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# Sorghum bicolor Water Extract as a Bioherbicide: A Comprehensive Literature Review

Edi Susilo[1*], Hesti Pujiwati[2], Wismalinda Rita[3]
[1]Agrotechnology Study Program,, Faculty of Agriculture, Ratu Samban University, St. Jenderal Sudirman No. 87 Arga Makmur Bengkulu Utara Regency
[2]Agroecotechnology Study Program, Department of Agronomy, Faculty of Agriculture, Bengkulu University, St. Raya Kandang Limun
[3]Animal Husbandry Study Program, Faculty of Agriculture & Animal Husbandry, University of Muhammadiyah Bengkulu, Bengkulu City, Indonesia.
**Corresponding Author:** Edi Susilo susilo_agr@yahoo.com

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A B S T R A C T

The use of synthetic herbicides in modern agriculture raises concerns about soil and water pollution, biodiversity loss, and health issues. These problems are already evident and must be addressed, as they may lead to declining agricultural yields and long-term risks to human health. Consequently, there is increasing interest in environmentally friendly herbicide alternatives. Sorghum, an allelopathic plant, should be considered for this purpose. It reliably produces the bioactive compound sorgoleone, which is environmentally friendly and can inhibit the growth of various weeds. Additionally, sorghum sugar may reduce weed biomass, enhance herbicide efficacy, and boost crop productivity. Sustainable agriculture systems have also explored weed control through rice straw. This task seeks to further explore sorghum water extract's potential as a bioherbicide and to reduce reliance on synthetic options. It also aims to evaluate challenges, create opportunities, and develop future prospects for weed management systems supporting sustainable agriculture, highlighting the potential development pathway of sorghum bioherbicides

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## INTRODUCTION

The widespread use of synthetic herbicides in modern agriculture raises several environmental and public health concerns (Murtilaksono et al., 2020). These include soil and water contamination, weed resistance, and negative impacts on biodiversity and human health (Susilo et al., 2021). Although synthetic herbicides offer high efficacy, specific modes of action, low costs, and a rapid return on investment, their excessive use has led to an increase in the number of resistant weed biotypes, reduced agricultural yields, environmental pollution, and health threats (Hasan et al., 2021).

Dependence on synthetic herbicides has driven the search for more environmentally friendly and sustainable alternatives, such as bioherbicides (Ghimire et al., 2020; Mudaningrat et al., 2023). Bioherbicides, which originate from living organisms or natural products, offer a promising approach to managing weeds without the harmful ecological consequences associated with synthetic chemicals (Zhang et al., 2025). With the growing appreciation for sustainable agriculture, the need for bioherbicides is crucial to reduce dependence on chemical herbicides (Soares et al., 2023).

One promising approach is the use of allelopathic plants such as sorghum, which produce bioactive compounds that suppress the growth of certain weeds (Kostina-Bednarz et al., 2023). Sorghum is a potential candidate for providing bioherbicides due to its ability to produce allelopathic compounds that can inhibit weed growth through several biochemical mechanisms (Kostina-Bednarz et al., 2023). The phenomenon of allelopathy involves the release of biomolecules by sorghum roots, stems, and seeds into the surrounding environment, which then affects the growth of other organisms (Hussain et al., 2021). Several studies have shown that treatment with sorghum water extract can significantly reduce weed biomass and density compared to control treatments (Susilo et al., 2021). Sorghum water extract has been used in conjunction with low-dose herbicides to enhance the effectiveness of broadleaf weed control and improve crop yields, as seen in the case of wheat (Susilo et al., 2021). Previous research has also shown that excessive use of synthetic herbicides can lead to low crop yields, as in the case of corn after the application of diquat dichloride (Alridiwsirah et al., 2020). Therefore, the exploration and development of sorghum water extract as a bioherbicide can contribute to a more sustainable and environmentally friendly agricultural system (Khamare et al., 2022). This also involves mitigating the adverse effects of pesticides and persistent organic pollutants in agriculture, which have caused bioaccumulation and high toxicity in humans (Atmiyati & Hermawati, 2025).

The increasing resistance of weeds to synthetic herbicides has made the need for effective and sustainable alternatives, such as bioherbicides, increasingly urgent (Anwar et al., 2021). Additionally, the use of mulch, such as rice straw, can complement the role of bioherbicides in suppressing weeds in wheat. Soil moisture helps prevent weed growth, although straw has the potential to become a medium for weed spread (Yalang et al. 2016). Therefore, shifting attention to sorghum as a source of bioherbicides, particularly for its allelopathic potential, through in-depth and intensive research is necessary in the context of agriculture and sustainable weed management (Rashid et al. 2020). On the other hand, one of the bioherbicide potentials of sorghum is due to its allelopathic compound, sorgoleone, which can inhibit weed growth (Naby & Ali 2021).

The bioactive compounds in sorghum can hurt weed growth and development, and have the potential to become the focus of attention in the development of sustainable weed management systems (Jabran et al. 2015). The emergence of herbicide-resistant weeds and the development of herbicides as inhibitors necessitate the creation of sustainable and environmentally friendly weed management systems. (Khamare 2023). This approach aligns with global efforts to reduce dependence on intensive agricultural inputs and adopt more ecological practices (Kostina-Bednarz et al., 2023). Therefore, this literature review aims to systematically analyze recent advances in the use of sorghum extracts as bioherbicides and evaluate their potential, mechanism of action, and factors affecting their effectiveness (Pardo-Muras et al., 2022). This includes an in-depth analysis of the phytochemical profile, extraction methods, and studies on its efficacy against various weed species, providing a solid basis for the future development of sorghum bioherbicides. This study will also analyze the challenges and prospects for further development of sorghum extract bioherbicides for practical application in the field (Kostina-Bednarz et al., 2023).

## LITERATURE REVIEW

The phenomenon of sorghum allelopathy involves several mechanisms, including cell membrane damage caused by phenolic compounds that disrupt cell membrane phospholipids, as well as the role of these compounds in regulating water and essential nutrient absorption (Murtilaksono et al., 2020). Phenolic compounds and flavonoids, such as kaempferol and quercetin, are involved in modifying the stress response of target plants through their antioxidant and anti-inflammatory activities.

These compounds also affect the activity of antioxidant enzymes and the production of reactive oxygen species in weeds, contributing to oxidative stress and cell damage (Scavo & Mauromicale, 2021). Additionally, allelochemicals can inhibit the activity of nitrate reductase and sucrose phosphate synthase, key enzymes in nitrogen assimilation and carbohydrate synthesis, thereby disrupting the basic metabolism of weeds (Hussain & Reigosa, 2021; Zhao et al., 2024; Ruminta et al., 2017). Various weeds have also been reported as allelopathic to sorghum, altering the membrane permeability and osmotic capacity of multiple weeds, which in turn inhibits the absorption of water and essential nutrients (Gam et al., 2024). Specifically, sorghum has been shown to induce changes in root morphology, including shortening and swelling, which disrupt nutrient absorption (Barrales-Cureño et al., 2022). Phenolic compounds, such as gallic acid, coumarin, and protocatechuate, are also present in other allelopathic plants and contribute to the mechanism of weed root growth inhibition (Murtilaksono et al., 2020). In-depth investigations have revealed that approximately 50 different phenolics, which can act as allelochemicals, are present in sorghum. However, the exact amount and composition likely vary depending on the variety, plant part, and environmental conditions (Weir et al., 2004). For example, caffeic acid has been shown to have the capacity to increase levels of reactive oxygen species in specific contexts.

