consideration was the presence of nonextracted or extracted litters. The second was the rate of soil mulching, specifically 2, 4 and 6 t ha^{-1}, alongside a control group with no mulch applied. A quantity of dry soil weighing eight kilos was carefully deposited in flat trays of 20 × 40 cm. A total of one hundred seeds of *D. aegyptium* or 50 seeds of *I. pes-tigridis* were sowed in the designated area, and treated or nontreated litter was applied as mulch on the soil. The trays were positioned within the greenhouse, where they were exposed to temperatures ranging from 26°C to 36°C, relative humidity levels between 80% and 100%, and a light intensity of 100 to 150 μmol per square metre per second, all maintained under a 12-h photoperiod. The tray was uniformly supplied with 1 L tap water once a day to protect against water leaching from the trays. Emergence of weeds was recorded at intervals of 7, 14, 21 and 28 days following the seeding process. Weed samples were obtained 35 days after planting, dried at a temperature of 60°C using a hot air oven, and the dry weight determined.

TABLE 1 | Physical and chemical properties of soil at depths of 0–15 and 15–30 cm.

	Soil depth (cm)	
Properties	**0–15**	**15–30**
Sand (%)	88.70	87.30
Silt (%)	9.84	10.08
Clay (%)	1.46	2.62
Texture class	Sandy-silt	Sandy-silt
pH	4.79	4.70
EC (dS m^{-1})	0.020	0.019
CEC (cmol kg^{-1})	5.94	5.74
OM (%)	1.12	0.99
Total *N* (%)	0.056	0.053
Available P (mg kg^{-1})	2.95	1.74
Exchange K (mg kg^{-1})	30.56	18.95
Soil bulk density (mg m^{-3})	0.89	0.83

2.5 | LC-ESI-QTOF-MS/MS Analysis

The experimental results indicated identical allelopathic effects from extracts of both green and fallen sugarcane leaves in suppressing the germination and growth of the test weeds. Consequently, extract from abscised leaves was used for further investigation of sugarcane leaf components. The leaf litter extract was prepared following the same method as in the residue sampling section. A liquid sample at a concentration of 20 mg/mL was filtered through a 0.22 um nylon membrane syringe filter before being submitted to the system for LC-ESI-QTOF-MS/MS analysis. The injection volume was 10 μL (Agilent 1260 Infinity Series High Performance Liquid Chromatography System, Agilent, Waldbronn, Germany). Separation was performed with the Luna C18 column, size 4.6 × 150 mm, 5 μm (Phenomenex, USA), at a flow rate of 500 μL/min with the control temperature at 35°C. The mobile phase A was water type I (Millipore, USA), and phase B was acetonitrile. Both phases contained 0.1% (v/v) formic acid. The gradient elution mode started with 5% solvent B and proceeded to 95% B in a linear gradient within 30 min; the final ratio was held for 10 min, after which a 5 min postrun was performed for column equilibration. The operating parameters for MS detection (Agilent 6540 Q-TOF-MS spectrometre, Agilent Technologies, Singapore) were as follows: drying gas (N_2) flow rate 10.0 L/min; temperature 350°C; nebuliser pressure 30 psig; capillary 3500 V; skimmer 65 V; octapole RFV 750 V and fragmentor voltage 250 V in negative mode and 100 V in positive mode. The mass range was set at *m/z* 100–1000 amu with a 250 ms/spectrum. The nontarget MS/MS mode was set

at three collision energies of 10, 20 and 40 V using high-purity nitrogen gas (99.99%) as the collision gas. Analysis of each sample was performed both in positive and negative ionisation modes, including the nontargeted MS/MS mode.

Data acquisition and analysis were respectively controlled with the MassHunter Data Acquisition Software, Version B.05.01 and MassHunter Qualitative Analysis Software, B06.0 (Agilent Technologies, USA). The m/z and fragmentation patterns of each compound were identified with reference to metabolite databases such as the METLIN PCD/PCDL database (Agilent Technologies, USA) and public databases such as the Human Metabolome Database (http://www.hmdb.ca) and the Lipid Maps Database (https://www.lipidmaps.org).

2.6 | Field Study

The field experiment was carried out on a farmer's field in Phitsanulok province, located in the lower northern region of Thailand at coordinates 16°35′49.3″N 100°24′29.1″E. The total rainfall recorded during the trial period was 1009 mm, with a uniform distribution seen from January to December 2021. The air temperature reached a peak of 36°C during the months of April and May, and dropped to a minimum of 19°C in January and December. Across the experimental period, the mean maximum temperature was 31°C and the mean minimum 24.5°C. (See Figure S1). The soil composition is principally sandy-silt. Soil samples were obtained from two depths: 0–15 cm and 15–30 cm, and analysed to determine their physical and chemical characteristics, described in Table 1. Before land preparation, a preliminary weed survey was conducted, revealing a community dominated by *D. aegyptium* (L.) Willd., *Digitaria ciliaris* (Retz.) Koel., *Brachiaria reptans* (Linn.) Gard., *I. pes-tigridis* L., *Tribulus terrestris* L., and *Cyperus rotundus* L. These species were also the most prevalent throughout the experimental period.

The experiment was conducted using a randomised complete block design with four replications. The trial consisted of six treatments, namely applying sugarcane leaf litter at rates of 4, 8 and 12 t ha^{-1}; hand hoeing or the use of farm machinery for mechanical weeding and a control group with no weed management. The unit plot was measured to be 10.8 m by 14 m, resulting in a total area of 151.2 square metres, sufficient to accommodate six rows within each unit.

The experiment started in early December 2020. The field first received two rounds of preparation with a 24-disc harrow, followed by subsoiling and motivation, all of which were carried out using a 105-hp tractor. On 10 December 2020, a total of 12 500 three-budded setts were planted in the field, with a row spacing of 1.8 m. Compost fertiliser was applied concurrently with sett planting at a rate of 31.25 t ha^{-1}. Application of litter treatments occurred 1 week following planting. The act of hand hoeing was performed by labourers on a monthly basis after planting for a total of 10 times. For mechanical weed, a cutaway cultivator was employed during the first month after planting (MAP), followed by an S-type spring type at the 2 and 4 MAP stages. Subsequently, a rotary tiller, operated by a smaller 24-hp tractor, was utilised at 6 MAP on the spaces between sugarcane rows.

