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Research Article

Effect of Sorghum Mulches on Emergence and Seedling Growth of Beggarticks, Goose Grass, and Sesame

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Rotation of sorghum (*Sorghum bicolor* L. Moench) with sesame (*Sesamum indicum* L.) in drought prone areas of Zimbabwe has raised concerns on whether these two crops are compatible in the rotational system. This is because sorghum is known to exhibit strong allelopathic effects on both crop and weed species. A greenhouse experiment was conducted to assess the effect of soil incorporated sorghum residues on the emergence and seedling growth of sesame and weeds. The emergence and early seedling growth of sesame and the weed significantly ($p < 0.05$) increased with increases in the amount of soil incorporated sorghum residues. Incorporating 27.7 g of the ground sorghum herbage caused a stimulatory effect on the emergence and early seedling growth of the test species. Liquid chromatography-mass spectrometry revealed the presence of 6 probable allelochemicals in sorghum residues, namely, 4-methylaminobutyrate, C16 sphinganine, oleamide, tauroursdeoxycholic acid, pisatin, and anhalonidine. From this study, it can be concluded that dry sorghum residues do not have an inhibitory effect on sesame emergence and growth at mulch rates that retard emergence and growth of weeds.

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop that has been extensively studied for its allelopathic potential and is widely documented as a source of allelochemicals [1]. Allelopathy is defined as the ability of a plant to cause either a suppressive or stimulatory effect on the growth and development of another plant, although this term is loosely used to describe inhibitory effects on the susceptible plant species [2]. Over the years, sorghum has become one of the most studied allelopathic crop, and research work focused on isolating allelochemicals responsible for the suppressive effects [3]. Allelopathic activity of sorghum is particularly attributed to sorgoleone and dhurrin, two important allelochemicals that are produced in the roots and shoots of sorghum, respectively [4, 5]. Several other allelochemicals with herbicidal activity have been isolated and identified in sorghum, and these include phenolic compounds, coumaric acid, vanillic acid, syringic acid, benzoic acid, gallic acid, caffeic acid, ferulic acid, chlorogenic acid, and protocatechuic acids [6, 7].

Methods of exploiting sorghum allelopathy include retention of crop residues as surface mulch, inclusion of sorghum into a crop rotational or intercropping system, and spraying of aqueous extracts (sorgaab) in combination with reduced herbicide dosages [8, 9]. Previous studies have reported that sorghum exhibited allelopathic activity on the growth and development of both crop and weed species [10]. Wild oat (*Avena fatua* L.), pigweed (*Amaranthus hybridus*), fat hen (*Chenopodium album* L.), nightshade (*Solanum nigrum* L.), sweet clover (*Melilotus parviflora* L.), black pigweed (*Trianthema portulacastrum* L.), field bindweed (*Convolvulus arvensis* L.), Mexican fire plant (*Euphorbia heterophylla* L.), and purple nutsedge (*Cyperus rotundus* L.)

are some of the weeds whose germination and/or growth is inhibited by sorghum extracts [2, 11–15].

Sesame (*Sesamum indicum* L.) is an important oil seed crop which is currently being promoted as an alternative to cotton (*Gossypium hirsutum* L.) in the arid ecological regions of Zimbabwe. This is because of its resilience to harsh conditions created by the adverse effects of climate change and variability. Hussain et al. [16] reported that sesame produces allelochemicals that inhibited growth and development of the purple nutsedge (*Cyperus esculentus* L.). Other studies reported sesame autotoxicity in crop production systems that promote monoculture of sesame [17]. In anticipation of growing sorghum in rotation with sesame, six registered sesame varieties were screened for tolerance to sorghum allelopathy. The objective of the study was to identify the sesame varieties that are tolerant to allelochemicals released by sorghum mulches at rates that are lethal to weeds of divergent morphology, namely, goose grass (*Eleusine indica* L. Gaertn) and beggarticks (*Bidens pilosa* L.). The present study also sought to profile possible allelopathic compounds from dry sorghum leaf and stem herbage using liquid chromatography-mass spectrometry (LC-MS).