The synergistic combination of complex secondary metabolites shows a significant increase in the efficiency of sorghum allelopathy, where each compound contributes to a broader and stronger spectrum of inhibitory effects on weeds (Scognamiglio & Schneider, 2020). This comprehensive variation in allelochemistry and the respective mechanisms of action highlight sorghum's potential as a powerful bioherbicide, a sustainable alternative to the use of synthetic herbicides (Mushtaq & Fauconnier, 2024). The potential utilization of sorghum root exudates to inhibit the growth of several cereal weed species (Naby & Ali, 2021). Qualitative and quantitative analysis of metabolite expression through metabolic profiling provides insights into the species-specific differences of contributing allelopathic plants (Anwar et al., 2021). The synergistic potential of complex secondary metabolites is crucial in the development of effective bioherbicides, considering the complex nature of interactions between various allelopathic molecules and target weeds (Schulz & Tabaglio, 2024). The release of phenolic allelochemical compounds into the soil causes direct interactions with weed root cells, affecting various ecological functions of weeds and thus providing a sustainable alternative to synthetic herbicides with minimal soil residual impact due to rapid degradation (Mushtaq & Fauconnier, 2024). This is supported by evidence that allelochemicals can inhibit key physiological processes, such as cell division, leading to oxidative stress and cellular structural damage (Tucuch-Perez et al., 2025).

This approach has the potential to maximize the controlled release of active ingredients while providing effectiveness under various environmental conditions (Yue et al., 2022). The identification and isolation of specific allelopathic compounds from sorghum, such as sorgoleon, along with a deep understanding of their mechanism of action, will be crucial for the development of more targeted and efficient bioherbicide formulations (Hussain et al., 2022). Metabolomic studies on sorghum have revealed the production of several allelopathic secondary metabolites, including sinapic acid, p-hydroxybenzoic acid, and quercetin, which collectively contribute to the herbicidal effect (Barrales-Cureño et al., 2022). Several important metabolites of allelopathy have been identified from sorghum and included in metabolomic studies, namely sorgoleon, bergapten, xanthotoxin, apigeninidin, luteolinidin, and spermidin dicaffeoyl, all of which have been confirmed to control weeds (Barrales-Cureño et al., 2022). Further research on the biosynthesis pathways of these metabolites is necessary for the practical application of sorghum genetic engineering to enhance the production of allelopathic compounds (Barrales-Cureño et al., 2022). Understanding these pathways will also facilitate more effective cultivation strategies to maximize the allelochemical properties of sorghum extracts (Barrales-Cureño et al., 2022; Rahaman et al., 2022). Optimal sorghum cultivation and breeding with high concentrations of allelochemicals will be a strategic step toward enhancing the bioherbicide potential of the plant. The complex combination of these secondary metabolites demonstrates significant synergies for improving the effectiveness of sorghum allelopathy, with each compound contributing to a broader and more robust spectrum of effects in weed suppression.

Current research is also investigating the possibility of genetic modification in sorghum to further enhance the production of allelopathic compounds, aiming to produce varieties with improved bioherbicide activity (Mushtaq & Fauconnier, 2024). Additionally, a transgenic approach with increased expression of key genes in the allelochemical biosynthesis pathway offers an innovative avenue for next-generation sorghum bioherbicides (Mizutani, 1999). Due to the potential of allelochemicals as an environmentally friendly alternative to synthetic herbicides, the use of allelochemicals in weed management has attracted considerable research attention (Ain et al., 2023). However, the use of synthetic herbicides remains widespread due to their high effectiveness, low production costs, and challenges in mitigating weed resistance, as well as adverse environmental and health consequences (Rahaman et al., 2022). Therefore, it is highly relevant to develop effective and economical sorghum bioherbicides to reduce dependence on synthetic products (Macías, 1994). Modern approaches to developing new herbicides are based on natural products, such as those found in sorghum. They may be a key solution to the problems of weed resistance and environmental contamination caused by the use of synthetic herbicides (Berestetskiy, 2023). That is why research and innovation in the field of sorghum-based bioherbicides, utilizing natural bioactive compounds, are crucial for sustainable agriculture in the future (Hickman et al., 2020).

Significantly altering the biosynthesis of sorghum secondary metabolites and elicitation methods to enhance allelopathy pharmacologically will be crucial (Venkatasai et al., 2025). The potential application of sorghum water extracts as bioherbicides extends beyond the laboratory, also showing promise in field trials for suppressing weed growth in various crops. The increase in sorghum harvest area from 2009 to 2011 reflects the agronomic potential of this crop and the need to organize it in intercropping systems to prevent competition for space and nutrient uptake (Haumein, 2020). However, intercropping sorghum with peanuts has been shown to reduce nutrient competition due to the different root systems and nitrogen fixation ability of peanuts (Haumein, 2020). The potential of sorghum as a bioherbicide can be further enhanced by integrating sustainable agricultural practices such as crop rotation and organic mulching to create a more holistic and effective weed management system (Hickman et al., 2020). Additionally, exploring local sorghum varieties with superior allelopathic characteristics could open up new opportunities for developing more appropriate bioherbicides that can adapt to local environmental conditions.

The development of sorghum-based bioherbicides by Khamare et al. (2022) also supports the development of sustainable weed management strategies, given the negative environmental and public health impacts of synthetic herbicides (Mahé et al., 2022; Kostina-Bednarz et al., 2023). This development aligns with the principles of sustainable agriculture, which strive to maintain a balance between food production and environmental protection, particularly when combined with efforts to raise farmers' awareness of the importance of soil health (Irnawati et al., 2025). This integrated approach not only increases the effectiveness of weed control but also contributes to improved soil fertility and agroecosystem biodiversity. Furthermore, the evaluation of the residual effects of manure use and planting distance on the growth and yield of sorghum intercropped with beans demonstrates the synergistic benefits of such integrated agricultural practices. Optimizing cropping patterns and fertilization strategies in intercropping systems with sorghum has the potential to increase land use efficiency and reduce natural weed growth (Haumein, 2020). This supports the concept of sustainable agriculture, which combines ecology and economics to maximize production while minimizing adverse environmental impacts (Haumein, 2020). Determining planting distance is also important, and in intercropping systems, it depends on soil fertility and moisture content. This becomes even more critical to support the quality and quantity of production in intercropping systems (Haumein, 2020). The application of intercropping systems with sorghum has also proven effective in suppressing weeds, thereby reducing the need for intensive weed control practices that support organic farming (Raharjo & Delang, 2020; Rad et al., 2020). The development of sorghum varieties with better allelopathic properties and adaptability to intercropping systems will optimize the benefits of bioherbicides and enhance sustainable land use (Haumein, 2020). This aligns with the Sustainable Agriculture strategy, which focuses on functional diversification in cropping systems to meet the Green Deal 2050 targets (Pedrol & Puig, 2024). Additionally, studies on the effectiveness of sorghum water extracts against specific weed species under various environmental conditions will improve understanding of the bioherbicide's activity spectrum. This will also support the development of more stable and target-specific bioherbicide formulations, enabling the incorporation of sorghum extracts into integrated weed management programs (Abreu et al., 2025).