The present study focuses on gathering data pertaining to the efficacy of weed management methods, as well as the growth and yield of sugarcane. Prior to hoeing and mechanical weeding, the density and dry biomass of weed species were evaluated in quadrants on a monthly basis over the initial 6 months. In each plot, four quadrats measuring 0.5 × 0.5 m were arranged in rows 2 and 5. Two quadrats were situated directly above the sugarcane rows, and the other two were located in the adjacent inter-row area, characterised by a row spacing of 1.8 m. This design facilitates the measurement of both weed density and biomass throughout the entire row and interrow area. The effects on sugarcane were evaluated in terms of plant height at 4–10 MAP. The final output was determined by manually harvesting two central rows in December 2021, each 8 m in length, resulting in a total harvested area of 28.8 m^{-2}. After harvest, data pertaining to agronomic traits and cane quality were collected and analysed. For each plot, six stalks of sugarcane were randomly selected and the commercial cane sugar (CCS) was determined using the following formula (Equation (1)) (Albertson and Grof 2004).

$$\mathrm{CCS} = \frac{3P}{2}\left(1 - \frac{F+5}{100}\right) - \frac{B}{2}\left(1 - \frac{F+3}{100}\right) \quad (1)$$

P = pol at 20°C, B = brix at 20°C and F = fibre percent.

2.7 | Data Analysis

Data were checked for normality using the Kolmogorov–Smirnov test (See Figures S2, S3, S4) and for homogeneity of variance using Levene's test prior to analysis of variance (ANOVA). All statistical analyses were performed using SPSS software (V.29). The ANOVA was applied for statistical analysis of the data. Whenever the ANOVA yielded statistically significant effects ($p < 0.05$), a post hoc pairwise comparison of means was conducted using Tukey's studentised range test.

3 | Results

3.1 | Effect of Aqueous Extract on Germination and Seedling Growth of *D. aegyptium* and *I. pes-tigridis*

The concentration of the extract significantly influenced the germination, shoot length and root length of both *D. aegyptium* and *I. pes-tigridis* ($p < 0.05$). Nonetheless, the extract type (green vs. fallen leaf) and its combination with concentration were not statistically significant (Table 2). This indicates a uniform allelopathic effect from both leaf sources. The inhibitory impact was dose-dependent, with maximal suppression at 100 g L^{-1}, where germination and growth of both weed species were completely prevented (0% of control). At lower concentrations (12.5–25.0 g L^{-1}), moderate inhibition was noted, with germination rates between 35% and 82%, and analogous trends in shoot and root growth. In the comparison of the two weed species, *D. aegyptium* and *I. pes-tigridis* exhibited analogous responses to escalating extract concentrations, suggesting a wide-ranging allelopathic potential of sugarcane leaf extract. Nonetheless, *I. pes-tigridis* demonstrated somewhat

TABLE 2 | Effect of crude aqueous extracts of green and fallen sugarcane leaves on germination, shoot length and root length of *Dactyloctenium aegyptium* and *Ipomoea pes-tigridis*.

	D. aegyptium			*I. pes-tigridis*		
	Germination	**Shoot length**	**Root length**	**Germination**	**Shoot length**	**Root length**
Treatments	**% of control**					
Extract sources						
Green leaf extract	25.0	22.7	20.0	50.6	47.6	36.2
Fallen leaf extract	22.4	27.3	20.0	50.0	49.1	35.4
F-test[1/]	ns	ns	ns	ns	ns	ns
Concentration						
12.5 g L^{-1}	46.3d	49.9b	50.0c	82.5c	91.3d	67.2b
25.0 g L^{-1}	35.0c	40.9b	20.0b	81.3c	74.1c	64.9b
50.0 g L^{-1}	13.5b	9.3a	10.0ab	37.5b	28.1b	11.2a
100.0 g L^{-1}	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
F test	*	*	*	*	*	*
Interaction Extract sources × concentrations *F* test	ns	ns	ns	ns	ns	ns
HSD	11.2	10.4	12.0	22.5	15.4	12.6

Note: F test: ns = no-significant; * = significant at $p < 0.05$; Means followed by the same letter in a column do not differ from each other by Tukey's test (HSD was calculated at a significance level of $p < 0.05$).

greater sensitivity at intermediate dosages, especially for root inhibition, indicating potential variations in absorption or physiological response.

3.2 | Allelopathic Effect of Sugarcane Leaf Litter as Soil Mulching on Emergence and Growth of *D. aegyptium* and *I. pes-tigridis*

Soil mulching with sugarcane leaf litter markedly inhibited the emergence and biomass growth of both *D. aegyptium* and *I. pes-tigridis*, exhibiting distinct variations according to extract type and mulch application rate. Throughout all time periods, non-extracted litter mulch demonstrated greater weed suppression relative to extracted litter, suggesting that both physical mulch effects and allelopathic chemicals played a role in the inhibitory activity.

For *D. aegyptium*, greater mulch rates resulted in a significant reduction in emergence and dry biomass, with the 8 t ha^{-1} rate nearly eradicating emergence by 7 DAS (0%) while preserving suppression throughout 28 DAS (7.5% of control). On the other hand, *I. pes-tigridis* exhibited a more progressive decline in biomass, with suppression stabilising at approximately 46%–50% of the control at the maximum rate. This indicates species-specific sensitivity, with *D. aegyptium* exhibiting greater susceptibility to both physical and chemical disruptions. ANOVA indicated substantial main effects of litter type and mulch rate ($p < 0.05$), along with a robust interaction between these two factors throughout all measurement intervals and both species (Table 3). The interaction highlights that the effectiveness of mulch rate is influenced by allelochemicals, emphasising the significance of bioactive molecules alongside soil surface coverage.

3.3 | LC-ESI-QTOF-MS/MS Analysis

The bioactive compounds in sugarcane leaf extract were identified using LC-ESI-QTOF-MS/MS in positive and negative ionisation modes (Figure 1), yielding a total of 54 successfully identified compounds (Table 4). These compounds were systematically categorised into various classes, including phenolic acids, simple phenols, flavonoids, organic acids, amino acids and peptides, fatty acids, alkaloids, terpenes, terpenoids and other miscellaneous compounds. Among the identified compounds, phenolic compounds (including phenolic acids, flavonoids and simple phenols) were the most abundant, constituting 25.93% of the total. This was followed by organic compounds at 18.52%, amino acids and peptides at 16.67%, fatty acids at 9.26% and terpenoids and terpenes at 5.56%. Alkaloids and other compounds were present in comparatively smaller quantities.

