



Research Article

The Allelopathic Efficacy of Sorghum (*Sorghum bicolor* L.) in Suppressing the Germination and Seedling Growth of Weeds in Sesame (*Sesamum indicum* L.) Crop

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Abstract | Allelopathy has emerged as eco-friendly, effective and sustainable tool for weed management. Sorghum contains various allelo-chemical compounds and weeds can be controlled by utilizing the allelopathic properties of sesame. The current Laboratory study was carried out access the allelopathic efficacy of sorghum (extract and powder) on preliminary growth stages of weeds associated with sesame. The experiment was laid out under a three replicated completely randomized design (CRD) with nine treatments including various concentrations of sorghum extract, powder, and their integration. The most common weeds species of sesame were selected and tested. The analysis of variance shown all levels of sorghum water extract and powder resulted in substantial suppression of weeds as compared to control. Sorghum extract @ 40 ml kg⁻¹ soil exhibited the strong allelopathic potential with significant reduction of weeds seed germination (37.20, 42.34, 39.57 and 39.67 %), root length (8.06, 3.56, 4.48, and 2.23 cm), shoot length (4.40, 42.34, 39.57 and 4.96 cm), fresh biomass (3.97, 3.67, 2.00 and 2.10 g), dry biomass (2.73, 1.23, 1.00 and 1.28 g), vigour index (699, 310, 514 and 519) and moisture content (29.42, 37.29, 34.18 and 32.29 %). Hence, the overall findings suggested that the sole application of Sorghum extract @ 40 ml kg⁻¹ soil exerted a higher phytotoxic potential and significantly suppressed the germination and seedling growth of all tested weeds as compared to control. Therefore, it is recommended the use of sorghum water extract was found to be more effective as compared to control as well as integrated doses.

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Introduction

Sesame (*Sesamum indicum* L.) is an important oilseed crop used for edible oil as well as used in food (Wei *et al.*, 2022). Sesame ranks 1st regarding oil content with 6335 k cal. per kg of seeds dietary energy (Vashisht *et al.*, 2023). Seeds of sesame are rich in oil content (15-60 %) with a greater concentration of fatty acids (unsaturated), (18-25 %) protein, (13.4-25.0 %) carbohydrates (9.8 %), with digestible fibre content gives high rank and qualities as compared to other oilseeds (Cruz *et al.*, 2019; Couch *et al.*, 2017). Sesame seeds are also rich in minerals (Ca, K, P, Mg, Fe, and Zn), vitamins (A, B1, B2, B3, B6, B6, B9, C and E), lignans and tocopherols (Gharby *et al.*, 2017). Sesame seeds are used as a food additive for nourishment with a rich flavor profile having more than two hundred volatile compounds (Jia *et al.*, 2019; Yin *et al.*, 2019). The extracted oil is also used in various industries such as cosmetics, pharmaceutical, bio-pesticides, soaps, biodiesels, animal feed, and varnishes (Mujtaba *et al.*, 2020; Nematian *et al.*, 2021; Lee *et al.*, 2022; Vasanthi and Rajavel, 2021). Sesame seeds have anticipatory effects against various human disorders including cardiovascular, lung cancer, liver, intestinal, osteoporosis as well as breast, colon, cervical, blood, and skin (Azab, 2014; Ogunsola and Fasola, 2014; Aslam *et al.*, 2019; Nakamura *et al.*, 2020). As a significant oilseed crop, sesame comes among the top ten traditional oilseed crops in Pakistan (Ali *et al.*, 2022). Sesame crop can adapt to harsh and stressful climatic conditions (Ayana, 2015). Biotic as well as abiotic threats adversely affect growth as well as development and yield especially the oil content of sesame crop (Yadav *et al.*, 2022). Sesame has an indeterminate growth habit where final yield production is obtained by capacity and source mobilization as well as photosynthesis (Karnan *et al.*, 2023). Being short durational and adaptable to climatic conditions (tropical as well as subtropical), it is grown throughout the year and fit well in several farming systems (Kouighat *et al.*, 2022; Zenawi and Mizan, 2019). In an agro-ecosystem crops and weeds having similar traits classification and sustainability are required to perform autonomous agricultural field practices (Shayo, 2023). In agricultural regions weeds reduce the amount as well as the quality of production faced by farmers in the form of significant financial losses (Sarić-Krsmanović *et al.*, 2019). Sesame has a susceptibility to sustain physiological stresses and inferiority in low genetic yield potential contributes