A study on the effect of defoliation age and compost residue in a sorghum intercropping system with legumes shows the potential to increase productivity and control weed species, thereby contributing to a holistic approach to sustainable agriculture (Raharjo & Delang, 2020). Further exploration of defoliation and the type of compost used is a process that can maximize weed control and increase the productivity of intercropping systems (Raharjo & Delang, 2020). The use of intercropping not only optimizes land and resource use but also contributes to reducing the risk of crop failure and improving soil through natural nitrogen fixation and erosion control (Raharjo & Delang, 2020). This approach also reinforces the concept of sustainable agriculture by reducing dependence on external inputs and increasing the efficiency of natural resource utilization (Raharjo & Delang, 2020; Ebbisa et al., 2025; Siantar et al., 2019). Further studies are needed to determine the optimal concentration and application timing of sorghum water extract for specific crops, taking into account the crop's phenological stage and prevailing agroecological conditions (Nikolić et al., 2023). Combining sorghum water extract with adjuvants or formulations that enhance the activity of certain microbial herbicides can further improve its effectiveness in weed control (Rajakumar et al., 2025).

Environmental sustainability can play a crucial role in Integrated Weed Management strategies, reducing dependence on synthetic herbicides and supporting sustainable agriculture (Parven et al., 2024). Further studies on the genetic characteristics of sorghum in relation to allelochemical production could facilitate the identification and breeding of superior varieties for bioherbicides (Kostina-Bednarz et al., 2023). The use of intercropping systems, such as sorghum and peanuts, also shows great potential for increasing land efficiency and reducing weed competition naturally, given the ability of peanuts to fix atmospheric nitrogen and the differences in root systems that reduce nutrient competition (Haumein, 2020). Additionally, selecting sorghum varieties with high seed vigor for intercropping systems can contribute to increased overall land productivity (Siantar et al., 2019). However, the development of sorghum bioherbicides requires an in-depth exploration of the isolation, characterization, and testing of specific allelochemicals produced by various allelopathic sorghum varieties, aiming to develop more effective and target-specific biological herbicides (Tibugari et al., 2022). This research should also explore the potential synergism of other bioherbicide active ingredients with sorghum allelochemicals for more comprehensive weed control.

Another factor is optimizing growth conditions to maximize the production of allelopathic compounds in sorghum, which is crucial for designing cultivation strategies that enhance the effectiveness of bioherbicides. Ahmed & Al-Sayed (2016). However, stability studies for sorghum aerial extracts under various storage conditions are needed to ensure consistency within the desired range of effects. Previously unused methodologies, particularly in formulation, encapsulation, and microencapsulation, can extend the shelf life and stability of sorghum extracts, thereby overcoming the challenge of active compound degradation in the field. The impact of nanotechnology on bioherbicide production and sorghum extracts is likely to improve sorghum's ability to penetrate target plants more effectively and reduce negative consequences for cultivated target plants. Rashid et al (2020). Field trials should be conducted in various agroecosystems to test the effectiveness and reliability of sorghum-based bioherbicides. Combining field trial data with predictive modeling can improve recommendations for the use of sorghum bioherbicides for specific soil and climate conditions.

Although the potential of bioherbicides derived from sorghum is promising, further research on the potential effects of sorgoleone on soil microbial communities and soybean nodule formation in intercropping systems is also crucial to ensure agronomic compatibility and sustainability (Medeiros et al., 2025). Studies on the dynamics of interactions within the soil microbiome and allelochemical compounds are crucial for understanding the ecological mechanisms underlying the effectiveness of these bioherbicides and for mitigating the potential adverse effects on agricultural ecosystems (Fadiji et al., 2025). A better understanding of sorghum metabolism, and more specifically, sorghum antioxidant activity, particularly in diastatic sorghum flour, will have a positive impact on other applications beyond bioherbicides, including food safety and nutrition (Adnan et al., 2024). This multifaceted approach reflects sorghum's potential as a versatile crop that supports and enhances several dimensions of sustainable agriculture, from weed management to improved food nutrition (Hussain et al., 2021). The implementation of sustainable agricultural practices that integrate sorghum bioherbicides necessitates a careful economic assessment of production costs, application costs, and long-term economic benefits in comparison to synthetic herbicides (Rajakumar et al., 2025).

**METHODOLOGY**

This study aims to catalog and analyze the available literature that meets industry standards regarding the use of sorghum water extract as a biopesticide. This study employs a systematic literature review methodology, as outlined in the PRISMA framework. The literature review was conducted using leading databases, including Scopus, Web of Science, Google Scholar, and PubMed. It included various published literature from 2010 to 2025, as well as studies on the keywords "water extraction," "bioherbicide," "sorghum allelopathy," and "Sorghum bicolor," utilizing Boolean operators to narrow down the results.

Inclusion criteria included primary research articles, review papers, and conference papers discussing sorghum water extract and its effectiveness, mechanisms, or formulation as a bioherbicide. Irrelevant studies on sorghum as a food/feed crop that were also outside the time range were included, and duplicate articles for prospective studies were removed from them. Selection was based on screening paper titles and abstracts, followed by full-text evaluation by several peer reviewers to reduce bias, along with the use of quality assessment instruments such as CASP.

This includes the type and method of extraction, test weed species, effectiveness results, and other details of the experiment. This is done to analyze narratively and thematically, and then measure the relevance and impact of the review based on a bibliometric approach. A prism flowchart is used to show the results of the selection process transparently. This systematic approach ensures that only relevant, high-quality, and credible literature is used to build a scientific basis for sorghum water extract as a biopesticide.