2. Materials and Methods

2.1. Study Site. The study was carried out in the greenhouse at the University of Zimbabwe (UZ)'s Department of Plant Production Sciences and Technologies in Harare, Zimbabwe, during the 2017/18 summer cropping season. The greenhouse experiment was conducted using natural light and average temperature and humidity and is given in Table 1. LC-MS was done in the Department of Pharmacy at the University of Zimbabwe.

2.2. Sorghum Biomass Preparation. Sorghum variety SC Macia mature plants were harvested dry from SEEDCO's Rattray Arnold Research Station (RARS) in Harare, Zimbabwe (17° 14′S, 31°14′E). RARS is in ecological region II, which is 1314 meters above sea level and receives an annual rainfall of above 750 mm. The stem and leaf portions were separated, chopped into 2 cm long pieces using secateurs, and dried in the oven at 70°C for 48 hours. The different plant parts were ground into powder using a hammer mill grinder. The ground powder was kept in the Weed Science Laboratory at the UZ for three days at room temperature (approximately 23–25°C) before being used in experiments.

2.3. Experimental Design. The greenhouse experiment for sesame was laid out as a $4 * 6$ factorial experiment biomass concentration and sesame variety as the factors. Four levels of sesame biomass concentration that were used in the study are given in Table 2. Six levels of sesame genotype were used, namely, BZ, IETC, Lind 02, LZ, M09, and Z94. The glasshouse experiment was laid out as a completely randomized design (CRD) with four treatments replicated six times. On the other hand, beggarticks and goose grass weed bioassays were laid out separately as CRD with four treatments replicated six times.

2.4. Experimental Procedure. Pots measuring 20 cm diameter and 18 cm height were three-quarter filled with oven sterilized sandy soil (clay 4%, silt 13%, and sand 83%). Sorghum ground residues were added to the pots and thoroughly mixed with the top 5 cm of the soil [18]. Stems and leaves were not separated because they were equally effective in the laboratory bioassay [19] and also to try to mimic field conditions where above ground tissues are retained as mulch. The treatments used in the study are given in Table 2. Ten sesame seeds or 25 weed seeds were shallowly planted in the respective pots in which the soil was mixed with different sorghum herbage, as given in Table 2. Thereafter, the pots were watered daily with 450 ml of water. The experiment was terminated 28 days after sowing of seeds of either sesame or weeds.

2.5. Nutritional Composition of Dry Sorghum Residues. Quantification of nitrogen in dry residues of sorghum variety SC Macia was carried out in the UZ's Food Nutrition Department using the Kjeldahl method described by [20]. In addition, quantification of phosphorus and potassium was done using UV-Vis and flame atomic absorption spectroscopy, respectively. The sample for the phosphorus and potassium analyses was prepared using the method described by Lozano-Calero et al. [21]. Nutritional composition of the sorghum dry residues is given in Table 3.

2.6. Liquid Chromatography-Mass Spectrometric (LC-MS) Analysis of Allelopathic Compounds in Sorghum Residues. To isolate possible allelopathic compounds in sorghum variety SC Macia herbage, 200 g of mixed leaf and stem powder was mixed with 1000 ml of 70% HPLC grade methanol. The mixture was shaken on an orbital shaker at 150 rpm for twelve hours at room temperature. Subsequently, the mixture was filtered using four layers of cheesecloth, and the filtrate was centrifuged at 4000 rpm for 15 minutes using a centrifuge (Model Dynac II Centrifuge, Clay Adams). Methanol in the resultant solution was removed at 80°C using a rotary evaporator (rotary evaporator, Biobase). To remove water from the aqueous solution remaining, beakers containing solution from the rotary evaporator were suspended in a waterbath set at a temperature of 80°C until all water had evaporated. Identification of possible allelopathic compounds in the crude sorghum extract was done using a Model Agilent Technologies' 6530 Accurate-Mass Q-TOF LC/MS [22].

2.7. Data Analysis. Data collected in the experiments were subjected to analysis of variance (ANOVA) using GenStat version 14. Data were tested for normality using the Shapiro–Wilk test. Mean separation was done using Fisher's protected least significance difference (LSD) at 5% significance level.