to low crop yield (Weldemichael and Gebremedhn, 2023). Weeds not only compete with crops regarding resources but also increase environmental stresses that lead to significant increment cost production and reduce crop market value (Kumar *et al.*, 2023). Weeds limit crop yield by interference with plant growth by allelopathy, competition, or both (Farooq *et al.*, 2020). Weeds are considered a serious problem for sesame crop fields, more than 23 families of weeds are aggressive and difficult to control (Bersisa *et al.*, 2016). The main cause of lower crop yield in Pakistan is due to the low soil fertility, drought, and weed crop competition (Ullah *et al.*, 2020). Weeds are considered severe pests harmful for field crops because of the opposition on nutrients, light, moisture, and space that leads to a significant fall in crop produce (Lahmod and Alsaadawi, 2014). The modern agro-techniques have adopted substantial application of a wide range of herbicides to combat weed infestation. This treatment is not only expensive but also suppresses the quality of soil, water, and food as well (Rajpurohit *et al.*, 2017).

Excessive application of herbicides triggered community trouble in environment sustainability as well as human health (Khamare *et al.*, 2022). Herbicidal dependency with the same mode of action created more than 513 weeds resistant against herbicides in above 267 species worldwide (Ofosu *et al.*, 2023). In consideration of human health, soil and water quality and environment sustainability, natural (eco-friendly) plant based products such as a variety of secondary metabolites, having potential to replace herbicides to manage weeds more effectively received attention during past two decades (Hussain and Reigosa, 2017). Although, allelopathy performs a pivotal role for natural, sustainable and integrated weed management (Jabran *et al.*, 2015). Allelopathy refers to any (positive and negative) impact of plants on each other by production and releasing allelochemicals into the environment (Golmaei *et al.*, 2023). Sorgoleone, an excellent allelo-chemical extract as root exudates from sorghum is a good example of a natural herbicide (Besançon *et al.*, 2020). It is one of the major secondary metabolites of sorghum which has been investigated to observe the direct effect on plant growth and development under laboratory, greenhouses, and field conditions (Uddin *et al.*, 2013). Water extract of sorghum is phytotoxic to various weed plant species including canarygrass, field bindweed, false amaranth, carpet weed, lambs quarters, and purple nutsedge (Cheema, 1988). Application of

0.5 % and 0.75 % doses of S-metolachlor with the combination of sorghum water extract at the pre-emergence stage of crop growth proved to be more effective in controlling purple nutsedge weed as compared to the standard rate of application (Iqbal and Cheema, 2008).

Purple nutsedge growth can be suppressed by 38-41 % with the application of sorghum as mulch material (Cheema and Akhlaq, 2004). The plant population of purple nutsedge was significantly decreased by 40-45% surface mulching and soil incorporation of sorghum (Nawaz and Farooq, 2016). A total of 66 % growth reduction of *Trainthema portulacastrum* was observed with a combined dose of sorghum and sunflower (Azhar et al., 2010). A multi-direction research approach toward the integration and incorporation of sorghum crop residues or as allelochemicals for tactical and alternative weed control plans can be a significant approach. Although numerous constraints in the implementation of allelopathy techniques for sustainable and eco-friendly weed management have been followed, however, there is a dire need to evaluate and explore allelopathy the hazardous-free potential methods for weed control strategy. The present study was conducted to evaluate the efficacy of sorghum as an allelopathic source to biologically suppress different species of weeds from sesame crop. The study will provide better insight into eco-friendly agronomic practices to control the weeds in different crops.

Materials and Methods

To investigate the allelopathic effects of sorghum (*Sorghum bicolor* L.), the laboratory experiment was conducted at Weed Science and Allelopathy Laboratory, Department of Agronomy, Sindh Agriculture University, Tandojam (GPS coordinates: 25.42640° N, 68.54340° E) during, 2020. The most common weed species of sesame (*Sesamum indicum* L.) including False Amaranth (*Digera arvensis* Forssk), Carpet weed (*Trianthema portulacastrum* L.), Field Bindweed (*Convolvulus arvensis* L.) and Purple Nutsedge (*Cyperus rotundus* L.) were selected and tested for germination and seedling growth response under allelopathic influence of sorghum powder and extracts. The experiment was performed under a three replicated completely randomized design (CRD) with a total of nine treatments including (control (check), sorghum extract @ 20 ml kg⁻¹ soil, sorghum extract