3.4 | Effect of Sugarcane Leaf Litter as Soil Mulch on Weed Management in a Sugarcane Field

Utilising sugarcane litter as a mulch on the soil surface led to reductions in both weed density (Figure 2) and weed dry weight

TABLE 3 | Effect of soil mulching with extracted and nonextracted sugarcane leaf litter on emergence and biomass of *Dactyloctenium aegyptium* and *Ipomoea pes-tigridis*.

	D. aegyptium					I. pes-tigridis				
	Emergence (plants tray^{-1})				Dry weight (mg tray^{-1})	Emergence (plants tray^{-1})				Dry weight (mg tray^{-1})
	7 DAS	14 DAS	21 DAS	28 DAS		7 DAS	14 DAS	21 DAS	28 DAS	
Treatments	% of control									
Litters										
Extracted litter	31.0b	40.3b	28.0b	29.1b	42.9b	65.6b	82.4b	82.4b	82.4b	87.7b
Nonextracted litter	17.1a	30.7a	15.2a	17.5a	24.0a	55.7a	61.8a	62.6a	62.6a	59.8a
F test	*	*	*	*	*	*	*	*	*	*
Mulching rates										
2 t ha^{-1}	50.0d	69.0d	38.8d	40.7d	61.4d	90.8	92.0	92.0	92.0	94.1
4 t ha^{-1}	34.5c	37.7c	24.5c	27.0c	42.5c	64.3	81.8	81.8	81.8	86.8
6 t ha^{-1}	11.7b	27.8b	16.8b	17.9b	20.9b	56.6	66.1	66.1	66.1	67.8
8 t ha^{-1}	0.0a	7.3a	6.3a	7.5a	8.9a	31.0	48.3	50.0	50.0	46.4
F test	*	*	*	*	*	*	*	*	*	*
Interaction Litters × Mulching rates *F* test	*	*	*	*	*	*	*	*	*	*
HSD	10.7	11.3	10.1	10.2	11.8	8.2	9.4	9.1	9.7	14.9

Note: F test: ns = no-significant; * = significant at $p < 0.05$; Means followed by the same letter in a column do not differ from each other by Tukey's test (HSD was calculated at a significance level of $p < 0.05$).

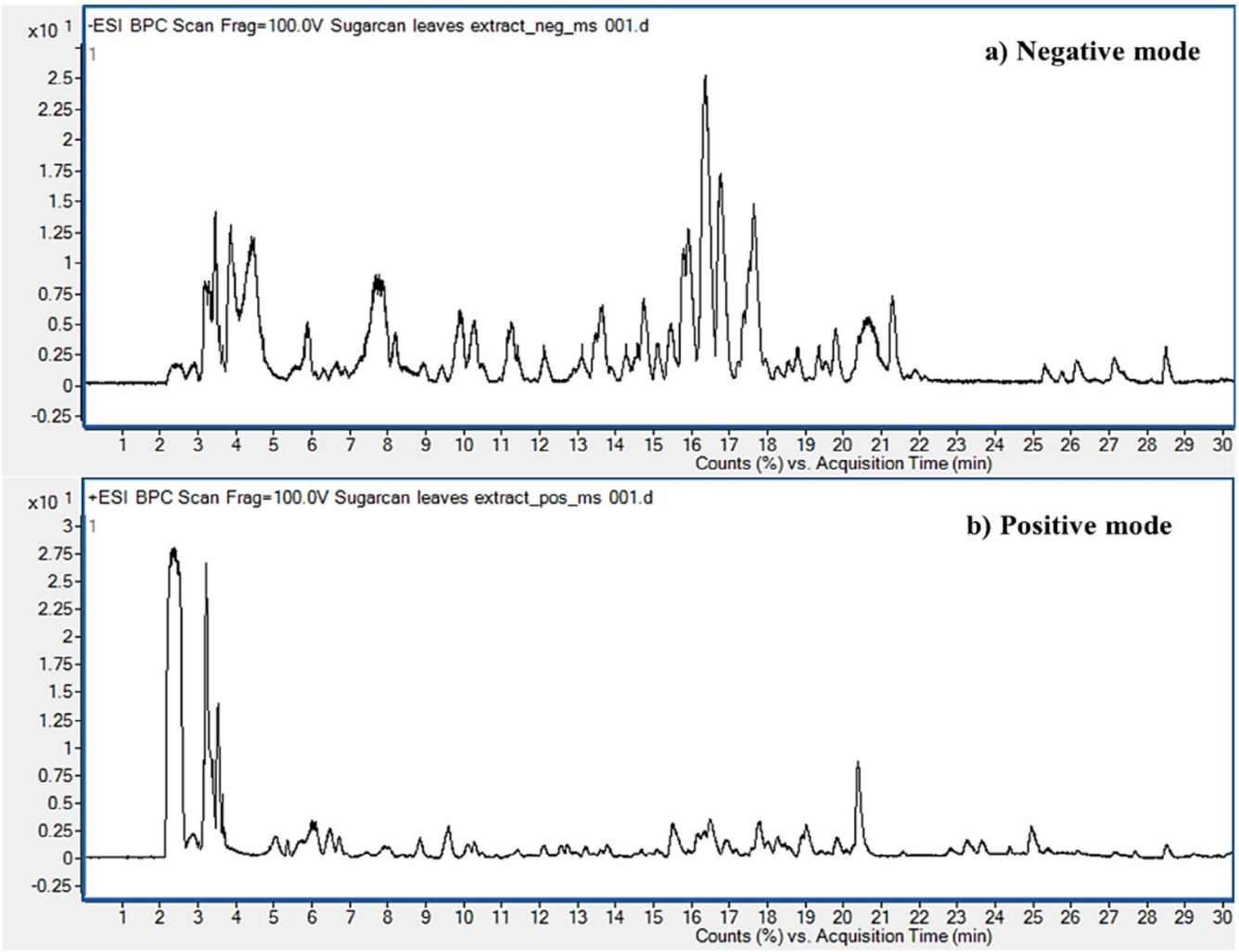


FIGURE 1 | LC-ESI-QTOF-MS/MS chromatograms of sugarcane leaf extract in positive and negative ionisation modes.

(Figure 4) compared to the weedy check (unweeded) plot, starting from 2 MAP. In the first month, there was no statistically significant difference in density among all treatments. At 4 MAP, a rapid increase in density was observed due to rainfall in the entire area (Figure 3), in which the litter application clearly suppressed weed density and dry weight (Figures 2 and 4). In plots treated with hoeing and mechanical weeding, weed density and dry weight varied as the practices detailed in the materials and methods section were implemented after data collection. At 6 MAP, litter mulching at rates of 4, 8 and 12 t ha^{-1} resulted in respective weed density reductions of 38.26%, 51.29% and 65.61% compared to the weedy check (Figure 2). Similarly, dry weight was reduced by 28.00%, 40.89% and 53.20%, respectively. At the same timepoint, hoeing and mechanical treatments reduced weed density by around 77% and dry weight by approximately 84%–89%. (Figure 4).