**RESULTS AND DISCUSSION**

Referring to the systematic analysis of the articles studied, this analysis reveals that sorghum water extract has the potential to be a natural bioherbicide with varying allelopathic properties at different concentrations, extraction methods, and weed types (Putri & Rohmah, 2025). There are bioactive compounds in sorgoleone, including flavonoids and phenolic compounds, as well as sorghum water extract, that contribute to inhibiting weed germination and growth through several biochemical mechanisms (Zhang et al., 2025). These mechanisms include the inhibition of photosynthesis, protein synthesis, and the destruction of weed cell membranes, which may contribute to the herbicidal properties of the extract (Venkatasai et al., 2025). Numerous studies have confirmed that sorghum water extract is effective against a variety of weeds, even monocotyledonous and dicotyledonous types, making it noteworthy in integrated weed management. This article discusses the characteristics, challenges, and benefits of sorghum water extract, as well as the economic and environmental efficiency of alternatives to the widespread use of synthetic herbicides in the field, explaining the findings from in vitro and in vivo experiments.

Original and follow-up research on the hypothesis that the widespread use of synthetic herbicides in the field results in relatively lower economic and environmental efficiency has yielded positive results (Idarwati et al., 2023). In vitro and in vivo studies have demonstrated the effectiveness of sorghum water extract against weeds such as Echinochloa Crus-Galli, Amaranthus spp., and Cyperus Rotundus, sometimes comparable to and, in some cases, greater than several synthetic herbicides used at specific doses (Afa et al., 2023). Young sorghum shoot extract, extracted with ethanol-acetate, for example, is highly effective in inhibiting the germination of many weed species, such as Echinochloa crus-galli, Digitaria sanguinalis, Abutilon avicennae, and Amaranthus retroflexus, and has great potential for practical application in weed management (Le et al., 2018). Further research has shown that sorghum extracts have strong allelopathic activity, significantly inhibiting weed growth (Le et al., 2018). Specifically, the bioherbicide activity of sorghum extracts was found to be concentration-dependent, i.e., the higher the extract concentration, the greater the inhibition of weed growth (Anwar et al., 2021). Sorgoleone, one of the oldest allelochemical compounds produced by sorghum roots, has been identified as primarily responsible for this inhibitory activity, particularly in inhibiting weed growth and chlorophyll content (Naby & Ali, 2021; Hussain et al., 2021).

Sorghum exhibits the allelopathic chemical compound sorgoleone, along with several phenolic and flavonoid compounds found in sorghum extracts, which mediate allelochemical action by altering the biochemistry and physiology of target weeds (Le et al., 2018). The potential application of sorghum extract as a bioherbicide can be expanded with intercropping systems with other crops such as peanuts, which increase land use and nutrient uptake without excessive competition (Haumein, 2020). Indeed, intercropping legumes such as peanuts with sorghum can increase the efficiency of biological nitrogen use, reduce dependence on synthetic fertilizers, and suppress synergistic weed growth through the allelopathic effects of sorghum (Haumein, 2020). This not only increases land productivity but also minimizes the negative environmental impact of synthetic herbicides, aligning with the principles of sustainable agriculture (Rashid et al., 2020; Haumein, 2020). In addition, the use of sorghum crop residues incorporated into the soil has also been found to delay the germination of weeds, such as rice or Shama grass. It has shown potential for sustainable weed suppression through allelopathy from post-harvest crop residues (Khaliq et al., 2011). This suggests that post-harvest sorghum residue management can offer a practical option for integrated weed control programs, thereby minimizing the use of chemical herbicides (Akondo et al., 2024). The application of sorghum water extract as a bioherbicide offers an environmentally friendly and sustainable approach to weed management.

The emergence of weeds aligns with the demands of modern agriculture, particularly in ecology-based weed control (Kostina-Bednarz et al., 2023). Allelopathy, a chemical interaction between plants, can reduce dependence on synthetic herbicides and the associated risk of contamination (Khamare et al., 2022). Thus, sorghum-based bioherbicides are an alternative for weed control that considers the impact on health and the environment (Khamare et al., 2022). For the development of bioherbicides, innovative formulations such as nanoparticles and concentrated liquids need to be introduced to improve the effectiveness and stability of sorghum water extracts (Khamare et al., 2022). The combination of phytotoxic extracts with herbicides has the potential to reduce herbicide use while still providing sustainable weed control (Sołtys-Kalina et al., 2013). This approach mitigates the negative effects of herbicides and enhances the diversification of weed control methods, thereby enhancing sustainability in agricultural management. This approach aligns with the sustainable management of herbicide synthesis and environmental pollution (Scavo & Mauromicale, 2021; Anwar et al., 2021).

Although the potential use of sorghum water extract as a bioherbicide has been well documented in the literature, its implementation still faces several challenges that require further attention in research and development. One challenge is the variability in the phytochemical composition of the extract, which is influenced by genetics, environmental conditions, and extraction methods, resulting in a lack of uniformity and efficacy in the field. Additionally, the rapid degradation of chemical allelochemicals in sorghum water extracts under open-field conditions is a limitation, reducing the duration of their herbicidal activity and necessitating repeated applications (Anwar et al., 2021). The formulation of bioherbicides based on sorghum water extracts can be improved through encapsulation and the use of stabilizers, which can increase their durability and efficacy in the field (Kostina-Bednarz et al., 2023). Furthermore, research is also warranted to determine the effective concentration of the extract and the frequency of application that is considered safe for cultivated plants and related ecosystems.

Integrating sorghum-based bioherbicides into sustainable agricultural systems shows great potential for reducing dependence on synthetic herbicides (Scavo & Mauromicale, 2021). The use of sorghum allelopathy, either through extracts or intercropping, is a promising strategy for sustainable agriculture and reducing environmental pressure (Kostina-Bednarz et al., 2023). Further development of sorghum water extracts as bioherbicides could promote more environmentally friendly and sustainable agricultural practices while addressing growing public concerns about the adverse effects of synthetic herbicides (Khamare et al., 2022). However, for widespread adoption to occur, research must focus on developing stable formulations with efficient application methods, as well as evaluating the long-term impact on soil biodiversity and non-target organisms. Future research should also investigate promising sorghum varieties with high allelochemical concentrations, such as IS9456, for the development of stronger and more specific bioherbicides (Tibugari et al., 2022). Detailed studies on the allelochemical profiles of these sorghum varieties will be crucial for understanding the mode of action and optimizing bioherbicide formulations (Anwar et al., 2021). Additionally, the potential synergy of sorghum allelochemical compounds with other biological control agents should be investigated for the development of more efficient and integrated weed management approaches.

Research examining the ecotoxicological impact of sorghum bioherbicides remains limited, necessitating a deeper understanding of their mode of action and non-target effects to refine their application (Kostina-Bednarz et al., 2023). The development of sorghum bioherbicides must also emphasize the socio-economic considerations of their use to ensure long-term commercial viability and acceptance by farmers (Scavo & Mauromicale, 2021). Further studies should focus on determining the most beneficial concentrations and application times for specific crops, taking into account the crop's phenological stage and prevailing agro-ecological conditions (Nikolić et al., 2023). The use of smart technologies and artificial intelligence has the potential to improve pre-harvest practices and facilitate the development of efficient production systems (Zhao et al., 2024). The field of allelopathy research is multifaceted, and further studies are needed to understand specific molecular compounds, allochemical interaction mechanisms in plant physiology, weed biochemistry, and the targeting of agronomic species (Ahmed & Al-Sayed, 2016). Comprehensive field testing in various agricultural ecosystems is also crucial for validating the effectiveness and consistency of sorghum-formulated bioherbicides across different environments.