@ 40 ml kg⁻¹ soil, sorghum powder @ 20 g kg⁻¹ soil, sorghum powder @ 40 g kg⁻¹ soil, sorghum extract @ 10 ml + powder @ 10 g kg⁻¹ soil, sorghum extract @ 10 ml + powder @ 20 g kg⁻¹ soil, sorghum extract @ 20 ml + powder @ 10 g kg⁻¹ soil, sorghum extract @ 20 ml + powder @ 20 g kg⁻¹ soil. The herbage of the allelopathic crop (sorghum) and propagative materials of test weeds were collected from Crop Science Research Institute, Agriculture Research Centre, Tandojam, Pakistan (GPS coordinates: 25°25'35.58" N, 68°31'29.568" E). Sorghum plants were harvested at the peak of the vegetative stages (50 days after sowing), and placed under the sunlight for drying purposes. The dried sorghum plants were chopped into 2 cm pieces and ground to a fine powder following the procedure adopted by (Iqbal and Cheema, 2008; Kobayashi et al., 2008). The chopped herbage of sorghum in the ratio of 1:10 (w/v) was soaked in water for 24 hours. The extract was filtered through muslin cloth for easy handling and application (Awan et al., 2009; Cheema et al., 2008). For the sowing of targeted weeds, aluminum boxes with sizes of 9cm × 5cm × 5cm were used. The canal sand at 5 kg was used for sowing purposes in each box. The powder of sorghum as per treatments was mixed thoroughly with sand in, respective boxes.

Twenty seeds and rhizomes (as the case may be) of respective test weeds i.e. False amaranth (*Digera arvensis* Forsk), carpet weed (*Trianthema portulacastrum* L.), Field bindweed (*Convolvulus arvensis* L.), and Purple nutsedge (*Cyperus rotundus* L.) were sown into the respective sandboxes separately. The sowing was done during 2nd week of May 2020. To moisten the canal sand canal water was applied. All boxes were carefully placed in the laboratory at room temperature. The aluminum boxes having a size of 9 cm× 5cm × 5cm were used for sowing purposes. The canal sand at 5 kg was used for sowing purposes in each box. The extract of sorghum as per treatments was applied and incorporated with sand in respective boxes at sowing time. Twenty seeds and/or rhizomes (as the case may be) of respective test weeds were sown into the respective sandboxes separately. The sowing was done during 2nd week of May 2020. The sandboxes were placed in the laboratory at room temperature.

Observations recorded

The whole data of the following parameters was recorded 20 days after sowing (DAS) by adopting the

methodology developed by Alsaadawi *et al.* (2005) and Cheema and Khaliq (2000).

The observations were recorded for germination and seedling growth of tested weeds such as seed germination (%), root length (cm), shoot length (cm), fresh biomass seedling⁻¹ (g), dry biomass seedling⁻¹ (g), vigour index and moisture content (%).

Statistical analysis

The collected data was statistically analyzed using The statistical software version 8.1. The least significant difference (LSD) test was applied to compare treatment superiority at a probability level of 0.05 (Singh and Chaudhary, 1985).

Results and Discussion

Allelopathic effects of sorghum extract and powder on seed germination and seedling growth of tested weed false amaranth (*Digera Arvensis* Forsk)

The results on germination and subsequent growth of false amaranth (*Digera arvensis* Forsk.) under the allelopathic influence of sole and integrated doses of sorghum extract and powder are presented in Table 1 and Figure 1. The Analysis of Variance illustrated that sorghum extract and powder caused significant ($P<0.05$) effects on seed germination and related growth traits of false amaranth. The results revealed that the lowest seed germination (37.33 %), root length (8.06 cm), shoot length (4.40 cm), fresh biomass seedling⁻¹ (4.04 g), dry biomass seedling⁻¹

(2.30 g), vigour index (680.40) and moisture content (30.42 %) were observed under sole application of extract @ 40 ml kg⁻¹ soil. integrated application of

