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Research Article

Allelopathic Effects of Aqueous Extracts From Sesame Leaves and Root on the Germination and Seedlings Growth of Maize and Sorghum

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Abstract— A laboratory and screen house experiment was carried out to investigate the allelopathic impacts of sesame (*Sesamum indicum*) leaf and root extracts at concentrations of 0%, 5%, 25%, 50%, and 75% on the germination, root and shoot development, seedling growth, plant height, leaf count, fresh and dry weight, germination rate, germination percentage, and photosynthetically active radiation in maize and sorghum seedlings. The findings revealed that the highest germination rates occurred at 5% and 25% concentrations, as well as in the control plants, showing statistically significant differences at ($P<0.05$). Conversely, germination was reduced at 50% concentration and completely inhibited at 75% concentration in root extract treatments. Measurements of plumule and radicle length, along with fresh and dry weights, demonstrated notable differences in maize when compared to sorghum. Moreover, root growth exhibited greater sensitivity to the allelopathic effects than shoot growth, a pattern similarly reflected in plant height and leaf numbers. The vigor index, germination rate index, and germination percentage were highest in the 5%, 25%, and control treatments for both maize and sorghum, while these parameters were lowest at 50% and 75% concentrations. These results indicate that lower concentrations of leaf or root extracts exert minimal effects on germination and seedling development in both maize and sorghum, with the intensity of the impact being concentration-dependent.

Keywords— Allelopathic, Aqueous, Sesame, Leaves, Root, Germination, Seedlings, Growth, Maize, Sorghum.

1. Introduction

The rapidly growing global population has posed significant challenges to food security, demanding urgent attention from scientists and farming communities. The agricultural sector, particularly crop production, faces immense pressures due to various biotic and abiotic factors. Key threats include weeds, insect pests, diseases, imbalanced crop nutrition, allelopathy, and environmental stresses [12], [7]. Additionally, soil characteristics, growth stages, plant species, as well as plant biochemical and physiological traits, contribute to reduced productivity [5]. Sorghum [9], a drought-resistant crop in the Poaceae family, is an essential grain and food source. Originating in Eastern Africa, sorghum is now widely cultivated across Africa, India, China, the United States, and Mexico [15]. Alongside sorghum, maize serves as a staple food for many populations [12]. A member of the grass family Poaceae, maize surpasses wheat and rice in total production. However, not all maize is consumed directly by humans; it is also utilized for producing corn ethanol, animal feed, and various maize-based products such as corn starch and corn syrup. The six primary types of maize include dent maize, flint maize, pod maize, popcorn, flour maize, and sweet corn [13]. Allelopathy is a natural ecological process where organisms influence each other's functioning positively or negatively within their shared environment [7]. This phenomenon occurs due to the release of secondary metabolites known as allelochemicals [11]. These chemicals are byproducts of various physiological processes in plants [8], [2]. Common allelochemicals include phenolics, alkaloids, flavonoids, terpenoids, momilactones, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates, carbohydrates, and amino acids [14], [6]. These substances can influence target plants' growth, development, and physiological processes either positively or negatively. Allelochemicals can impact seed germination by altering cell membrane permeability, respiration, protein synthesis, gene expression, hormone equilibrium, and cell division. However, their effects are concentration-dependent, with high concentrations inhibiting growth and low concentrations promoting it [13], [8]. These compounds also persist in the environment during a plant's life cycle and through the decomposition of its residues [5]; [10]. In agricultural systems, allelopathy plays a vital role in crop interactions. Chemical compounds produced by plants, known as allelochemicals, are released through various mechanisms such as leaf litter decomposition, root exudation, and volatilization. These chemicals affect other plants through inhibitory or stimulatory effects, impacting germination, seedling growth, and development [6]. Sesame (*Sesamum indicum* L.), often referred to as the "Queen of Oil Seeds," is a valuable oilseed crop primarily grown in Northern Nigeria. A member of the family Pedaliaceae, it is known for its resilience and ability to thrive in harsh conditions, such as high temperatures and drought, with minimal farming inputs [9]. Historically, sesame has been cultivated in areas unsuitable for other crops, making it an essential crop for subsistence farmers. However, sesame's allelopathic properties have been observed to negatively impact neighboring crops, affecting their growth and productivity [7]. Despite its importance, there is limited research on the allelopathic effects of sesame on cultivated crops. This study aims to investigate the allelopathic impacts of sesame on the germination and growth of nearby plants, contributing to the understanding of its role in crop interactions [6].