Identification of weed species was conducted prior to the establishment of the experimental area, with 20 weed species being present in the field. However, only a few major weed species were regularly observed and predominated. These included four dicotyledons: *I. pes-tigridis*, *T. terrestris*, *Euphorbia heterophylla* L. and *Trianthema portulacastrum* L. along with three monocotyledons: *D. aegyptium*, *D. ciliaris* and *B. reptans*. Finally, one sedge species, *C. rotundus*, was also noted.

In the weedy check plot, the highest dry weight was obtained for *D. ciliaris* at about 25 g/0.25 m^2, followed by *B. reptans* (18.9 g/0.25 m^2), *Dactyloctenium aegymtium* (16.9 g/0.25 m^2), *C. rotundus* (13.5 g/0.25 m^2), *I. pes-tigridis* (12.0 g/0.25 m^2), *E. heterophylla* (8.0 g/0.25 m^2), *T. portulacastrum* (8.0 g/0.25 m^2) and finally *T. terrestris* (5.4 g/0.25 m^2). Soil mulching with sugarcane litter significantly decreased the dry weight of all weeds, especially grass species (Table 5).

3.5 | Effect of Mulching With Sugarcane Leaf Litter on Sugarcane Yield and Yield Components

The results evaluated the effect of sugarcane leaf litter mulching on sugarcane growth and yield components, comparing it to hoeing, mechanical weeding and a weedy check control. Results revealed significant differences among treatments in cane stand density (stalks ha^{-1}), cane yield (t ha^{-1}) and CCS (Table 6 and Figure S5. Among the treatments, hand hoeing demonstrated the most significant results, achieving the highest cane stand (70 370.4 stalks ha^{-1}) and cane yield (126.8 t ha^{-1}). In contrast, the weedy check control group exhibited markedly lower performance, with 29 166.8 stalks ha^{-1} and 31.0 t ha^{-1} yield. Mechanical weeding showed intermediate efficacy,

TABLE 4 | Bioactive compounds identified in sugarcane leaf extract analysed by LC-ESI-QTOF-MS/MS.

No.	Compound	Molecular formula	Molecular mass (g/mol)	Retention time (min)	*m/z*	Ionisation	Class
1	Malic acid	$C_4H_6O_5$	134.09	4.41	133.01	$[M-H]^-$	Organic acid
2	*trans*-Aconitate	$C_6H_6O_6$	174.10	7.75	173.00	$[M-H]^-$	Organic acid
3	(R)-2-Hydroxybutane-1,2,4-tricarboxylate	$C_7H_{10}O_7$	203.13	8.18	205.03	$[M-H]^-$	Organic acid
4	*O*-Dihydroxyphenylalanine	$C_9H_{13}NO_4$	197.18	9.42	198.07	$[M-H]^-$	Amino acid
5	Gentiopicroside	$C_{16}H_{20}O_9$	356.32	9.51	401.10	$[M+HCOO]^-$	Terpenoid
6	3-*O*-Ethyl-L-ascorbic acid	$C_8H_{12}O_6$	204.18	9.90	249.06	$[M+HCOO]^-$	Organic acid
7	Tarennoside	$C_{16}H_{22}O_9$	358.34	13.1	357.11	$[M-H]^-$	Organic acid
8	5-*O*-Feruloylquinic acid	$C_{17}H_{20}O_9$	368.33	13.63	367.10	$[M-H]^-$	Phenolic acid
9	Salicylic acid	$C_7H_6O_3$	138.12	14.28	137.02	$[M-H]^-$	Phenolic acid
10	*N*-Carbobenzoxyglycylproline	$C_{15}H_{18}N_2O_5$	292.29	14.75	351.11	$[M+HCOO]^-$	Amino acid
11	Kaempferol 3-apiosyl-(1->2)-glucoside	$C_{26}H_{28}O_{15}$	580.50	15.06	579.13	$[M-H]^-$	Flavonoid
12	Methyl 10,12,13,15-bisepidioxy-16-hydroperoxy-8E-octadecenoate	$C_{19}H_{32}O_8$	402.48	15.45	433.20	$[M+HCOO]^-$	Fatty acid
13	Bilobalide	$C_{15}H_{18}O_8$	368.34	16.77	371.09	$[M+HCOO]^-$	Terpene
14	Isobutylglycine	$C_{11}H_{16}N_4O_4$	131.17	18.28	267.12	$[M-H]^-$	Amino acid
15	4-(2-hydroxypropoxy)-3,5-dimethyl-Phenol	$C_{11}H_{16}O_3$	196.24	19.35	195.11	$[M-H]^-$	Phenol
16	9-Hydroxy-7-megastigmen-3-one glucoside	$C_{19}H_{32}O_7$	442.52	19.54	417.21	$[M+HCOO]^-$	Norisoprenoid
17	(3S,7E,9S)-9-Hydroxy-4,7-megastigmadien-3-one 9-glucoside	$C_{19}H_{30}O_7$	415.198	19.8	415.19	$[M+HCOO]^-$	Norisoprenoid
18	2,3-Dihydroxybenzoic acid	$C_7H_6O_4$	154.12	20.64	153.01	$[M-H]^-$	Phenolic acid
19	Azelaic acid	$C_9H_{16}O_4$	188.22	21.29	187.09	$[M-H]^-$	Fatty acid
20	8-C-Methylquercetin 3-methyl ether	$C_{17}H_{14}O_7$	316.26	25.33	329.06	$[M-H]^-$	Flavonoid
21	Undecanedioic acid	$C_{11}H_{20}O_4$	216.27	25.75	215.12	$[M-H]^-$	Fatty acid
22	Corchorifatty acid F	$C_{18}H_{32}O_5$	308.41	26.23	327.21	$[M-H]^-$	Fatty acid
23	(9S,10E,12S,13S)-9,12,13-Trihydroxy-10-octadecenoic acid	$C_{18}H_{34}O_5$	330.46	27.12	329.23	$[M-H]^-$	Fatty acid
24	Pentane-1,2,2,3,3,4,4-heptol	$C_5H_{12}O_7$	214.28	2.39	185.06	$[M+H]^+$	Alcohol
25	6-Hydroxy-2-cyclohexen-one-carboxylic acid	$C_7H_7O_4$	156.14	3.20	156.04	$[M+H]^+$	Carboxylic acid