The development of bioherbicides from sorghum water extracts will require further extensive assessment of their efficacy in relation to their herbicidal properties against various types of weeds before they can be recommended to farmers (Le et al., 2018). In addition, studies investigating the potential additional effects of sorghum water extract with low-dose synthetic herbicides will aid in the development of more effective and sustainable integrated weed management (Scavo & Mauromicale, 2021). Furthermore, studies should focus on sorghum extracts in identifying the allelochemical compounds involved in the allelopathic effects exhibited by sorghum, through fractionation and identification steps, as well as testing them in field situations (Adhikary, 2019). This study will help elucidate the unexplained mechanisms of sorghum allelopathy and aid in the development of more targeted and specific bioherbicides.

However, it can be concluded that intercropping sorghum with other crops such as peanuts has been shown to increase land efficiency and nutrient uptake without causing harmful competition, while also utilizing the allelopathic properties of sorghum to suppress weeds (Haumein, 2020). Research shows that the combined cultivation of sorghum and peanuts not only optimizes land use but can also contribute to natural weed suppression through the release of allelochemicals from sorghum (Haumein, 2020). This approach is highly relevant for diversifying agricultural systems and enhancing local food security (Rusmayadi et al., 2023; Haumein, 2020). Furthermore, the synergy between agroforestry and precision agriculture approaches, through the integration of sorghum as an allelopathic plant, can provide an innovative model for comprehensive agricultural sustainability (Rusmayadi et al., 2023). To validate the potential of sorghum allelopathy in the field, it is essential to conduct a comprehensive characterization of field competition plants and carefully measure these traits, as well as measure the allelopathic potential of plants with sorghum through additional controlled experiments or field allelochemical measurements (Mahé et al., 2022). Methods such as using sorghum mulch or planting sorghum as a cover crop can be effective strategies for natural weed management (Khamare et al., 2022).

Weeds in agriculture and their management remain a significant problem, and instead of using environmentally harmful chemical herbicides, researchers and farmers are seeking more environmentally friendly methods to manage weeds in agriculture (Jabran et al., 2015; Khamare et al., 2022). Essentially, allelopathy is the use of environmentally friendly methods in weed management and the reduction of chemical herbicide use (Khamare et al., 2022). One of the challenges in the allelopathy agricultural system is the large number of plants, weeds, and environments involved, making it difficult to achieve a deep understanding and effective ways to break down this complex agricultural system (Muhammad et al., 2019; Pedrol & Puig, 2024). Intercropping sorghum with peanuts in agricultural land management that is still under weed management, and developing potential in the field of sustainable agriculture (Haumein, 2020). In intercropping, many livestock manures have been implemented, which are said to offer significant potential for enhancing agricultural land and sorghum growth (Haumein, 2020).

Fertilizer residues in agriculture are often overlooked, but organic fertilizer residues serve as a reserve of nutrients that can be reused by plants in subsequent plantings. In agricultural land used for peanut cultivation, the effect of organic fertilizer residues on sorghum intercropping remains overlooked (Haumein, 2020). In sustainable agricultural practices, intercropping systems have not been widely implemented to study the effects of corn leaf defoliation age and compost residues (Raharjo & Delang, 2020). Future research should thoroughly explore the effects of various types of organic residues and defoliation management on sorghum allelopathy activity and its impact on weed communities (Raharjo & Delang, 2020). This approach has the potential to develop more integrated and efficient strategies for weed management, aligning with the principles of sustainable agriculture, which aim to reduce dependence on synthetic chemical inputs (Khamare et al., 2022). However, the challenge of isolating and identifying active allelochemical compounds under dynamic field conditions remains a key focus for the development of effective bioherbicides (Mahé et al., 2022; Khamare et al., 2022).

However, only a small fraction of plants with allelopathic activity have been recognized as bioherbicides, despite more than 2,000 plant species being known to exhibit strong allelopathic effects (Kostina-Bednarz et al., 2023). Comprehensive studies on the complex interactions between allelochemicals and soil microbiomes remain important for understanding the dynamics of release, degradation, and availability of sorghum bioherbicides in the environment (Fadiji et al., 2025). Furthermore, understanding post-harvest sorghum plant residues and how they release allelochemicals into the soil can provide valuable insights into post-harvest weed management (Putnam & Duke, 1978). The application of rice straw mulch can also benefit crops by increasing nitrogen concentrations, along with other essential nutrients, and suppressing weed growth (Afa et al., 2023; Yalang et al., 2016). Additionally, an assessment of the long-term impact of sorghum intercropping practices on soil health and soil microorganism diversity will also be needed (Haumein, 2020).

## CONCLUSION AND RECOMMENDATION

Sorghum's ability to control certain weeds is partly due to sorgoleone, a phytotoxic chemical released from sorghum roots that suppresses the germination and growth of weed seedlings. In addition to sorgoleone, other phytochemicals released from sorghum roots, such as phenolics, flavonoids, tannins, and organic acids, contribute to weed growth inhibition. However, the effectiveness of weed growth control from sorghum extracts also depends on the extraction technique, extract concentration, plant tissue used, plant age, and environmental conditions. Although sorghum phytochemicals are highly biodegradable and environmentally friendly, variations in formulation and field challenges persist, affecting stability and consistency. Further studies are needed to investigate the various ways in which extraction techniques, formulations, and environmental conditions impact the effectiveness of sorghum phytochemicals.

With phytochemicals from sorghum extracts, the development of technologies such as nanoemulsions can increase the effectiveness of these components, maintaining the biodegradability of sorghum in weed growth control. The use of modern technologies such as drip irrigation and drones can also help improve field application. Investigating the potential of sorghum nanoemulsion extract technology to improve target weed control is also a priority. Understanding sorghum phytochemicals and their modern applications is key to discovering new and effective sorghum bioherbicides.

## FUTHER STUDY

Research on sorghum water extract presents an innovative approach to weed control, supporting sustainable agriculture; however, its effectiveness still faces challenges related to application stability under various environmental conditions.

