SORGHUM AND ITS ALLELOPATHIC POTENTIAL – PERSPECTIVES FOR WEED MANAGEMENT IN HORTICULTURE

SORGUL ȘI POTENȚIALUL SĂU ALELOPATIC – PERSPECTIVE PENTRU MANAGEMENTUL BURUIENILOR ÎN HORTICULTURĂ

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Abstract
Sorghum (Sorghum bicolor L.) is a xerophytic plant of the Poaceae family, known both for its adaptability to drought conditions and for its nutritional value. It has a deep root system and a metabolism that can generate bioactive compounds with allelopathic effects on other plants in the same environment. The main compound involved in this process is sorgoleone, a benzoquinone derived from root exudates and root hairs, which has herbicidal effects on weeds. Sorgoleone and its associated compounds are continuously released into the rhizosphere during the growing season, influencing the competitiveness of nearby plants and contributing to natural weed control. This allelopathic mechanism is mediated by the enzymatic biosynthesis of sorgoleone and the transport of bioactive compounds in the rhizosphere, offering opportunities for its application in sustainable horticultural systems and integrated weed management. The present study focuses on recognizing the allelopathic properties of sorghum, highlighting its potential as a natural resource for the development of innovative, efficient, and environmentally friendly agricultural practices.
Keywords: sorghum, sorgoleone, allelopathy, influence.

Rezumat
Sorgul (Sorghum bicolor L.) este o plantă xerofilă din familia Poaceae, recunoscută atât pentru adaptabilitatea sa la condiții de secetă cât și pentru valoarea sa nutritivă. Aceasta prezintă un sistem radicular profund și un metabolism ce poate genera compuși bioactivi cu efecte alelopatice asupra altor plante din același mediu. Principalul compus implicat în acest proces este sorgoleona, o benzochinonă derivată din exudatele rădăcinilor și perișorilor radiculari, ce prezintă efecte erbicide asupra buruienilor.
Sorgoleona și compuși asociați acesteia sunt eliberați continuu în rizosferă pe parcursul perioadei de creștere influențând competitivitatea

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plantelor din proximitate, contribuind la controlul natural al buruienilor. Acest mecanism alelopatic este mediat de biosinteza enzimatică a sorgoleonei și transportul compușilor bioactivi în rizosferă, oferind oportunități pentru aplicarea sa în sisteme horticole sustenabile și în managementul integrat al buruienilor. Studiul prezent se axează pe recunoașterea proprietăților alelopatice ale sorgului punând în evidență potențialul său ca resursă naturală pentru dezvoltarea practicilor agricole inovatoare, eficiente și ecologice.

Cuvinte cheie: sorg, sorgoleonă, alelopatie, influență.

INTRODUCTION

Sorghum *(Sorghum bicolor L.)* is a perennial herbaceous species at its base but behaves as an annual in our country. It belongs to the *Poaceae* family and can reach heights of up to 2.5 m, with an external morphology similar to that of corn. This species is the main source of grain in Africa and is also widely cultivated in southern Europe, Central America, and South Asia. The plant has a nodular stem, supported by a well-developed root system capable of penetrating deep into the soil. The leaves are alternate, broad, slightly pubescent, with sharp edges and an intense green color. The inflorescences are grouped in panicles, either sparse or slightly bent, up to 70 cm long. The fruit is an oval achene, red or pink in color [De Oliveira *et al.*, 2021; Gomes *et al.*, 2023; Istrate *et al.*, 2023].

Sorghum is mainly cultivated in areas with a high risk of drought due to its particular resistance to water deficiency, which is why it is also known as the "camel plant." Its root system is about twice as developed as that of corn, which allows it to efficiently utilize soil water resources. From a nutritional point of view, sorghum is an important source of energy, being rich in vitamins, fiber, and other bioactive compounds that are beneficial to human health.

The cultivation requirements of sorghum are similar to those of corn. Seed germination occurs at minimum temperatures of 10–12°C, and optimal development occurs at temperatures between 25–35°C. The plant adapts to a wide range of soils, tolerating a pH between 4.5 and 8.5. Being a heliophilous species, sorghum needs direct light, which promotes growth, development, and resistance to biotic and abiotic stress; in shady conditions, these processes are significantly affected [Macias *et al.*, 2019].