(Continues)

TABLE 4 | (Continued)

No.	Compound	Molecular formula	Molecular mass (g/mol)	Retention time (min)	*m/z*	Ionisation	Class
26	[3-(dimethylamino)propoxy]sulfonic acid	$C_5H_{13}NO_4S$	167.23	3.26	222.01	$[M+K]^+$	Sulfonic acid
27	*trans*-4-Aminocyclohexanecarboxylic acid	$C_7H_{13}NO_2$	143.19	3.50	144.12	$[M+H]^+$	Amino acid
28	Palythinol	$C_{13}H_{22}N_2O_6$	302.32	4.85	303.15	$[M+H]^+$	Amino acid
29	Cys Gly Pro	$C_{10}H_{17}N_3O_4S$	275.32	5.88	276.09	$[M+H]^+$	Peptide
30	4-Oxo-L-proline	$C_5H_7NO_3$	129.11	5.96	130.04	$[M+H]^+$	Amino acid
31	Leucine	$C_6H_{13}NO_2$	131.17	6.03	132.11	$[M+H]^+$	Amino acid
32	Isoleucine	$C_6H_{13}NO_2$	131.17	6.43	132.11	$[M+H]^+$	Amino acid
33	4-Pyridoxic acid	$C_8H_9NO_4$	183.16	7.81	184.05	$[M+H]^+$	Pyridine carboxylic acid
34	Ethyl syringate	$C_{11}H_{14}O_5$	226.23	7.81	227.09	$[M+H]^+$	Phenolic acid
35	Phenyl alanine	$C_9H_{11}NO_2$	165.19	8.73	166.08	$[M+H]^+$	Amino acid
36	Valyltyrosine	$C_{14}H_{20}N_2O_4$	280.32	10.29	281.14	$[M+H]^+$	Peptide
37	2-Methoxy-1,3-benzenediol	$C_7H_8O_3$	140.14	11.26	141.05	$[M+H]^+$	Phenolic acid
38	2-Isopropylmalic acid	$C_7H_{12}O_5$	176.17	11.28	199.05	$[M+Na]^+$	Carboxylic acid
39	Portulacaxanthin I	$C_{14}H_{17}N_2O_7$	374.34	12.01	325.10	$[M+H]^+$	Betalain
40	3-Carboxy-4-methyl-5-propyl-2-furanpropanoic acid	$C_{12}H_{16}O_5$	240.25	12.46	241.10	$[M+H]^+$	Heterocyclic acid
41	3-Amino-1,4-dimethyl-5H-pyrido[4,3-b]indole	$C_{13}H_{13}N_3$	271.31	12.75	212.10	$[M+H]^+$	Heterocyclic acid
42	Dihydroferulic acid	$C_{10}H_{12}O_4$	196.19	14.52	197.07	$[M+H]^+$	Phenolic acid
43	4-Hydroxy-(3′,4′-dihydroxyphenyl)-valeric acid	$C_{11}H_{14}O_5$	226.22	14.95	227.09	$[M+H]^+$	Phenolic acid
44	Kaempferol 3-apiosyl-(1->2)-glucoside	$C_{26}H_{28}O_{15}$	580.50	15.04	581.14	$[M+H]^+$	Flavonoid
45	Schaftoside	$C_{26}H_{28}O_{14}$	564.49	16.34	565.15	$[M+H]^+$	Flavonoid
46	Loliolide	$C_{11}H_{16}O_3$	196.24	18.2	197.11	$[M+H]^+$	Terpenoid
47	Propofol glucuronide	$C_{18}H_{26}O_7$	354.39	18.23	355.17	$[M+Na]^+$	Glucuronide
48	Swertisin	$C_{22}H_{22}O_{10}$	446.40	18.47	447.12	$[M+H]^+$	Flavonoid
49	4-Heptyloxyphenol	$C_{13}H_{20}O_2$	208.30	18.84	209.15	$[M+H]^+$	Phenol
50	4-(2-hydroxypropoxy)-3,5-dimethyl-Phenol	$C_{11}H_{16}O_3$	196.11	18.93	197.11	$[M+H]^+$	Phenol
51	Tricin 7-glucoside	$C_{23}H_{24}O_{12}$	492.44	20.20	493.13	$[M+H]^+$	Flavonoid
52	Trideca-5,8,11-trienoic acid	$C_{13}H_{20}O_2$	208.30	22.80	209.15	$[M+H]^+$	Fatty acid
53	Undeca-2,5,8-trienoic acid	$C_{11}H_{16}O_2$	180.24	24.92	181.12	$[M+H]^+$	Fatty acid
54	5,7-Dihydroxy-8,4′-dimethoxyisoflavone	$C_{17}H_{14}O_7$	180.24	25.32	331.07	$[M+H]^+$	Flavonoid

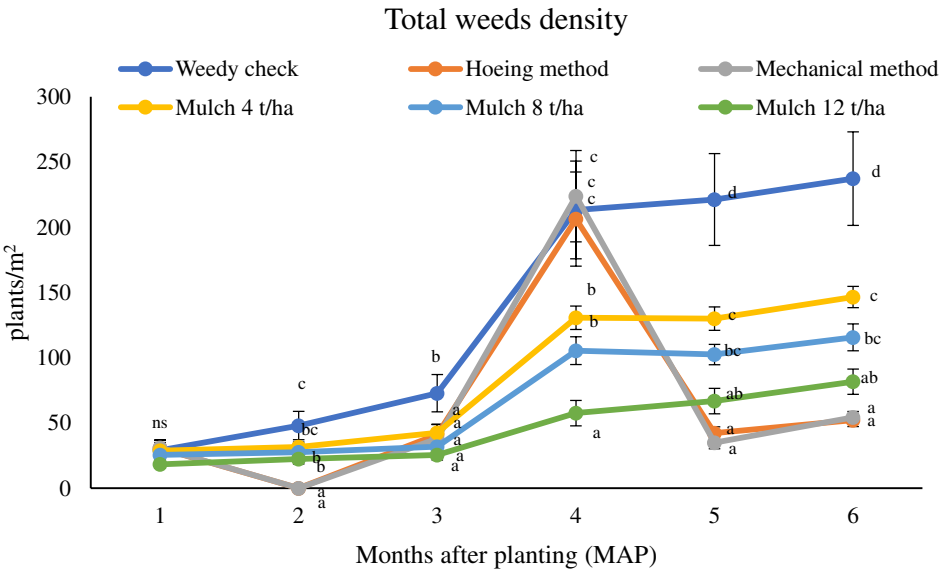


FIGURE 2 | Total weed density as affected by sugarcane leaf litter mulching rates. Values represent means ± standard error ($n = 4$). Treatments sharing the same lowercase letter are not significantly different according to Tukey's HSD test at $p < 0.05$. See Supplementary Figure S2 for visual representation of weed emergence patterns.