Table 1: Average temperature and humidity in the greenhouse.

Average temperature (°C)	Average max temperature (°C)	Average min temperature (°C)	Average humidity (%)	Average max humidity (%)	Average min humidity (%)
29.5	35.9	16.4	52.9	97.3	29.8

Table 2: Treatments used in the soil incorporated biomass greenhouse experiment.

Treatments	Concentration of sorghum whole plant biomass added to the soil in the pots
Treatment 1	Control (no biomass added)
Treatment 2	10.5 g ground sorghum biomass
Treatment 3	18.4 g ground sorghum biomass
Treatment 4	27.7 g ground sorghum biomass

Table 3: Macronutrient composition of the dry sorghum residues used in the study.

Nutrient	Amount of nutrient in 2 g ground sorghum sample	Amount of nutrient in 10.5 g sorghum biomass/19.4 m^2	Amount of nutrient in 18.4 g sorghum biomass/19.4 m^2	Amount of nutrient in 27.7 g sorghum biomass/19.4 m^2	Recommended nutrient amount/19.4 m^2 [2]
Nitrogen	0.238	1.249	2.189	3.296	0.02716
Phosphorus	0.264	1.387	2.431	3.659	0.0543
Potassium	0.131	0.686	1.202	1.809	0.0272

3. Results

3.1. Effect of Different Soil Incorporated Sorghum Residues on Sesame. The interaction between sesame variety and biomass concentration on the final emergence, dry shoot weight, and dry root weight of sesame was not significant ($p > 0.05$). There were significant ($p < 0.05$) differences among the sesame varieties on the final emergence percentage (Table 4). Final emergence of sesame was significantly lower in IETC compared to the other sesame varieties (Table 4). On the other hand, the final emergence percentage of Lindi Zimbabwe was significantly higher than Brown Zimbabwe, Ziada 94, and Lindi 02 but was statistically similar to Mtwara 09. Incorporation of sorghum ground biomass did not affect dry shoot and dry root weight of all the varieties used in the study (Table 4).

3.2. Effect of Sorghum Soil Incorporated Biomass on Beggarticks. The effect of soil incorporated sorghum biomass amount was significant ($p < 0.05$) on final emergence of beggarticks, but not on dry shoot ($p > 0.05$) and dry root weight (Figure 1). Beggarticks final emergence percentage increased with increasing concentration of soil incorporated sorghum residues (Figure 1(a)). There were no significant differences between the other treatments except 27.7 g pot^{-1}, which resulted in significantly higher final emergence than the other treatments. Conversely, the different concentrations of sorghum soil incorporated biomass did not significantly ($p > 0.05$) affect dry root and shoot weight of beggarticks (Figures 1(b) and 1(c)).

3.3. Effect of Sorghum Soil Incorporated Biomass on Goose Grass Emergence and Growth. The effect of soil incorporated sorghum biomass concentration was significant ($p < 0.05$) on final emergence, dry shoot, and root weight of goose grass (Figure 2). All the parameters measured increased as the sorghum ground biomass concentration increased from 0 g to 10.5 g pot^{-1}; emergence, dry shoot weight, and dry root weight also increased from 0 g to 10.5 g pot^{-1}. However, a further increase in sorghum ground biomass concentration from 10.5 to 18.4 g pot^{-1} did not significantly ($p > 0.05$) affect seedling emergence and growth.

3.4. Liquid Chromatography-Mass Spectrometric Analysis of Allelopathic Compounds in Sorghum Whole Plant Dry Residues. LC-MS analysis of extracts of sorghum variety SC Macia showed major molecular peaks at different *m/z* values of the possible allelopathic phenolic compounds (Figure 3). At a retention time range of 22.913–23.354 minutes, phenolic compounds 4-methylaminobutyrate (Figure 1(a)), C16 sphinganine (Figure 3(b)), and anhalonidine (Figure 3(c)) were detected (Table 5). Tauroursdeoxycholic acid (Figure 4(a)), pisatin (Figure 4(b)), and oleamide (Figure 4(c)) were detected at a retention time range of 0.160–0.364 minutes (Table 5).