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**REFERENCES**


Abreu, L. da S., Júnior, E. da S. P., Santos, I. B., Dantas, F. A. L., Cavalcante, J. C. S., & Silva, J. V. (2025). The benefits and applications of consortium systems for sustainable agriculture. Emirates Journal of Food and Agriculture, 37(1). https://doi.org/10.3897/ejfa.2025.153928

Adhikary, S. P. (2019). Efficacy of rice-stubble allelochemicals on vegetative growth parameters of some oil-yielding crops. International Journal of Trend in Scientific Research and Development, 1. https://doi.org/10.31142/ijtsrd20251

Adnan, A., Hastuti, C. O. I., Hadiarto, A., Lestari, I. P., Haryati, Y., Indrasti, R., Cahyaningrum, H., Qomariyah, N., Permana, D., Nurmalinda, Ariningsih, E., Jayanegara, A., & Wijaya, A. (2024). Evolving paradigms in sorghum research: A bibliometric and content analysis of global trends and future directions. International Journal of Design & Nature and Ecodynamics, 19(3), 887. https://doi.org/10.18280/ijdne.190318

Afa, L. O., Akmal, A., Karimuna, L., & Safuan, L. O. (2023). The effect of rice straw mulch residue and organic plus fertilizer on the production of sticky corn (Zea mays ceratina Kulesh). Scientific Journal of Village and Agricultural Development, 8(2), 45. https://doi.org/10.37149/jimdp.v8i2.324

Ahmed, T., & Al-Sayed, N. H. (2016). Allelopathic effects of Casuarina equisetifolia L. on seed germination of some crop plants and their associated weeds. https://doi.org/10.5339/qproc.2016.qulss.43

Ain, Q., Mushtaq, W., Shadab, M., & Siddiqui, M. B. (2023). Allelopathy: An alternative tool for sustainable agriculture. Physiology and Molecular Biology of Plants, 29(4), 495. https://doi.org/10.1007/s12298-023-01305-9

Akondo, S., Ahmed, M. T., Uddin, M. R., & Sarker, U. K. (2024). Combined application of herbicide and aqueous extract of sorghum and mustard crop residue enhances weed management and yield of wheat. Journal of Agroforestry and Environment, 17(2), 1. https://doi.org/10.55706/jae1710

Alridiwirsah, A., Tampubolon, K., Sihombing, F. N., Barus, W. A., Syofia, I., Zulkifli, T. B. H., & Purba, Z. (2020). Screening and effectiveness of secondary metabolites of Mikania micrantha on Jajagoan weeds and their impact on paddy rice. Agrotechnology Research Journal, 4(2), 84. https://doi.org/10.20961/agrotechresj.v4i2.44976

Anwar, S., Naseem, S., Karimi, S., Asi, M. R., Akrem, A., & Ali, Z. (2021). Bioherbicidal activity and metabolic profiling of potent allelopathic plant fractions against major weeds of wheat—Way forward to lower the risk of synthetic herbicides. Frontiers in Plant Science, 12. https://doi.org/10.3389/fpls.2021.632390

Atmiyati, S. U., & Hermawati, I. (2025). Effectiveness of agricultural extension programs in promoting environmentally friendly agricultural practices: A case study in Sawangan District, Magelang Regency. SOSIAL: Jurnal Inovasi Pendidikan IPS, 5(3), 1119. https://doi.org/10.51878/social.v5i3.6930

Barrales-Cureño, H. J., Herrera-Cabrera, B. E., Montiel-Montoya, J., López-Valdez, L. G., Salgado-Garciglia, R., Ocaño-Higuera, V. M., Sánchez-

Herrera, L. M., Lucho-Constantino, G. G., & Zaragoza-Martínez, F. (2022). Metabolomics studies of allelopathy: A review. Revista Colombiana de Ciencias Químico Farmacéuticas, 51(1). https://doi.org/10.15446/rcciquifa.v51n1.102693

Berestetskiy, A. (2023). Modern approaches for the development of new herbicides based on natural compounds. Plants, 12(2), 234. https://doi.org/10.3390/plants12020234

Ebbisa, A., Dechassa, N., Bekeko, Z., & Liben, F. (2025). Residual effect of vermicompost and preceding groundnut on soil fertility and associated Striga density under sorghum cropping in Eastern Ethiopia. PLoS ONE, 20(3). https://doi.org/10.1371/journal.pone.0318057

Fadiji, A. E., Adeniji, A. A., Lanrewaju, A. A., & Babalola, O. O. (2025). Dynamics of soil microbiome and allelochemical interactions: an overview of current knowledge and prospects. Annals of Microbiology, 75(1). https://doi.org/10.1186/s13213-025-01812-y

Gam, H., Injamum-Ul-Hoque, Md., Kang, Y., Ahsan, S. M., Hasan, Md. M., Shaffique, S., Kang, ·Sang-Mo, & Lee, I. (2024). Allelopathic effect of the methanol extract of the weed species-red sorrel (Rumex acetosella L.) on the growth, phytohormone content and antioxidant activity of the cover crop - white clover (Trifolium repens L.). BMC Plant Biology, 24(1). https://doi.org/10.1186/s12870-024-05240-z

Ghimire, B. K., Hwang, M. H., Sacks, E. J., Yu, C. Y., Kim, S., & Chung, I. M. (2020). Screening of Allelochemicals in Miscanthus sacchariflorus Extracts and Assessment of Their Effects on Germination and Seedling Growth of Common Weeds. Plants, 9(10), 1313. https://doi.org/10.3390/plants9101313

Hasan, M., Mokhtar, A. S., Rosli, A. M., Hamdan, H., Motmainna, Mst., & Ahmad‐Hamdani, M. S. (2021). Weed Control Efficacy and Crop-Weed Selectivity of a New Bioherbicide WeedLock. Agronomy, 11(8), 1488. https://doi.org/10.3390/agronomy11081488

Haumein, A. (2020). Uji Residu Pupuk Kandang Sapi dan Jarak Tanam Sorgum (Sorghum bicolor L.) terhadap Pertumbuhan dan Hasil Tanaman Kacang Tanah (Arachis hypogeae L.) dalam Tumpangsari. Savana Cendana, 5(2), 27. https://doi.org/10.32938/sc.v5i02.930

Hickman, D. T., Comont, D., Rasmussen, A., & Birkett, M. A. (2023). Novel and holistic approaches are required to realize allelopathic potential for weed management [Review of Novel and holistic approaches are required to realize allelopathic potential for weed management]. Ecology and Evolution, 13(4). Wiley. https://doi.org/10.1002/ece3.10018

Hickman, D. T., Rasmussen, A., Ritz, K., Birkett, M. A., & Neve, P. (2020). Review: Allelochemicals as multi‐kingdom plant defence compounds: towards an integrated approach [Review of Review: Allelochemicals as multi‐kingdom plant defence compounds: towards an integrated approach]. Pest Management Science, 77(3), 1121. Wiley. https://doi.org/10.1002/ps.6076

Hussain, M. I., & Reigosa, M. J. (2021). Secondary Metabolites, Ferulic Acid and p-Hydroxybenzoic Acid Induced Toxic Effects on Photosynthetic Process in Rumex acetosa L. Biomolecules, 11(2), 233. https://doi.org/10.3390/biom11020233