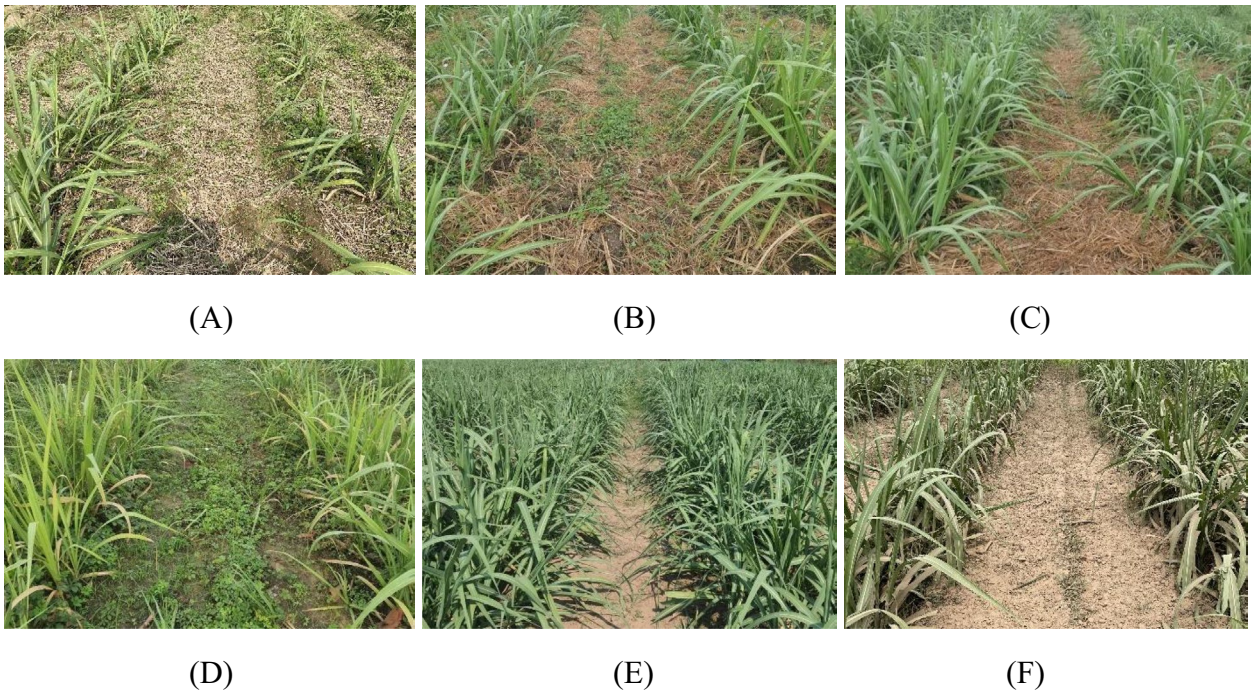


FIGURE 3 | Visual comparison of sugarcane plots at 4 months after planting under six different weed management treatments: (A–C) mulching with sugarcane leaf litter at rates of 4, 8 and 12 t ha^{-1}, respectively; (D) weedy check (no control); (E) manual hoeing and (F) mechanical weed control.

yielding 49 305.6 stalks ha^{-1} and 80.9 t ha^{-1}, while litter mulch applications displayed dose-dependent effects. Mulching at 12 t ha^{-1} achieved 56 944.4 stalks ha^{-1} and 111.6 t ha^{-1}, approaching 88% of the hoeing treatment's productivity. Notably, lower mulch rates (4–8 t ha^{-1}) still substantially improved yields compared to unweeded controls, with 84.3–104.2 t ha^{-1} versus 31.0 t ha^{-1}, confirming the allelopathic weed suppression capacity of sugarcane residues. Statistical analysis revealed significant differences ($p < 0.05$) in both stalk density (HSD = 1112.4) and yield (HSD = 15.2), with coefficients of variation at 41.8% and 36.8%, respectively). CCS values remained consistent across treatments (14.1–14.9), indicating that weed management methods did not compromise sucrose quality.

4 | Discussion

The study highlights the allelopathic potential of sugarcane residues and extracts through the integration of laboratory,

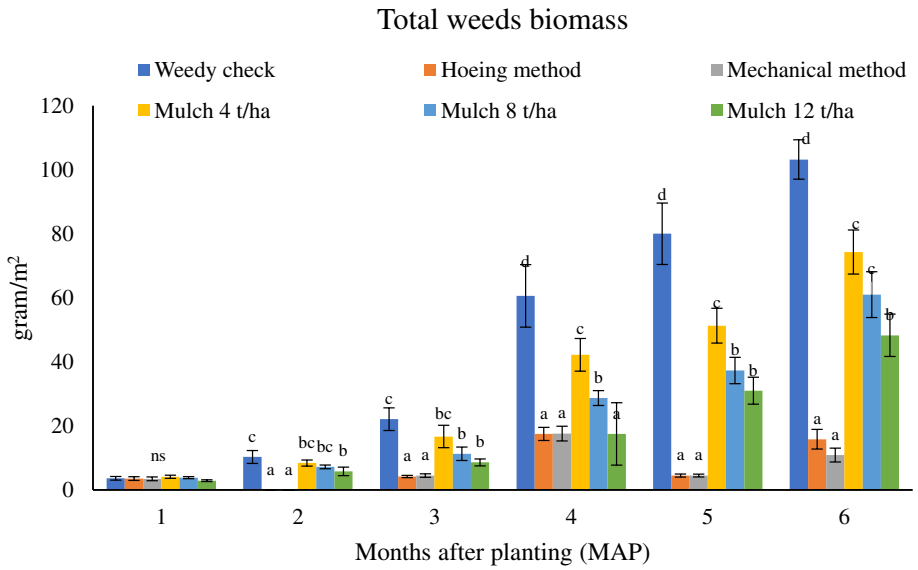


FIGURE 4 | Total weed dry weight as affected by sugarcane leaf litter mulching rates. Values represent means ± standard error ($n = 4$). Treatments sharing the same lowercase letter are not significantly different according to Tukey's HSD test at $p < 0.05$. See Supplementary Figure S3 for visual representation of weed emergence patterns.

greenhouse and field experiments with chemical profiling via LC-ESI-QTOF-MS/MS. The results collectively provide a robust framework for understanding the mechanisms behind weed suppression and the improvement of sugarcane yield through allelopathy.