Beyond its agronomic and nutritional importance, sorghum is recognized for its ability to produce bioactive compounds with allelopathic roles. The plant synthesizes a series of secondary metabolites that can act either as inhibitors or stimulators of the growth of organisms and plants in the surrounding ecosystem. This allelopathic capacity is attributed in particular to lipid and protein substances that form a complex improperly called "sorgoleon". This is released naturally into the soil through the roots and trichomes, exerting an inhibitory effect on weeds [Liang and Niu, 2022; Hamburda *et al.*, 2013; Waligora *et al.*, 2023; Wang *et al.*, 2021; Zhao *et al.*, 2019].

Sorgoleone, the main active compound, is found in the hydrophobic exudates of the roots and has herbicidal effects on nearby plant species. Chemically, sorgoleone belongs to the benzoquinone class, with the molecular formula $C_{22}H_{30}O_4$ and consisting of 2-hydroxy-5-methoxy -1,4-benzoquinone, in which the hydrogen atom in position 3 is substituted by the (4Z,7Z)-pentadec-1,4,7-trien-15-yl group. Studies conducted by Pan ZhiQiang and colleagues [2018] have shown that the biosynthesis of sorgoleone is catalyzed by the enzyme CYP71AM1 and cytochrome P450 CYP71. Sorgoleone and its analogues, such as resorcinol and other related hydroquinones, are produced exclusively by living root hairs and are released as golden droplets into the rhizosphere. Secretion occurs throughout the growing season and remains active in the soil for an indefinite period [Uddin *et al.*, 2013]. Under stress conditions, the roots also release low molecular weight compounds, organic acids, phenolic compounds, and proteins, which contribute to the plant's adaptation. Root hairs are the main site of sorgoleone biosynthesis, where it is stored in the form of dense osmiophilic deposits, constituting up to 85% of the dry weight of the exudate [Uddin *et al.*, 2013; Massalha *et al.*, 2017; Murimwa *et al.*, 2022; Santos *et al.*, 2012].

Through these mechanisms, sorghum plays an important role not only as a source of food and fodder, but also as an active ecological factor with potential for use in natural weed control.

MATERIAL AND METHOD

The working material under study consists of specialized literature comprising over 300 papers on sorgoleone and related substances, 67 papers on the allelopathic effect of sorgoleone, and over 12,000 papers on sorghum, published to date by various authors and researchers in the field. For the present study, we selected the most detailed studies that best included the necessary details about the allelopathic effect of sorghum, its associated substances, and the possibility of its use as a bioherbicide in weed control.

The working method consists of deepening and understanding the results obtained so far by researchers in the field in order to understand exactly the mechanisms of sorghum allelopathy and its potential for beneficial use.

RESULTS AND DISCUSSIONS

After a thorough analysis of the studies conducted to date, from those selected bibliographically, we found that sorghum plants contain certain enzymes and substances that can have an allelopathic effect against weed growth but also against crop pests, without having negative effects on the crops themselves.

The selected studies focused largely on laboratory testing and on the exact identification of the substance with allelopathic properties present in the plant, named sorgoleone after the plant, which is based on a classic benzoquinone (2-hydroxy-5-methoxy-1,4-benzoquinone).

A study on the cytochrome P450CYP71 enzyme and the biosynthesis of sorgoleone in a laboratory setting showed that sorgoleone, a hydrophobic compound exuded from sorghum roots, is primarily responsible for the plant's allelopathic effect. Its biosynthesis is catalyzed by enzymes, including cytochrome P450 (CYP71AM1), which facilitates the formation of dihydro-sorgoleone, subsequently oxidized to its active form. Studies have shown that root exudate contains between 40-90% sorgoleone, a component that inhibits weed growth. The presence and function of the enzymes involved in this process have been confirmed by genetic analyses (BLASTIN, TBLASTIN), highlighting their essential role in suppressing competing species and the potential of sorghum as a natural bioherbicide [Pan *et. al*. 2018]

Uddin et al. in a paper on the effects of jasmonates on sorgoleone accumulation the effects of jasmonates on sorgoleone accumulation showed that jasmonic acid (Ja) and methyl jasmonate (MeJa) stimulate sorgoleone biosynthesis in sorghum roots, with the effect being dependent on concentration and exposure time. At 0.5 μM, sorgoleone levels increased significantly, but at higher concentrations, root production and development were inhibited. The expression of genes involved in biosynthesis (DES2, DES3, ARS1, ARS2, OMT3) reached maximum values 12–48 h after treatment. The results suggest an important regulatory role of jasmonates in root hair growth and allelopathic compound secretion, opening up possibilities for the use of these substances for biological weed control (Figure 1) [Uddin *et. al.*, 2012].