Statement of the Problem

In numerous African countries, over 80% of the population relies on agriculture as their primary source of livelihood. However, poverty and malnutrition remain widespread, affecting a significant portion of the population. Enhancing agricultural productivity is essential for alleviating poverty and ensuring food security [14]. Sorghum (*Sorghum bicolor* L.) and maize are vital grain crops, particularly in arid regions, due to their drought tolerance. In northern Nigeria, sesame is also extensively cultivated. However, sesame has been observed to exert adverse allelopathic effects on other traditional crops grown in its vicinity [8].

The continuous cultivation of the same crop on the same land over time degrades soil health [15] and exacerbates pest and disease problems. Such challenges can be mitigated through practices like intercropping and mixed cropping. Studies have shown that sesame produces numerous allelochemicals, and understanding its allelopathic properties could help minimize its inhibitory impact on neighboring crops.

There is limited information on the allelopathic effects of sesame (*Sesamum indicum*) on the growth and productivity of intercropped plants. Research on the release of secondary metabolites by sesame through leaching and root exudation remains scarce. These compounds, known to elicit either stimulatory or inhibitory responses in surrounding plants, influence growth and development [13]. Additionally, sesame's allelochemicals are released through various plant parts, including roots, stems, leaves, flowers, and seeds [2]. Such allelopathic effects could significantly reduce the yields of sorghum and maize in northern Nigeria, warranting further investigation.

Objectives of the Study

This study aimed to assess the allelopathic effects of sesame on intercropped sorghum and maize in the same environment. The objectives of the study are:

i. To determine the effects of sesame leaf extracts on the germination and seedling growth of maize and sorghum seeds.
ii. To determine the effects of sesame root extracts on the germination and seedling growth of maize and sorghum.

Justification

Plants with allelopathic tendencies have been shown to significantly influence the growth and development of neighboring plants by inhibiting seed germination, reducing soil fertility, and negatively impacting yield productivity. Addressing poverty alleviation has become increasingly urgent due to the growing population. Sorghum and maize, as essential food crops, serve as staple foods for over 500 million people across more than 90 countries. These crops are primarily cultivated for their edible grains, particularly in developing regions [4]. Sesame, predominantly grown in the northern part of the country, has been reported to exert detrimental allelopathic effects on other crops cultivated in its proximity. It is crucial to conduct comprehensive research to assess how sesame's allelopathy influences the yields of sorghum and maize in this region. Furthermore, investigating sesame's allelopathic properties could assist in identifying suitable rotational crops that are compatible with sesame, thereby improving crop productivity and sustainability [13].

2. Related Work

The term *allelopathy* was first introduced in 1937 by Austrian scientist [12]. The word originates from the Greek terms "allelon," meaning "of each other," and "pathos," meaning "to suffer," reflecting the adverse effects organisms may exert on one another [1]. In 1996, the International Allelopathy Society defined allelopathy as "any process involving secondary metabolites produced by plants, microorganisms, viruses, and fungi that influence the growth and development of agricultural and biological systems (excluding animals), with both positive and negative effects" [8]. The concept of allelopathy dates back over 2,000 years. Around 300 BC, Theophrastus was the first to observe allelopathy, noting that chickpea (*Cicer arietinum*) plants hinder the growth of weeds [4]. Later, Pliny the Elder (Plinius Secundus, 1 A.D.) described the effects of exudates from plants like chickpea, barley (*Hordeum vulgare*), and bitter vetch (*Vicia ervilia*) on other plants and the environment [3]. In the 1600s, Japanese agronomists identified that red pine (*Pinus densiflora*) leaves, when washed by rain, had harmful effects on crops growing below [5]. During the same era, English botanists also observed that plants struggled to grow under red pine trees [7]. In 1832, DeCandolle attributed "soil sickness" in agriculture to root exudates [11]. Although this hypothesis was later refuted due to insufficient experimental evidence, it highlighted the need for scientific inquiry into allelopathy. Despite recognition of the phenomenon for two millennia, scientific research into allelopathy only began in the 20th century [10]. Compounds responsible for allelopathic interactions, known as allelochemicals, were identified in the mid-20th century [13]. These secondary metabolites, produced through acetate and shikimate acid pathways, include flavonoids, phenolic acids, alkaloids, terpenoids, coumarins, brassinosteroids, glucosinolates, and many more. Allelochemicals are found in various plant parts such as roots, stems, leaves, flowers, rhizomes, pollen, fruits, and seeds.