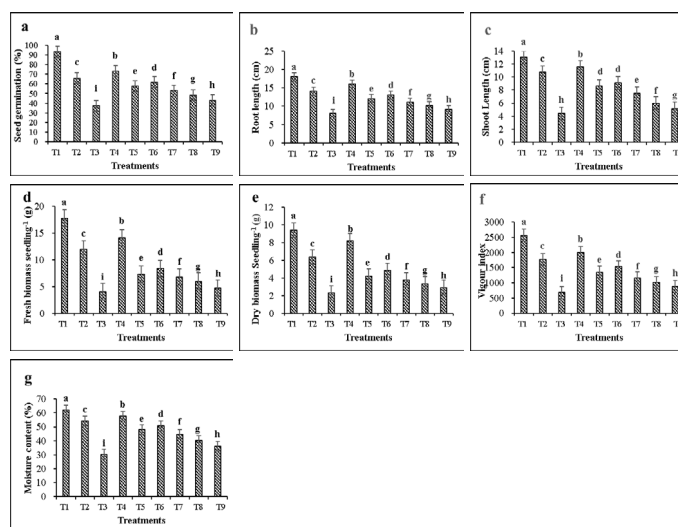


Figure 1: The phytotoxic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling⁻¹; e, Dry biomass seedling⁻¹; f, Vigour index, and g. Moisture content of False amaranth. Whereas, T1= Control (check), T2= Sorghum extract @ 20 ml kg⁻¹ soil, T3= Sorghum extract @ 40 ml kg⁻¹ soil, T4= Sorghum powder @ 20 g kg⁻¹ soil, T5= Sorghum powder @ 40 g kg⁻¹ soil, T6= Sorghum @ 10 ml + powder @ 10 g kg⁻¹ soil, T7= Sorghum extract 10 ml + powder 20 g kg⁻¹ soil, T8= Sorghum extract @ 20 ml + powder @ 10 g kg⁻¹ soil, and T9= Sorghum extract @ 20 ml + 20 g kg⁻¹ soil.

Table 1: The allelopathic effects of sorghum extract and powder on seed germination and seedling growth of false amaranth.

Treatments	SG (%)	RL (cm)	SL (cm)	FBS ⁻¹ (g)	DBS ⁻¹ (g)	VI	MC (%)
T ₁ = Control (Check)	93.30 a	18.00 a	13.03 a	17.83 a	9.43 a	2567.03 a	62.10 a
T ₂ = SE @ 20 ml kg ⁻¹ soil	65.70 c	14.07 c	10.73 c	12.00 c	6.37 c	1769.37 c	54.26 c
T ₃ = SE @ 40 ml kg ⁻¹ soil	37.18 i	8.06 i	4.40 h	4.04 i	2.30 i	680.40 i	30.42 i
T ₄ = SP @ 20 g kg ⁻¹ soil	73.33 b	16.07 b	11.57 b	14.13 b	8.20 b	2001.00 b	57.78 b
T ₅ = SP @ 40 g kg ⁻¹ soil	57.44 e	12.07 e	8.60 d	7.31 e	4.23 e	1351.30 e	48.01 e
T ₆ = SP @ 10 ml + P @ 10 g kg ⁻¹ soil	61.88 d	13.03 d	9.11 d	8.35 d	4.84 d	1531.13 d	50.70 d
T ₇ = SE @ 10 ml + P @ 20 g kg ⁻¹ soil	53.13 f	11.09 f	7.50 e	6.77 f	3.79 f	1160.29 f	44.53 f
T ₈ = SE @ 20 ml + P @ 10 g kg ⁻¹ soil	48.26 g	10.17 g	6.00 f	6.00 g	3.35 g	1011.66 g	40.21 g
T ₉ = SE @ 20 ml + P @ 20 g kg ⁻¹ soil	42.99 h	9.08 h	5.17 g	4.68 h	2.94 h	874.01 h	36.17 h
p-value	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
S.E ±	1.4375	0.3410	0.2903	0.2367	0.1857	57.644	0.7429
LSD _{0.05}	3.0474	0.7228	0.6154	0.5017	0.3936	122.20	1.5750

SE, sorghum extract; SP, sorghum powder; E, extract, and P, powder. SG, seed germination; RL, root length; SL, shoot length; FBS⁻¹, fresh biomass per seedling, and DBS⁻¹, dry biomass per seedling. VI refers to the Vigour Index, and MC stands for Moisture Content. Additionally, ** denotes significance.