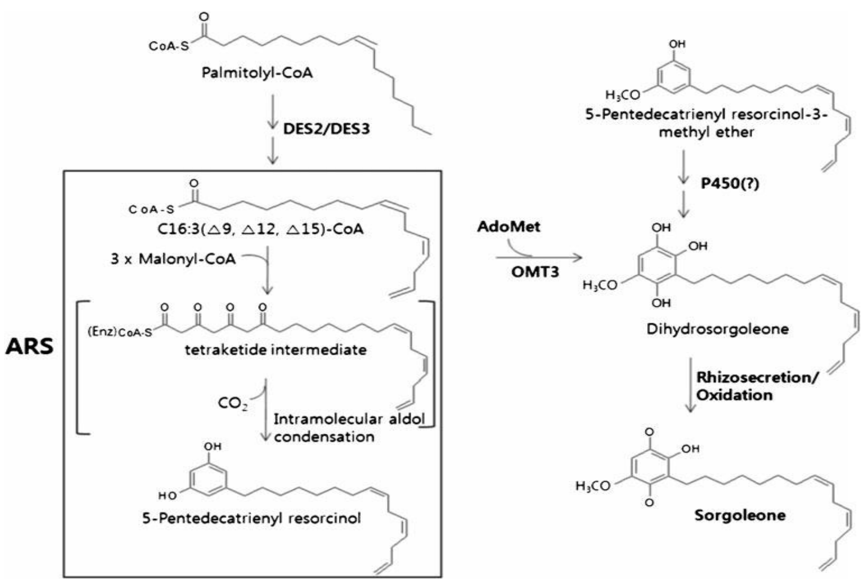

Fig. 1. The chemical formula of sorgoleone and its absorption by Baerson 2008 [Uddin *et. al.,* 2013]

The role of alkylresorcinols in sorgoleone biosynthesis was demonstrated by Cook and his colleagues [2010] in their paper, *Sorghum bicolor (L.)* plants produce sorgoleone, a benzoquinone compound with an inhibitory effect on monocots and dicots. Biosynthesis involves the ARS1 and ARS2 genes, which are predominantly expressed in root hairs, where resorcinol accumulation occurs. RT-PCR and GS-MS analyses confirmed the localization of these genes and their role in the synthesis of the compound. The process is based on the use of fatty acyl-CoA and leads to an increase in the concentration of allelochemicals in the rhizosphere, supporting the plant's potential as a natural weed control agent [Cook *et. al*. 2010].

Sorgoleone is a major allelochemical compound released by the root hairs of sorghum, playing a decisive role in the plant's phytotoxic activity. In a laboratory study conducted on four soil types sampled from two different regions (Denmark and the US), the mineralization of sorgoleona was analyzed until complete CO_2 degradation, in order to assess its potential as a biocide. The results showed that the mineralization process took place in all the soils tested, starting with the rapid degradation of the methoxyl group, followed by a slower mineralization of the rest of the molecule. Kinetics analysis also showed that microorganisms in American soils were able to use sorgoleone as an energy source, which has important implications for its persistence and applicability in integrated weed control strategies (Figure 2) [Gimsing *et. al*. 2009].

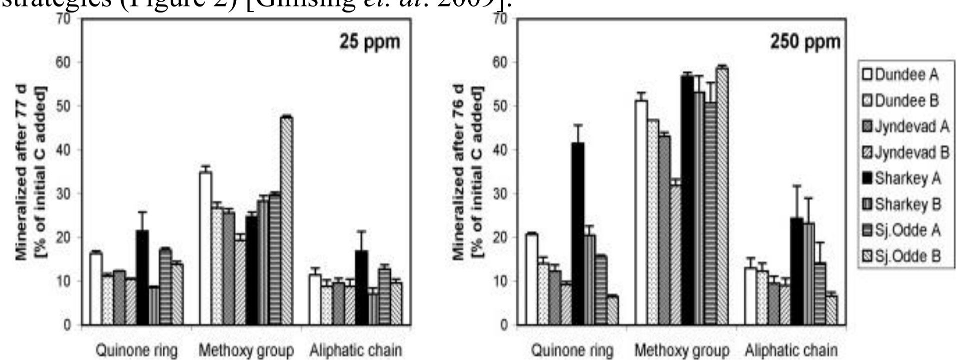

Fig. 2. Mineralization of the molecule after 76–77 days when applying the two concentrations obtained [Gimsing *et. al*. 2009]