4. Discussion

The ground residues of sorghum were not effective at suppressing sesame, beggarticks, and goose grass seedling emergence and dry weight under greenhouse conditions. Increasing the amount of sorghum residues stimulated emergence and early seedling growth of all the test species. The highest final emergence percentage and early seedling growth were observed at maximal amount of sorghum biomass incorporated into the soil. These results contradict the findings by Ayeni and Kayode [14] who reported that increasing the amount of ground sorghum residues from 0 g to 50 g in 5600 g of soil reduced *Euphorbia heterophylla*

Table 4: Effect of soil incorporated sorghum biomass on the final emergence, shoot dry weight, and root dry weight of six sesame varieties.

Sesame variety	Emergence (%)	Dry shoot weight (g)	Dry shoot weight (g)
	Sesame varietal effect		
IETC	18.3[a]	0.798	0.211
Brown Zimbabwe	39.6[b]	1.205	0.298
Ziada 94	40.0[b]	1.221	0.241
Lindi 02	35.0[b]	0.946	0.259
Mtwara 09	46.2[bc]	1.165	0.411
Lindi Zimbabwe	56.7[c]	1.444	0.220
P value	<0.001	0.063	0.340
LSD	14.15	ns	ns
CV%	63.0	73.7%	126.8%
	Sorghum residue level effects		
Biomass amount	Emergence (%)	Dry shoot weight (g)	Dry root weight (g)
0 (control)	26.9[a]	0.649[a]	0.133[a]
10.5	38.6[b]	1.205[b]	0.298[ab]
18.4	38.6[b]	1.221[b]	0.199[bc]
27.7	53.1[c]	1.634[c]	0.434[c]
P value	<0.001	<0.001	0.002
LSD	11.55	0.4047	0.1571
CV%	63.0	73.7	126.8

Means followed by the same letter in the column are not significantly different at $p < 0.05$.

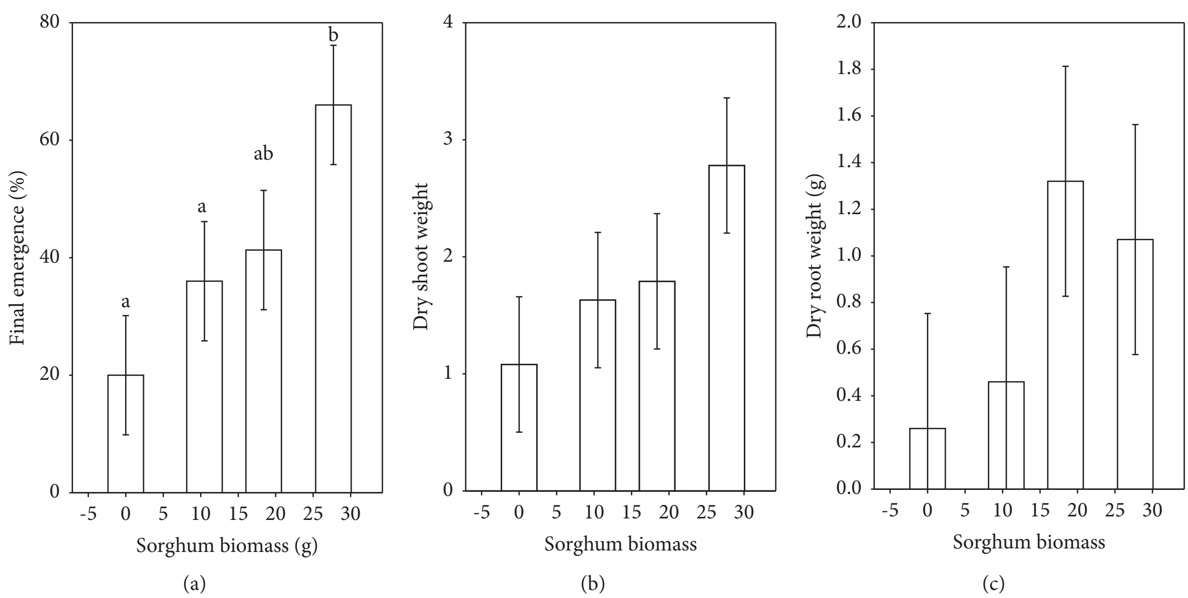


Figure 1: Effect of ground sorghum biomass on the final emergence (a), shoot dry weight (b), and root dry weight (c) of beggarticks. Bars indicated with different letters show that there were significant ($p < 0.05$) differences between treatments. Error bars represent LSD at $p < 0.05$.