Aqueous extracts of sugarcane leaves significantly inhibited the germination and early growth of *D. aegyptium* and *I. pes-tigridis*, confirming their allelopathic potential. These extracts contain phenolic acids such as ferulic, vanillic and p-coumaric acids—compounds known to disrupt key physiological processes related to germination and root development, including α-amylase activity and auxin-mediated root elongation (Devi and Prasad 1992; Zhou et al. 2012). Roots were more sensitive than shoots, consistent with reports that allelochemicals primarily affect meristematic tissues where active cell division occurs (Majeed et al. 2017). The comparable inhibitory effects observed between green and fallen leaf extracts indicate that allelopathic constituents remain stable after senescence, suggesting both materials can serve as effective inputs for residue-based weed suppression. While the bioassay effectively demonstrated dose-dependent inhibition, the experimental design may not fully differentiate between germination inhibition and growth suppression because both were evaluated on the same seed cohort. To more precisely isolate allelopathic mechanisms, future studies should incorporate a dual-assay approach using pregerminated seeds to distinguish postgermination effects. This refinement would aid in identifying specific physiological pathways targeted by sugarcane-derived allelochemicals and strengthen their potential application in sustainable weed management.

Sugarcane leaf litter was utilised as mulch to evaluate its physical and chemical efficacy in weed suppression. At higher application rates (6–8 t ha^{-1}), mulching markedly decreased the appearance and biomass of *D. aegyptium* and *I. pes-tigridis*. Nonextracted litter showed significantly higher inhibitory effects than extracted litter, indicating that allelochemicals contained in intact leaves are essential for weed suppression. This finding is consistent with Laosinwattana et al. (2007), who indicated that nonextracted residues of *Vetiveria* spp. exhibited stronger inhibitory effects than ethanol-extracted material. These findings emphasise the dual role of sugarcane leaf litter: physically, by blocking light and maintaining soil temperature (El-Metwally et al. 2022), and chemically, by releasing allelopathic substances that inhibit seedling growth. The enhanced performance of nonextracted litter indicates a synergistic relationship between intact organic matter and the soil environment, wherein microbial activity may increase the availability of allelochemicals. This method enhances soil organic matter, potentially augmenting soil structure and fertility. Phenolic acids, including caffeic and syringic acids, are recognised for their capacity to modify membrane permeability and nutrient absorption (Safdar et al. 2014). To reduce background weed seed contamination, the soil was pretreated with hot water. The procedure, although efficient, may have unintentionally modified the microbial communities responsible for allelochemical breakdown. Future research should examine the influence of soil bacteria on the sustained effectiveness of mulch-based weed management. The findings suggest the utilisation of unprocessed sugarcane leaf litter as an economical, sustainable alternative for chemical herbicides, enhancing eco-friendly weed management and encouraging soil health.

Field application of sugarcane leaf litter as mulch reduced weed density by up to 65% and dry weight by 53%, particularly for grass weeds like *D. aegyptium*. The substantial reduction in weed biomass and density demonstrates the efficacy of sugarcane mulch as an integrated weed management strategy. The greater suppression of grass weeds is noteworthy given their aggressive growth and competition for resources. This aligns with findings from Alves et al. (2021), who reported similar results in upland rice systems. Alongside this weed

TABLE 5 | Effect of mulching with sugarcane leaf litter on the dry weight of eight major weed species at 6 months after planting.

	Dry weight ($g\,m^{-2}$)							
	Grasses				Broadleaves			Sedge
Treatment	*Dactyloctenium aegyptium*	*Digitaria ciliaris*	*Brachiaria reptans*	*Ipomoea pes-tigridis*	*Tribulus terrestris*	*Euphorbia heterophylla*	*Trianthema portulacastrum*	*Cyperus rotundus*
Weedy check	16.9 ± 2.3c	29.5 ± 4.5c	18.9 ± 6.1c	12.0 ± 3.2c	5.4 ± 1.2b	8.0 ± 3.0b	8.0 ± 2.4c	13.5 ± 4.2c
Hoeing	0.6 ± 0.1a	12.2 ± 2.2ab	0.6 ± 0.1a	0.0a	1.1 ± 0.1a	0.6 ± 0.1a	0.2 ± 0.1a	0.5 ± 0.2a
Mechanical	0.4 ± 0.1a	8.0 ± 2.0a	0.5 ± 0.1a	0.0 a	0.7 ± 0.1 a	0.6 ± 0.1a	0.3 ± 0.1a	0.4 ± 0.1a
Litter mulch 4 t ha^{-1}	6.8 ± 2.1b	18.4 ± 2.8b	9.0 ± 3.2b	6.0 ± 2.0b	2.8 ± 0.8a	8.0 ± 2.2b	6.0 ± 1.6c	10.2 ± 4.0bc
Litter mulch 8 t ha^{-1}	6.0 ± 2.2b	13.0 ± 2.5ab	8.0 ± 3.1b	5.0 ± 1.8b	1.8 ± 0.6a	6.0 ± 2.1b	5.0 ± 1.5bc	7.2 ± 2.7b
Litter mulch 12 t ha^{-1}	6.0 ± 2.0b	10.5 ± 2.3ab	7.0 ± 2.7b	4.4 ± 1.6b	1.6 ± 0.5a	6.0 ± 1.9b	2.0 ± 0.8ab	6.8 ± 2.4b
F test	*	*	*	*	*	*	*	*
HSD	5.5	10.0	6.0	4.3	2.2	5.3	3.4	3.9

Note: F test: * = significant at $p < 0.05$; Data represented as mean ± standard error of four replications. Means followed by the same letter in a column do not differ from each other by Tukey's test (HSD was calculated at a significance level of $p < 0.05$).

suppression, sugarcane yield increased significantly, from 31 t ha^{-1} in the control plot to 111.6 t ha^{-1} in plots treated with 12 t ha^{-1} of mulch. This substantial improvement highlights the multifaceted benefits of mulching, which include improved soil moisture retention, reduced erosion and enhanced nutrient cycling (Wang and Xing 2016). Soil mulching helps retain soil moisture by reducing evaporation from the soil surface and also helps regulate soil temperature, reducing heat stress and maintaining consistent moisture levels, thereby creating a more stable environment for plant growth (Ye et al. 2023; Demo and Asefa Bogale 2024). Mechanical weeding suppressed weeds similarly to hand hoeing, although it may have caused crop damage like sugarcane stool bruising or uprooting, resulting in decreased yields. Mulching using sugarcane leaf litter inhibits weeds without damaging the crop. This approach improves soil health and prevents disease transmission. The synergy of intact organic material and allelochemicals is shown by the improved performance of nonextracted mulch. These data suggest sugarcane residues as a sustainable weed control technique. These findings underscore the value of leveraging agricultural residues like sugarcane leaves in sustainable farming systems. By adopting such practices, farmers can achieve higher yields while promoting environmental sustainability. A significant limitation of the present investigation is that the field experiment was executed inside one specific growing season. This supported an initial assessment of the allelopathic impact of sugarcane leaf litter in field conditions; however, more multi-season studies are necessary to address environmental variability and to enhance generalisation.