These substances are released into the environment through processes such as volatilization, root exudation, rainwater leaching, and decomposition of plant residues. Microbial activity can further enhance their production [8], [12]. Advances in analytical techniques for bioassays, extraction, isolation, and identification of allelochemicals have significantly enhanced our understanding of their roles in allelopathic interactions [6].

3. Theory/Calculation

Over the past three decades, considerable research has explored the potential influence of allelopathy on agricultural systems [4], [10], [6]. More recently, attention has focused on the use of allelopathy as a tool for weed suppression. Allelopathic plants offer promising strategies for reducing weed populations, improving soil fertility, and increasing crop productivity [4]. Allelopathic suppression of weeds has been documented in various crops, including barley (*Hordeum vulgare*), alfalfa (*Medicago sativa*), brassicas (*Brassica spp.*), sorghum (*Sorghum spp.*), sunflower (*Helianthus annuus*), oat (*Avena fatua*), rye (*Secale cereale*), rice (*Oryza sativa*), tobacco (*Nicotiana tabacum*), sesame (*Sesamum indicum*), wheat (*Triticum aestivum*), and clovers (*Trifolium spp.*) [9], [12], [2]. Research has shown that allelochemicals released by certain plants can inhibit the germination, growth, and development of weeds and competing crops, ultimately affecting yield [12], [5]. For instance, [1] reported that 25 rapeseed cultivars exhibited significant allelopathic effects on the shoot and root growth of several weed species, including *Amaranthus retroflexus* (redroot pigweed), *Solanum nigrum* (black nightshade), *Portulaca oleracea* (common purslane), *Physalis angulata* (cutleaf ground cherry), and *Echinochloa colonum*. Earlier, [11] proposed the application of allelopathic crops for weed management through methods such as crop rotation, intercropping, and cover cropping. Similarly, [15] demonstrated that interactions between cover crops (such as clover, hairy vetch, basil, and dill) and planting dates significantly influenced weed biomass. Allelochemicals are present in various plant parts, including leaves, roots, and flowers, with the highest concentrations typically found in leaves and roots [7], [3]. For instance, extracts from the shoots and roots of *Brassica* species have been shown to inhibit seed germination significantly, with germination rates reduced by up to 58.7% using *Brassica napus* stalk extract and 54.3% with *Brassica campestris* root extract [6], [1]. Allelochemicals and other secondary metabolites are introduced into the environment through various mechanisms, including root exudation, volatilization, leaching, decomposition of plant residues, and extraction. The type and concentration of these compounds in plant extracts, leachates, or decomposing materials determine their toxicity [13].

4. Experimental Method/Procedure/Design

Experimental Design

Greenhouse and laboratory experiments were conducted using a Completely Randomized Design (CRD) with two treatments, replicated four times. The study adopted a factorial approach involving two factors: sorghum (*Sorghum bicolor L.*), maize (*Zea mays L.*), and various concentrations of sesame (*Sesamum indicum*) extracts. A preliminary study was conducted beforehand to mitigate potential errors and other confounding factors during the main experiment.

Extract Preparation

Sesamum indicum plants were cultivated to full maturity on a farm. Once fully grown, plant parts (leaves and roots) were separated, cut into pieces approximately 2 cm in length, thoroughly washed, and dried at 80°C for 24 hours in an oven. The dried plant parts were ground into fine powder using a mortar and pestle and sieved through an 8.0 mm aperture wire mesh, as outlined by [15]. A 100 g sample of powdered material from each part was stored for analysis. To prepare crude extracts, 20 g of the powder from each part (leaf and root) was dissolved in 1 liter of distilled water. The resulting mixture was filtered through Whatman filter paper to create pure extract concentrations of 5%, 25%, 50%, and 75% for both leaves and roots.