L. germination percentage, dry shoot, and dry root weight. Kandhro et al. [15] reported that ground sorghum herbage suppressed broadleaved weeds, *Trianthema portulacastrum* L., *Digera arvensis* L., and *Convolvulus arvensis* L., but not beggarticks. These results imply that farmers cannot rely on sorghum mulches to control weeds in sesame because of the stimulatory effect they have on the crop and weeds. During the first three to four weeks, sesame seedlings are a poor competitor with more vigorous weeds, and if the weeds and crop emerge simultaneously, weeds affect sesame seedling establishment [19].

The findings from this study suggest that sorghum allelopathy is influenced by several factors, and in this case, lack of allelopathic activity in the greenhouse experiment could be a result of several factors including soil type, presence of microorganisms in the soil, or high levels of nitrogen (N), phosphorus (P), and potassium (K) in sorghum ground residues. In this study, NPK levels supplied to the germinating and developing sesame, beggarticks, and goose grass seeds increased as the amount of ground sorghum residues increased. The NPK levels provided by sorghum residues (Table 3) exceeded the required amounts

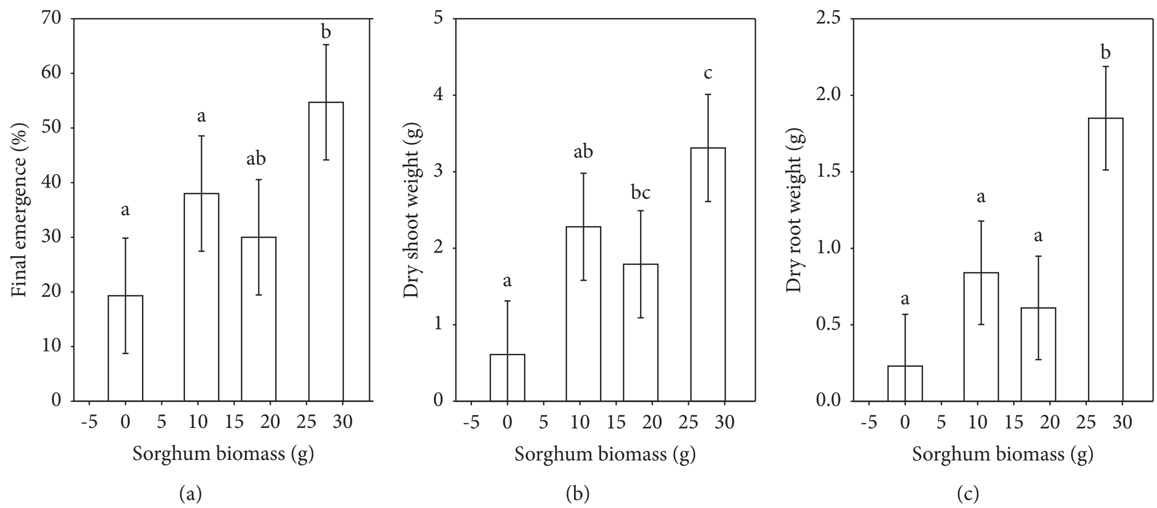


Figure 2: Effect of ground sorghum biomass on (a) the final emergence, (b) shoot dry weight, and (c) root dry weight (c) of goose grass. Bars indicated with different letters show that there was a significant ($p < 0.05$) differences between treatments. Error bars represent LSD at $p < 0.05$.