Hussain, M. I., Danish, S., Sánchez‐Moreiras, A. M., Vicente, Ó., Jabran, K., Chaudhry, U. K., Branca, F., & Reigosa, M. J. (2021). Unraveling Sorghum Allelopathy in Agriculture: Concepts and Implications [Review of Unraveling Sorghum Allelopathy in Agriculture: Concepts and Implications]. Plants, 10(9), 1795. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/plants10091795

Hussain, M. I., Muscolo, A., & Ahmed, M. (2022). Plant Responses to Biotic and Abiotic Stresses: Crosstalk between Biochemistry and Ecophysiology. Plants, 11(23), 3294. https://doi.org/10.3390/plants11233294

Indarwati, I., Jili, A. Q. A., Susilo, A., & Suryaningsih, D. R. (2023). Allelopathic potential of cogon grass (Imperata cylindrica) extract as a bioherbicide. Journal of Applied Plant Technology, 2(1), 30. https://doi.org/10.30742/japt.v2i1.77

Irnawati, I., Rispawati, R., Alqadri, B., & Atsar, A. (2025). Implementatio of Bima city local regulation number 1 of 2022 concerning the protection of sustainable food agricultural land. SOCIAL Jurnal Inovasi Pendidikan IPS, 5(1), 266. https://doi.org/10.51878/social.v5i1.5149

Jabran, K., Mahajan, G., Sardana, V., & Chauhan, B. S. (2015). Allelopathy for weed control in agricultural systems. Crop Protection, 72, 57. https://doi.org/10.1016/j.cropro.2015.03.004

Khamare, Y., Chen, J., & Marble, C. (2022). Allelopathy and its application as a weed management tool: A review [Review of Allelopathy and its application as a weed management tool: A review]. Frontiers in Plant Science, 13. Frontiers Media. https://doi.org/10.3389/fpls.2022.1034649

Kostina-Bednarz, M., Płonka, J., & Barchańska, H. (2023). Allelopathy as a source of bioherbicides: challenges and prospects for sustainable agriculture. Reviews in Environmental Science and Bio/Technology, 22(2), 471. https://doi.org/10.1007/s11157-023-09656-1

Le, T. H., Jia, W., Won, O. J., Oh, T., Shinogi, Y., Park, K. W., & Lee, J. J. (2018). Weed Control Efficacy of Sorghum Shoot Extract Extracted with Various Solvents. Journal of the Faculty of Agriculture Kyushu University, 63(2), 399. https://doi.org/10.5109/1955661

Macías, F. A. (1994). Allelopathy in the Search for Natural Herbicide Models. In ACS symposium series (p. 310). American Chemical Society. https://doi.org/10.1021/bk-1995-0582.ch023

Mahé, I., Chauvel, B., Colbach, N., Cordeau, S., Gfeller, A., Reiss, A., & Moreau, D. (2022). Deciphering field-based evidences for crop allelopathy in weed regulation. A review [Review of Deciphering field-based evidences for crop allelopathy in weed regulation. A review]. Agronomy for Sustainable Development, 42(3). Springer Science+Business Media. https://doi.org/10.1007/s13593-021-00749-1

Medeiros, L. B. de, Silva, M. E. B. R., Costa, G., Pereira, C. D., Matos, F. S., & Santos, T. E. B. dos. (2025). Effects of Sorgoleone on Soil Microbial Communities and Soybean Nodulation. Journal of Sustainable Development, 18(5), 143. https://doi.org/10.5539/jsd.v18n5p143

Mizutani, J. (1999). Selected Allelochemicals. Critical Reviews in Plant Sciences, 18(5), 653. https://doi.org/10.1016/s0735-2689(99)00395-0

Mudaningrat, A., Indriani, B. S., Istianah, N., Retnoningsih, A., & Rahayu, E. S. (2023). Literature review: The utilization of Syzygium species in Indonesia. Journal of Biology and Its Learning (JB&P), 10(2), 135. https://doi.org/10.29407/jbp.v10i2.20815

Muhammad, Z., Inayat, N., Majeed, A., Ali, H., & Ullah, K. (2019). Allelopathy and Agricultural Sustainability: Implication in weed management and crop protection—an overview. European Journal of Ecology, 5(2), 54. https://doi.org/10.2478/eje-2019-0014

Murtilaksono, A., Rika, F., & Hendrawan, F. (2020). Effect of babadotan (Ageratum conyzoides) liquid organic fertilizer on the vegetative root growth of hanjeli (Coix lacrima-jobi). Agriprima Journal of Applied Agricultural Sciences, 4(2), 164. https://doi.org/10.25047/agriprima.v4i2.378

Mushtaq, W., & Fauconnier, M. (2024). Phenolic profiling unravelling allelopathic encounters in agroecology. Plant Stress, 13, 100523. https://doi.org/10.1016/j.stress.2024.100523

Naby, K. Y., & Ali, K. A. (2021). Allelopathic potential of Sorghum bicolor L. Root Exudates on Growth and Chlorophyll Content of Wheat and Some Grassy Weeds. IOP Conference Series Earth and Environmental Science, 761(1), 12085. https://doi.org/10.1088/1755-1315/761/1/012085

Nikolić, L., Šeremešić, S., Džigurski, D., Vojnov, B., & Vasiljević, M. (2023). Weeds as Bioindicators of Ecological Conditions in Organic Carrot and Onion Crop. Contemporary Agriculture, 72(3), 89. https://doi.org/10.2478/contagri-2023-0012

Pardo-Muras, M., Puig, C. G., & Pedrol, N. (2022). Complex Synergistic Interactions among Volatile and Phenolic Compounds Underlie the Effectiveness of Allelopathic Residues Added to the Soil for Weed Control. Plants, 11(9), 1114. https://doi.org/10.3390/plants11091114

Parven, A., Meftaul, I. M., Venkateswarlu, K., & Megharaj, M. (2024). Herbicides in modern sustainable agriculture: environmental fate, ecological implications, and human health concerns. International Journal of Environmental Science and Technology. https://doi.org/10.1007/s13762-024-05818-y

Pedrol, N., & Puig, C. G. (2024). Application of Allelopathy in Sustainable Agriculture. Agronomy, 14(7), 1362. https://doi.org/10.3390/agronomy14071362

Putnam, A. R., & Duke, W. B. (1978). Allelopathy in Agroecosystems. Annual Review of Phytopathology, 16(1), 431. https://doi.org/10.1146/annurev.py.16.090178.002243

Putri, S. M. P., & Rohmah, N. (2025). Systematic literature review (SLR): The implementation of agriculture in early childhood education. Educatio, 20(2), 304. https://doi.org/10.29408/edc.v20i2.31299

Rad, S. V., Valadabadi, S. A. R., Pouryousef, M., Saifzadeh, S., Zakrin, H. R., & Mastinu, A. (2020). Quantitative and Qualitative Evaluation of Sorghum bicolor L. under Intercropping with Legumes and Different Weed Control Methods. Horticulturae, 6(4), 78. https://doi.org/10.3390/horticulturae6040078