Laboratory Experiment: Seed Culture and Treatment

The seed culture and treatment protocol was adapted from [10] with modifications tailored to this study. Seeds of sorghum and maize were sterilized in a water-to-bleach solution (10:1 v/v) for 5 minutes to prevent contamination. The seeds were then rinsed four times with sterile distilled water. For testing, 80 sterile Petri dishes (9 cm in diameter) were prepared. Each dish was labeled appropriately, lined with moist Whatman filter paper and tissue paper, and then ten sterilized seeds of either sorghum or maize were evenly spaced within the dishes. Seeds were soaked in distilled water (control) and various concentrations of sesame extract for 24 hours. To ensure proper seedling development, 10 ml of distilled water was added to keep the filter paper moist throughout the experiment.

a. Measured Parameters

i. Variables measured are;

a. Radicle length:- the length of the radicle (root) was measured using a ruler (cm).

b. Plumule length:- Length of plumule (shoot) length was measured using a ruler in cm

c. Fresh weight and dry weight (g):- was measured by using an electronic balance

ii. Germination percentage was calculated using the following equation [7]:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of the total seeds}} \times 100$$

iii. Vigor index:- Vigor index of the seedling was calculated by using the formula suggested by Abdul-Baki and Anderson (1973).

iv. Mean germination time(MGT) :- was calculated by using the equation

MGT= (n*d)/N, where n=no of seeds germinated on each day, d=no of days from the beginning of the test, and N=total no of seeds germinated at the termination of the experiment (Ellis and Roberts,1981)

v. Germination rate index :- was calculated using the formular

=(Gt/Dt) where Gt is the number of the germinated seed on day t and Dt is the time corresponding to Gt in days.

Measure parameters

i. Plant height :-the plant would be measured using a meter rule(cm)
ii. Number of leaves :- leaves of the plant would be counted
iii. Fresh root weight and fresh shoot weight
iv. Dry root weight and dry shoot weight
v. Photosynthetic activities such as CO_2,PAR and RH.

5. Results and Discussion

The impact of sesame leaf extract on the germination rate index and germination percentage was statistically significant at P<0.05P < 0.05P<0.05. The maximum germination rate index and germination percentage values of 13.98 and 11.38, and 92.5% and 85%, respectively, were recorded at the lowest extract concentrations of 5% and 25%, outperforming the control. Conversely, the lowest germination indices were observed at the 75% concentration for maize (Table 2). For sesame root extract, the highest germination rate index and percentage were seen in the control, while reductions were evident at concentrations of 5%, 25%, and 50%, with values of 11.38, 6.10, and 0.27 for the germination rate index and 70%, 37.5%, and 2.5% for germination percentage, respectively. At the highest concentration of 75%, no germination occurred at all (Table 2). Similarly, for sorghum, the sesame leaf and root extracts significantly influenced the germination rate index and germination percentage. The highest values were observed in the control, followed by the 5% and 25% concentrations, showing minimal differences between them. No germination was recorded in treatments with 50% and 75% concentrations (Table 3).

Table 2: Germination Parameters of Sorghum

Sesame part	Concentration	Germination Parameters (Mean±SE)					
		Germination rate index	Germination %	Vigor index	Fresh weight	Dry weight	Mean germination time
Leaf	Control	20.83±0.00a	100±0.00a	1247±108.04ab	0.13±0.03ab	0.02±0.00a	2.5±0.00d
	5%	17.56±0.63b	92.5±2.50a	786.75±55.08cd	0.09±0.01ab	0.03±0.00a	2.56±0.02cd
	25%	11.54±1.02c	70.00±4.10b	480.75±45.12e	0.13±0.01ab	0.35±0.00a	2.66±0.02a
	50%	0.00±0.00d	0.00±0.00d	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00e
	75%	0.00±0.00d	0.00±0.00d	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00e
Root	Control	20.83±0.00a	100±0.00a	1335±56.64a	0.13±0.03ab	0.02±0.00a	2.5±0.00d
	5%	17.40±0.44b	92.50±2.50a	993±88.33bc	0.11±0.01ab	0.03±0.01a	2.58±0.01bc
	25%	9.50±1.51c	55.00±6.50c	541.50±66.77de	0.27±0.16a	0.03±0.00a	2.64±0.03ab
	50%	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00b	0.00±0.00b	0.00±0.00e
	75%	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00b	0.00±0.00b	0.00±0.00e
	P-value	**0.000**	**0.000**	**0.000**	**0.190**	**0.000**	**0.000**

Note: Means with different alphabet across the column have significant variation at P < 0.05

The plumule and radicle length were also measured which shows that at all the treatment levels with the concentrations that germinated of both the sesame leaf and root extract significantly reduced as compared with the control (fig. 2,3,4 and 5) respectively.