The study conducted by Einhellig and his colleagues [1992] tested a benzoylhydroxide compound derived from sorgoleone, or predominantly from its main active ingredient, on rice, corn, and soybean crops. In the case of rice and corn crops, the results obtained were favorable, unlike those recorded for soybean crops, where the experiment did not show high safety, as the substance had negative effects not only on weeds but also on the crop plant. However, the compound degraded in the soil within a relatively short period of time, approximately 17–21 days after application, without negatively affecting the activity of soil microorganisms (Table 1) [Einhellig *et. al*. 1992].

Table 1

Effects of benzothiazine extracts on crop weed growth [Einhellig *et. al.* 1992].

Sorgoleone treatment (#M)				
	0	10	50	100
Setaria viridis				
Total plant wt (mg)	42.9 a	29.4 b	15.8 c	13.4 c
Shoot wt (mg)	32.8 a	22.0 b	11.8 c	10.5 c
Root wt (mg)	10.1 a	7.4 b	4.0 c	2.9 c
Shoot-root ratio	3.3 a	3.2 a	3.6 a	3.6 a
Digitaria sanguinalis				
Total plant wt (mg)	29.1 a	9.9 b	6.8 b	6.5 b
Shoot wt (mg)	24.3 a	7.9 b	5.7 b	4.8 b
Root wt (mg)	4.8 a	2.0 b	1.1 b	1.7 b
Shoot-root ratio	5.2 a	7.3 a	5.9 a	3.2 a
Echinochloa crus-galli				
Total plant wt (mg)	134.8 a	87.4 b	40.6 c	NT b
Shoot wt (mg)	105.0 a	65.7 b	29.9 b	NT
Root wt (mg)	29.8 a	21.7 a	10.7 b	NT
Shoot-root ratio	3.5 a	3.1 a	2.9 a	

The main weed species identified in the crops were *Setaria viridis, Eleusine indica, Digitaria sanguinalis, Amaranthus retroflexus, Echinochloa crus-galli and Solanum nigrum*. The bezothiazine derivative showed promising results in corn crops, suggesting that the development of a bioherbicide based on this compound could be a viable solution for weed management in the future [Einhellig *et. al.* 1992].

CONCLUSIONS

Analysis of the literature on the allelopathic potential of *Sorghum bicolor (L.)* highlights its remarkable ability to produce and release bioactive compounds with herbicidal properties, particularly sorgoleone. This compound, synthesised in root hairs and exuded into the rhizosphere, is the allelochemical agent responsible for inhibiting the germination and growth of competing weed species.

Biochemical and molecular studies confirm that sorgoleone biosynthesis is catalysed by specific enzymes, such as cytochrome P450 (CYP71AM1), and is regulated by signal molecules such as jasmonates, which stimulate the expression of key genes involved in this process (DES2, DES3, ARS1, ARS2, OMT3). These mechanisms highlight the existence of a complex regulatory network that contributes to the plant's allelopathic efficiency and ecological adaptability.

Experimental research also shows that sorghum degrades relatively quickly in the soil — generally within 17–21 days of application — without negatively affecting the activity of microorganisms. This supports its potential use in sustainable agricultural systems as a natural bioherbicide, reducing dependence on synthetic chemicals.

The positive results obtained in maize and rice crops treated with sorghum leonine derivatives, in contrast to the less favorable results observed in soybean crops, indicate that the allelopathic effects of these compounds are species-dependent. This highlights the need for targeted application and optimisation of conditions of use in an agronomic context.

Overall, the conclusions reinforce the role of *Sorghum bicolor (L.)* not only as a resistant and valuable plant from an agronomic and nutritional point of view, but also as a promising source of natural allelopathic compounds. Further studies on sorghum and its analogues could contribute to the development of effective and environmentally friendly bioherbicides that are compatible with the principles of sustainable agriculture.

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