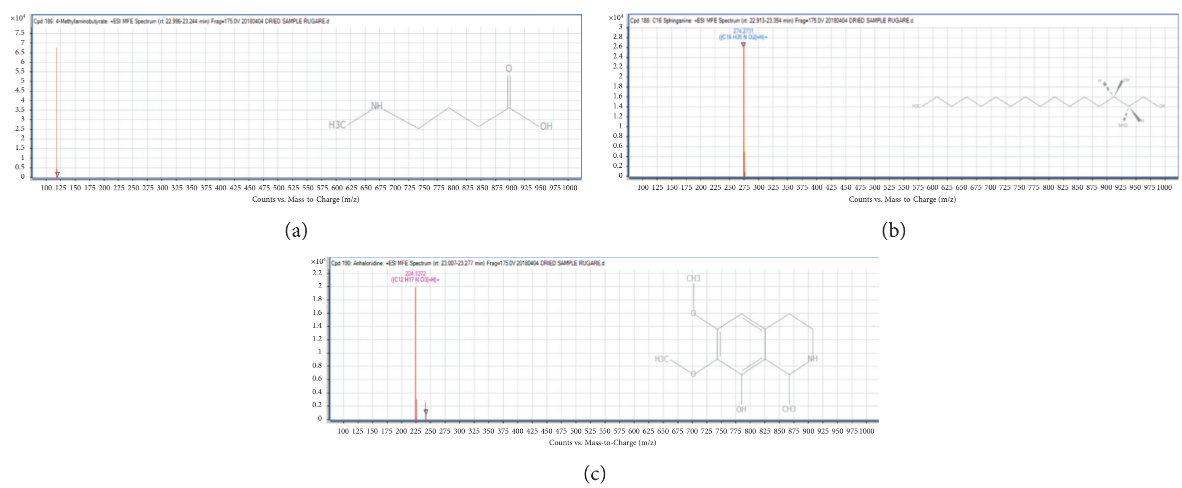
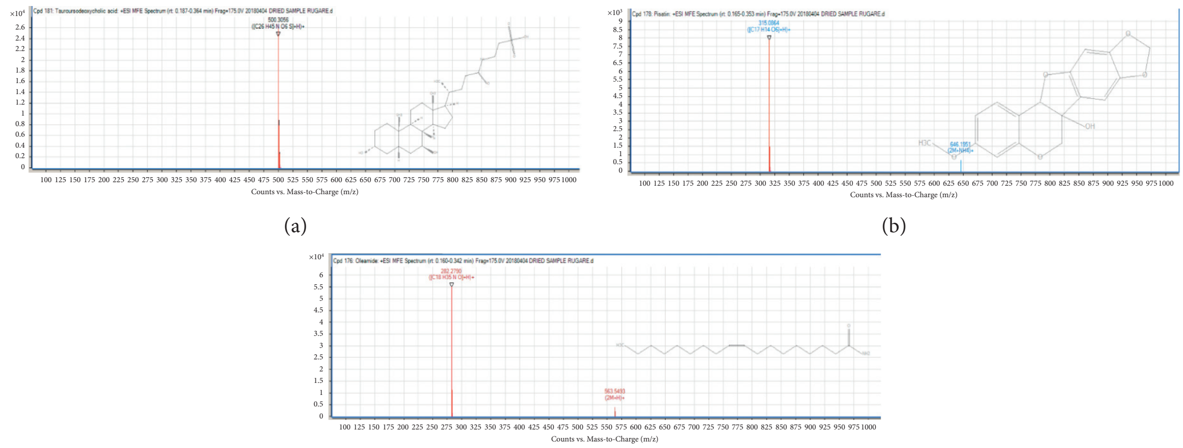


Figure 3: Cumulative LC-MS spectra for (a) 4-methylaminobutyrate, (b) C16 sphinganine, and (c) oleamide that were detected in sorghum variety SC Macia extracts.

Table 5: Retention times, mass spectra data, and tentative identification of the phenolic compounds in sorghum variety SC Macia.