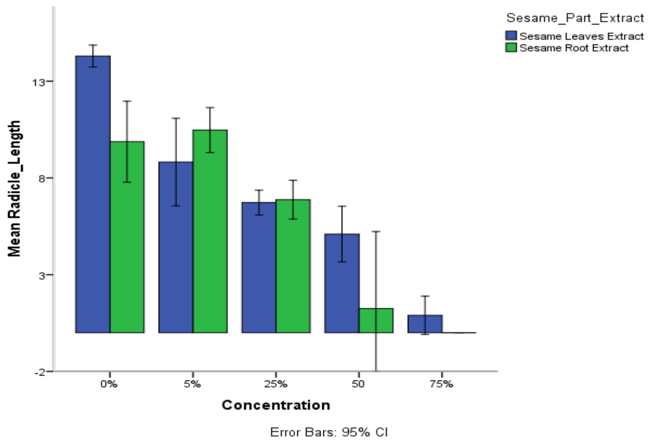

Figure 1: Radicle length of maize at different concentration of both leaf and root sesame extracts.

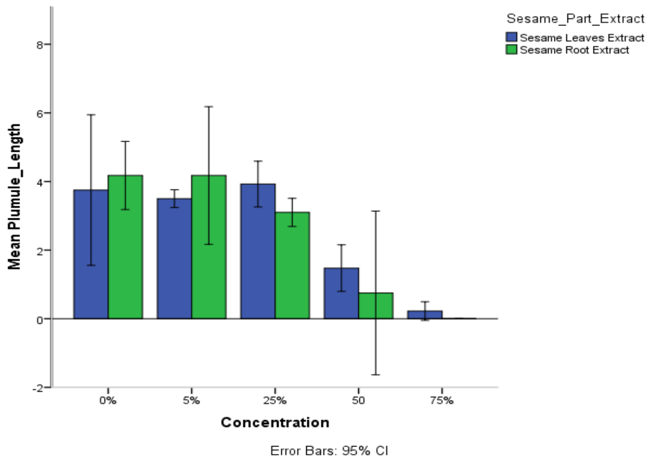

Figure 2: The plumule length of maize at different concentration of both leaf and root sesame extracts.

Discussion

The impact of sesame leaf and root extracts on the germination rate index and germination percentage demonstrated that the allelochemicals in these extracts exert inhibitory effects on maize and sorghum germination. Among the extracts, the root extract exhibited the highest inhibitory potential, followed by the leaf extract. This inhibition is likely caused by the interference of the extracts with seed physiological processes, as suggested by [8]. This aligns with findings reported by [14]. Similar results were reported by [3], who highlighted that the allelopathic effects vary depending on the plant parts from which the extracts are derived. Interestingly, as the extract concentrations increased, germination rates and percentages decreased, with the root extracts being more inhibitory than leaf extracts. Research has shown that allelochemicals have a stronger effect on roots than on seedling growth [9], [1], [6]. This study also revealed that sesame leaf and root extracts significantly impacted seedling growth, leaf number, and plant height in maize and sorghum. These effects were concentration-dependent, with the observed growth enhancement potentially due to the accumulation of higher concentrations of specific allelochemicals. As noted by [1], the allelopathic effects of plants are dependent on their type and concentration, where increased extract concentrations led to a decline in germination indices and growth characteristics while enhancing inhibitory effects. Both leaf and root extracts reduced plumule length, radicle length, and fresh and dry biomass in a concentration-dependent manner. The radicle length was more adversely affected than the shoot length, which is expected since roots are the first plant tissue to interact with allelochemicals [2]. These findings suggest that allelopathic aqueous extracts generally have a more pronounced effect on radicle growth inhibition than plumule growth [7], [13], [15]. Allelopathic effects of sesame extracts can either promote or inhibit companion plant growth and development [11]. Interestingly, the leachate from sesame had a stimulatory effect on the germination of *M. corchorifolia* seeds, possibly due to the growth-promoting nature of specific allelochemicals in the leachate, as opposed to the blended extract [3], [6]. Statistical analysis revealed significant differences in fresh weight at higher treatment concentrations compared to the control, although no significant difference was noted in dry weight.