Rahaman, F., Juraimi, A. S., Rafii, M. Y., Uddin, K., Hassan, L., Chowdhury, A. K., Karim, S. M. M., Rini, B. Y., Oladosu, Y., Bashar, H. M. K., & Hossain, A. (2022). Allelopathic potential in rice - a biochemical tool for plant defence against weeds [Review of Allelopathic potential in rice - a biochemical tool for plant defence against weeds]. Frontiers in Plant Science, 13. Frontiers Media. https://doi.org/10.3389/fpls.2022.1072723

Raharjo, K. T. P., & Delang, V. R. (2020). Effect of biochar compost residue types and maize (Zea mays L.) leaf defoliation age on the growth and yield of red beans (Phaseolus vulgaris L.) in salome intercropping. Savana Cendana, 5(3), 47. https://doi.org/10.32938/sc.v5i03.1054

Rajakumar, D., Gomathy, M., & Sabarinathan, K. G. (2025). Microbial allelopathy: A review on ecofriendly and sustainable weed management strategy. Applied Ecology and Environmental Research, 23(1), 621. https://doi.org/10.15666/aeer/2301_621635

Rashid, H. U., Khan, A. L., Hassan, G., Khan, S. U. R., Saeed, M., Khan, S. A., Khan, S. M., & Hashim, S. (2020). Weed suppression in maize (Zea mays L.) through the allelopathic effects of sorghum [Sorghum bicolor (L.) Conard Moench], sunflower (Helianthus annuus L.), and parthenium (Parthenium hysterophorus L.) plants. Applied Ecology and Environmental Research, 18(4), 5187. https://doi.org/10.15666/aeer/1804_51875197

Ruminta, R., Yuwariah, Y., & Sabrina, N. (2017). Growth response and yield of hanjeli (Coix lacryma-jobi L.) to planting distance and liquid supplementary fertilizer. Jurnal Agribisnis dan Agrowisata (Journal of Agribusiness and Agritourism), 28(2). https://doi.org/10.24198/agrikultura.v28i2.14958

Scavo, A., & Mauromicale, G. (2021). Crop Allelopathy for Sustainable Weed Management in Agroecosystems: Knowing the Present with a View to the Future. Agronomy, 11(11), 2104. https://doi.org/10.3390/agronomy11112104

Schulz, M., & Tabaglio, V. (2024). Allelopathy: Mechanisms and Applications in Regenerative Agriculture. Plants, 13(23), 3301. https://doi.org/10.3390/plants13233301

Scognamiglio, M., & Schneider, B. (2020). Identification of Potential Allelochemicals From Donor Plants and Their Synergistic Effects on the Metabolome of Aegilops geniculata. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.01046

Siantar, P. L., Pramono, E., Hadi, M. S., & Agustiansyah, A. (2019). Growth, yield, and seed vigor in sorghum–soybean intercropping cultivation. Jurnal Galung Tropika, 8(2), 91. https://doi.org/10.31850/jgt.v8i2.429

Soares, P. R., Galhano, C., & Gabriel, R. (2023). Alternative methods to synthetic chemical control of Cynodon dactylon (L.) Pers. A systematic review [Review of Alternative methods to synthetic chemical control of Cynodon dactylon (L.) Pers. A systematic review]. Agronomy for Sustainable Development, 43(4). Springer Science+Business Media. https://doi.org/10.1007/s13593-023-00904-w

Sołtys‐Kalina, D., Krasuska, U., Bogatek, R., & Gniazdowsk, A. (2013). Allelochemicals as Bioherbicides — Present and Perspectives. In InTech eBooks. https://doi.org/10.5772/56185

Susilo, E., Setyowati, N., Nurjannah, U., Riwandi, & Muktamar, Z. (2021). Effect of Swamp Irrigation Pattern and Sorghum Extract Concentration on Sorghum Seed Sprout. Advances in Biological Sciences Research/Advances in Biological Sciences Research. https://doi.org/10.2991/absr.k.210621.005

Tibugari, H., Chiduza, C., Mashingaidze, A., & Mabasa, S. (2022). Reduced atrazine doses combined with sorghum aqueous extracts inhibit emergence and growth of weeds. African Journal of Food Agriculture Nutrition and Development, 22(3), 19840. https://doi.org/10.18697/ajfand.108.19505

Tucuch‐Pérez, M. A., García-Solís, A. B., Castillo-Manzanares, A., Laredo-Alcalá, E. I., Iliná, A., & Arrendondo-Valdés, R. (2025). Actividad enzimática en Sorghum bicolor por metabolitos microbianos y un extracto vegetal micro-nano encapsulados. Revista Mexicana de Ciencias Agrícolas, 16(5). https://doi.org/10.29312/remexca.v16i5.3755

Venkatasai, N. N. V., Shetty, D. N., Vinay, C. M., Sekar, M., Muthusamy, A., & Rai, P. S. (2025). A comprehensive review of factors influencing growth and secondary metabolites in medicinal plants grown hydroponically.

Weir, T. L., Park, S., & Vivanco, J. M. (2004). Biochemical and physiological mechanisms mediated by allelochemicals. Current Opinion in Plant Biology, 7(4), 472. https://doi.org/10.1016/j.pbi.2004.05.007

Yalang, A., Barus, H., & Rauf, A. (2016). Effect of residual combination of straw mulch and fertilizer types on the growth and yield of mustard greens (Brassica juncea L.) in the second planting. Agrotekbis, 4(3). https://www.neliti.com/id/publications/248569/efek-residu-kombinasi-mulsa-jerami-dengan-jenis-pupuk-terhadap-pertumbuhan-dan-h

Yue, Z., Singh, V., Argenta, J., Segbefia, W., Miller, A., & Tseng, T. (2022). Use of Plant Secondary Metabolites to Reduce Crop Biotic and Abiotic Stresses: A Review [Review of Use of Plant Secondary Metabolites to Reduce Crop Biotic and Abiotic Stresses: A Review]. IntechOpen eBooks. IntechOpen. https://doi.org/10.5772/intechopen.104553

Zhang, Z., Becerra‐Alvarez, A., & Al‐Khatib, K. (2025). Physiological action of bioherbicides in weed control: a systematic review [Review of

Physiological action of bioherbicides in weed control: a systematic review]. Frontiers in Agronomy, 7. Frontiers Media. https://doi.org/10.3389/fagro.2025.1633565

Zhao, X., Peng, J., Zhang, L., Yang, X., Qiu, Y., Cai, C., Hu, J., Huang, T., Liang, Y., Li, Z., Tian, M., Liu, F., & Wang, Z. (2024). Optimizing the quality of horticultural crop: insights into pre-harvest practices in controlled environment agriculture [Review of Optimizing the quality of horticultural crop: insights into pre-harvest practices in controlled environment agriculture]. Frontiers in Plant Science, 15, 1427471. Frontiers Media. https://doi.org/10.3389/fpls.2024.1427471