Proposed compound	Chemical formula	Rt (min)	Exact mass	Calculated mass	Volume (%)	Score
4-Methylaminobutyrate	$C_5H_{11}NO_2$	23.093	117.0785	117.1565	1.15	98.30
C16 sphinganine	$C_{16}H_{35}NO_2$	23.131	273.2659	273.5009	0.89	96.19
Oleamide	$C_{18}H_{35}NO$	0.216	281.2716	281.4529	0.60	85.42
Tauroursdeoxycholic acid	$C_{26}H_{45}NO_6S$	0.279	499.2973	499.854	0.40	84.91
Pisatin	$C_{17}H_{14}O_6$	0.263	314.079	314.2504	0.15	82.83
Anhalonidine	$C_{12}H_{17}NO_3$	23.145	223.1199	223.2764	0.38	82.55

reported by Mudani [23]. This suggests that high amounts of nutrients in ground sorghum herbage could have masked the detrimental effects of allelopathy. The lack of phytotoxic activity could be attributed to the presence of high amounts of nitrogen, phosphorus, and potassium in larger amounts which consequently allowed the sesame and weeds to grow luxuriously. The high levels of nitrogen provided to sesame, beggarticks, and goose grass in this study may have assisted in breaking seed dormancy and a concomitant increase in seed germination and seedling emergence. It is also possible that the high levels of phosphorus contained in the sorghum residues could have stimulated root development, thereby



(a) (b)

(c)

Figure 4: Cumulative LC-MS spectra for (a) tauroursdeoxycholic acid, (b) pisatin, and (c) anhalonidine that were detected in sorghum variety SC Macia extracts.

promoting faster seedling development resulting in increased growth of seedlings. It is also possible that the germination, emergence, and growth stimulation that was observed could be due to toxicant-induced hormesis. Recent allelopathy studies have attributed an increase in seedling growth when allelochemicals are applied at dosages lethal to weeds but stimulatory to crops to hormesis [24, 25]. The results of this study encourage retention of sorghum residues as surface mulches not soil-incorporated residues to suppress weeds in sesame by creating a microclimate that discourages germination and growth of photoblastic weed seeds. Similar recommendations were given by Muslim Al-Eqaili et al. [26] who reported that wheat (*Triticum aestivum* L.) residues as surface mulches were effective at controlling weeds, whilst wheat residue incorporation into the soil was not effective in managing weeds. The use of sorghum residues or aqueous extracts for weed control may not effectively control weeds when used alone. Therefore, sorghum allelopathy should be a component of an integrated weed control strategy. The lack of phytotoxic damage on sesame when planted in soils mixed with sorghum residues suggests the possibility of rotating sorghum with sesame without the fear of crop damage due to sorghum allelopathy.

The possible allelopathic compounds in sorghum variety SC Macia above ground parts were identified as 4-methylaminobutyrate, C16 sphinganine, anhalonidine, tauroursdeoxycholic acid, pisatin, and oleamide. These compounds were isolated and identified at a retention time range of 0–25 minutes. Most of the phenolic compounds were obtained at a retention time range of 0-1 minute as shown by a major peak during this period. The compound 4-methylaminobutyrate with *m/z* 117 and 23.093 retention time had the highest volume, but its presence in sorghum is not yet documented. Pisatin which was eluted at m/z 314 and retention time 0.263 minutes has been identified as the defence molecule against pathogen attack in several plants including tomato (*Solanum esculentum* L.) and peas (*Pisum sativum* L.) [27].

All the compounds that were obtained in this study have not yet been reported in sorghum as possible allelochemicals. This could be because most research focus has been on sorgoleone and dhurrin as the major allelochemicals in sorghum, and identification of specific phenolics or flavonoids is still yet to be done [28]. It is also because previous research studies were carried out using live sorghum plant material which contains high levels of sorgoleone and dhurrin. Since in conservation agriculture (CA) most farmers use dry material, we considered it appropriate to use dry sorghum material in order to mimic the situation that is under smallholder conditions.

5. Conclusion

From this study, it can be concluded that soil incorporated dry sorghum residues does not have inhibitory effects on the germination and emergence of sesame and the weeds. Liquid chromatography-mass spectrometry revealed the presence of six probable allelochemicals in sorghum residues, namely, 4-methylaminobutyrate, C16 sphinganine, oleamide, tauroursdeoxycholic acid, pisatin, and anhalonidine.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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