The height, fresh weight, and dry weight of rice and sorghum grown in soil enriched with sesame residues were significantly lower, as observed by [2], [15], [6]. However, fresh root aqueous extracts of *Tithonia diversifolia* were reported by [5] to enhance shoot length and seedling fresh and dry weight in maize. Similarly, extracts from *Euphorbia serpens* leaves stimulated the growth of *Lactuca sativa* and *Cassia mimosoides* [8], while *Phytolacca americana* extracts promoted growth in other crops (Kim et al., 2005). Sesame extracts were observed to suppress radicle length in these crops, as roots are particularly sensitive to allelopathy. This study showed a consistent decline in radicle and plumule length with increasing aqueous extract concentrations, corroborating the findings of Sahu and Devkota, who noted significant inhibition of root and shoot growth in *Oryza sativa* by aqueous leaf extracts of *Mikania micrantha*. Furthermore, Jiang et al. observed a similar trend in two herb species influenced by root exudates from *Picea asperata*, emphasizing the critical role of radicle growth in overall plant development and the reflection of plumule growth on seedling growth rates.

6. Conclusion and Future Scope

The findings from this experiment demonstrate that sesame leaf and root extracts significantly affect both the germination and vegetative growth of maize and sorghum. The plants exhibited varied responses to the allelochemicals present in the extracts, with higher concentrations consistently showing an inhibitory effect. The pronounced inhibition observed, particularly at elevated concentrations, underscores the potential role of these allelochemicals in interfering with critical physiological processes required for seed germination and subsequent growth. The differential responses between maize and sorghum suggest that plant species have varying sensitivities to allelopathic compounds, which could be attributed to their unique genetic, physiological, and biochemical characteristics. Such variability highlights the complexity of plant-allelochemical interactions and suggests that the impact of these substances may be context-dependent, influenced by both the type of extract (leaf or root) and its concentration. These findings not only contribute to our understanding of the allelopathic properties of sesame but also offer practical implications. For instance, sesame extracts could potentially be explored for use as natural bio-herbicides in agricultural practices, particularly in controlling weeds or managing crop competition. However, the inhibitory effects on beneficial crops like maize and sorghum raise concerns about the broad applicability of this approach and necessitate careful evaluation of concentration levels and application methods.

Future Scope

1. Comprehensive Species Analysis: Future studies should examine the effects of sesame extracts on a wider range of plant species to better understand species-specific sensitivities and tolerance levels.
2. Chemical Profiling of Allelochemicals: A detailed chemical analysis of the bioactive compounds present in sesame leaf and root extracts is needed to identify the specific allelochemicals responsible for the observed inhibitory effects. This can aid in the development of targeted agricultural applications.
3. Application Methodologies: Research on optimal application techniques, such as foliar sprays or soil amendments, could help minimize negative impacts on non-target crops while leveraging the herbicidal properties of sesame extracts.
4. Environmental Impact Studies: The long-term effects of using sesame extracts on soil health, microbial communities, and overall ecosystem dynamics should be thoroughly investigated to ensure sustainable agricultural practices.
5. Concentration Threshold Exploration: Further experimentation is required to establish safe and effective concentration thresholds that balance the beneficial and inhibitory effects of sesame extracts on different crops.
6. Combination with Other Allelopathic Agents: Exploring the synergistic or antagonistic effects of combining sesame extracts with other natural plant-derived compounds could open new avenues for integrated weed and crop management strategies.

7. Potential for Breeding and Genetic Studies: Investigating the genetic basis of maize and sorghum sensitivity to allelochemicals could lead to the development of crop varieties with enhanced tolerance to allelopathic substances, improving their resilience in intercropping systems or in fields treated with sesame-derived products.

In conclusion, while this study establishes the inhibitory effects of sesame leaf and root extracts on maize and sorghum at higher concentrations, it also presents opportunities for further research to harness these properties in a controlled and sustainable manner. Understanding and managing the dual role of sesame extracts as both inhibitors and potential bio-herbicides could revolutionize certain aspects of agricultural science and practice.

Recommendations

The conclusions led to the following suggestions being made:

1. Farmers should avoid mixed cropping system with sesame plants since it's found to interfere with the germination and growth traits of these plant.
2. Farmers should dedicate a portion of land mainly for the cultivation of sesame because of its great economic and health importance.
3. It's also advisable farmers should also find a systematic ways of harvesting sesame in the farm so as to reduce the larger amount of leaves and roots left on the farmland, these will reduce their effects when they're decayed in the soil.

Conflict of Interest

This unique replica is not being considered for publishing anywhere and has not been disseminated. There are no conflicts of interest to declare as a result.

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Author Contributions

Each author made an equal contribution to this research thesis. They all looked over and verified the original manuscript's final draft.

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