The LC-ESI-QTOF-MS/MS analysis of sugarcane (cv. Khon Kaen 3) leaf extracts revealed a wide variety of 54 bioactive chemicals. These included phenolic acids, flavonoids, fatty acids and terpenoids. Phenolic acids were the most abundant, making up 25.93% of the total. Flavonoids and fatty acids followed, representing 22.22% and 20.37%, respectively. This chemical complexity agrees with previous studies that have shown sugarcane residue contains allelochemicals. These compounds are known to hinder seed germination and the growth of seedlings (Gomes et al. 2016; Sampietro and Vattuone 2006). The presence of phenolic acids, particularly salicylic acid, 5-O-feruloylquinic acid and 2,3-dihydroxybenzoic acid, is especially noteworthy when considering the observed suppression of *D. aegyptium* and *I. pes-tigridis* in both bioassays and pot experiments. Macías et al. (2005) showed that these chemicals can disrupt the activity of enzymes, the structure of membranes and the balance of hormones in the weeds they target. Schaftoside, tricin-7-glucoside and swertisin, all of which were identified, are known to impede cell division and slow down root growth (Aziz et al. 2022). This could explain the severe suppression of root biomass seen in the tests. The difference in how the two weed species responded is likely due to the permeability of their seed coats, which affects how they absorb water-soluble allelochemicals. Hijano et al. (2021) found that the amount of allelochemicals varied depending on the plant variety, particularly in the types of fatty acids present. For example, the CTC 2 and IAC 911099 cultivars contain different fatty acids, such as palmitic and linoleic acid. These acids are known to disrupt membranes in cucumber cotyledons. The Khon Kaen 3 variety revealed a unique combination of long-chain and dicarboxylic fatty acids, including azelaic acid

TABLE 6 | Effect of mulching with sugarcane leaf litter on sugarcane yield and yield components.

Treatment	Cane stand (stalks ha^{-1})	Cane yield (t ha^{-1})	CCS
Weedy check	29 166.8 ± 4781c	31.0 ± 7.3c	14.9 ± 0.90
Hoeing	70 370.4 ± 7945a	126.8 ± 9.4a	14.7 ± 0.72
Mechanical	49 305.6 ± 5680b	80.9 ± 13.0b	14.1 ± 0.84
Litter mulch 4 t ha^{-1}	49 074.1 ± 6246b	84.3 ± 13.0b	14.6 ± 0.67
Litter mulch 8 t ha^{-1}	54 861.1 ± 5584b	104.2 ± 10.0ab	14.3 ± 0.64
Litter mulch 12 t ha^{-1}	56 944.4 ± 4641b	111.6 ± 9.2ab	14.4 ± 0.63
F test	*	*	ns
HSD	1112.4	15.2	0.9
CV%	41.8	36.8	4.8

Note: F test: ns = no-significant; * = significant at $p < 0.05$; Data represented as mean ± standard error of four replications. Means followed by the same letter in a column do not differ from each other by Tukey's test (HSD was calculated at a significance level of $p < 0.05$) (Figure S4).

and undeca-2,5,8-trienoic acid. These compounds might work together to improve the allelopathic effects when used as mulch. The presence of corchorifatty acid F and trideca-trienoic acid further supports the idea that oxidised fatty acids are involved in signalling pathways that restrict the growth of nearby plants. The results imply that the effectiveness of weed suppression seen with non-extracted mulch treatments, both in pots and in the field, might be due to the combined effects of the amount and variety of allelochemicals. This is especially true for those in the phenolic and fatty acid groups.

Notably, the complex mixture of toxic and nontoxic compounds present in sugarcane residues suggests that their allelopathic effects may result from interactions of multiple compounds rather than the actions of individual components, with multiple allelochemicals synergising to enhance their inhibitory effects. Prior studies by Inderjit et al. (2002) and Jia et al. (2006) have emphasised that such interactions among phenolic acids, flavonoids and fatty acids are often more potent than individual compounds acting alone. Given the variability in chemical composition observed among sugarcane cultivars, cultivar selection is of great import in maximising allelopathic potential. In field conditions, some research has shown that soil microorganisms efficiently metabolise phenolics when they are added to soil as the sole carbon source; however, alternative carbon sources are metabolised more readily than phenolics, supporting greater phytotoxicity. Thus, adding both phenolics and other toxic or nontoxic carbon sources can reduce microbial degradation of soil phenolics and increase their inhibitory effects on plant growth (Blum and Shafer 1988; Zhang et al. 2010; Zhou et al. 2012). Blum (1996) proposed that such interactions could elucidate why crop residues with similar phenolic content may exhibit differing inhibitory effects on plant growth.

5 | Conclusion

This study shows that sugarcane leaf remains as soil mulch can decrease weed emergence and growth and enhance sugarcane yield, emphasising its utility in sustainable weed management. LC-ESI-QTOF-MS/MS investigation validated allelopathic activity in phenolic acids and related compounds, supporting observed inhibitory effects. However, the present investigation does not determine which chemicals directly reached weed seeds or seedlings or their respective suppression effects in different plant species. Thus, chemical profiling is suggestive rather than mechanistic.

Research showed that using sugarcane residue as mulch can reduce weed pressure and reduce the need for synthetic herbicides in sugarcane cultivation. More research is required to understand compound-specific effects, species-dependent sensitivity and long-term effects of sugarcane residues on soil biological processes and agroecosystem sustainability.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data are available from the corresponding author upon request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Rainfall, maximum and minimum temperatures during the experiment period (January to December 2021). **Figure S2:** Kolmogorov–Smirnov test of weed density data. **Figure S3:** Kolmogorov–Smirnov test of weed dry weight data. **Figure S4:** Kolmogorov–Smirnov test of stalk, yield and CCS data.