extract @ 20 ml + powder @ 20 g kg⁻¹ soil followed in allelopathic efficacy resulting in 49.99 % seed germination, 9.08 cm root length, 5.17 cm shoot length, 4.68 g fresh biomass seedling⁻¹, 2.94 g dry biomass seedling⁻¹, 874.01 vigour index, and 36.17 % moisture content. Correspondingly, the combined application of extract at 20 ml + powder at 10 g kg⁻¹ soil ranked 3rd in phytotoxic potential having 48.26 % seed germination, 10.17 cm root length, 6.00 cm shoot length, 6.00 g fresh biomass seedling⁻¹, 3.35 g dry biomass seedling⁻¹, 1011.66 vigour index and 40.21 % moisture content. However, the highest seed germination (93.30 %), root length (18.00 cm), shoot length (13.03 cm), fresh biomass seedling⁻¹ (17.83 g), dry biomass seedling⁻¹ (9.43 g), vigour index (2567.03), and moisture content (62.10 %) were recorded under control (check) condition. Moreover, the overall findings indicated that the inhibitory allelopathic influence of sorghum was form and dose-specific. The extract was observed greater allelopathic potential as compared to powder. Higher doses either in the form of extract or powder caused significantly greater inhibitory effect over lower doses. A combination of extract @ (20 ml) + powder @ (20 g) proved more allelopathic in contrast to a similar dose (40 g) of powder. Among powders and extracts, soil incorporation of allelopathic plant extracts appeared the most phytotoxic, as it subsequently exaggerated germination and seedling growth traits of tested weeds. Soil incorporation or addition of plant material into the root zone of another plant can inhibit growth (Bais *et al.*, 2003). Water extract of sorghum plant parts (stem, leaves, rhizomes) significantly suppressed seed germination and seedling growth of *Amaranthus retroflexus* (Yarnia *et al.*, 2009), *Echinochloa colonum* (Nazir *et al.*, 2022), *Phalaris minor*, *Chenopodium album*, *Senebiera*, *Cyprus rotundus* and *Remex dentatus* (Khan *et al.*, 2015). Sorghum extract, powder, and herbage applied as selective weed control in wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and soybean (*Glycine max* L.) corroborated by earlier studies and have found positive influence to suppress the weeds (Cheema *et al.*, 2008). Metos *et al.* (2020) investigated that Sorghum contains several secondary metabolites and suppress the succeeding growth traits of weeds associated with phytotoxic properties of allele chemicals in water extracts and powders.

Phytotoxic efficacy of sorghum suppresses the seed germination and related growth traits of Carpet weed (Trainthema potulacastrum L.)

The data concerning allelopathic influences of various

rates of sorghum E and P on seed germination and seedling growth of carpet weed applied solely and in combination with each other is shown in Table 2 and Figure 2. It is assumed from the Analysis of Variance that seed germination and subsequent growth traits of carpet weed were exaggerated significantly ($P < 0.05$) by applying sorghum extract and powder. It is proved from the compiled data that application of sorghum extract @ 40 ml kg⁻¹ soil resulted in minimum seed germination (41.56 %), root length (8.10 cm), shoot length (3.13 cm), fresh biomass seedling⁻¹ (3.67 g), dry biomass seedling⁻¹ (1.23 g), vigour index (310.33) and moisture content (37.19 %). The combination of extract @ 20 ml + powder @ 20 g kg⁻¹ rated 2nd in phytotoxic potential where 46.22 % seed germination, 4.03 cm root length, 4.10 cm shoot length, 4.00 g fresh biomass seedling⁻¹, 2.27 g dry biomass seedling⁻¹, 372.67 vigour index, and 41.15 % moisture content. Moreover, the slight reduction in inhibitory efficacy of sorghum was observed when its extract and powder were mixed with each other @ 20 ml + 10 g kg⁻¹ soil where different traits declined to 49.21 % seed germination, 4.55 cm root length, 5.03 shoot length, 4.51 g fresh biomass seedling⁻¹, 2.73 g dry

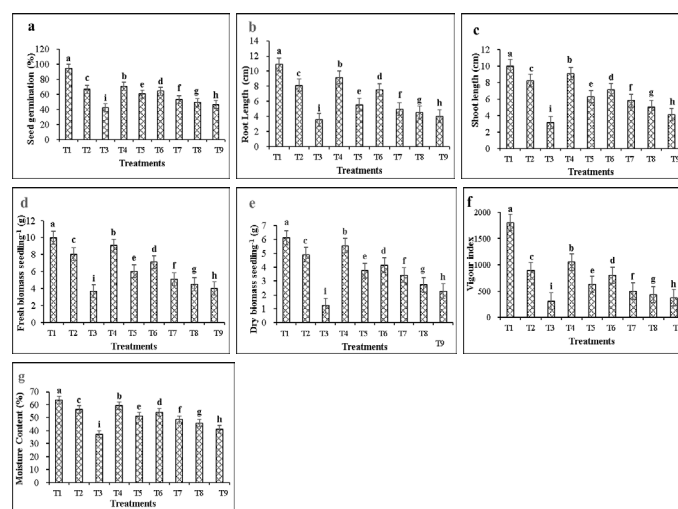


Figure 2: Allelopathic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling⁻¹; e, Dry biomass seedling⁻¹; f, Vigour index, and g. Moisture content of Carpet weed. Whereas, T1= Control (check), T2= Sorghum extract @ 20 ml kg⁻¹ soil, T3= Sorghum extract @ 40 ml kg⁻¹ soil, T4= Sorghum powder @ 20 g kg⁻¹ soil, T5= Sorghum powder @ 40 g kg⁻¹ soil, T6= Sorghum @ 10 ml + powder @ 10 g kg⁻¹ soil, T7= Sorghum extract 10 ml + powder 20 g kg⁻¹ soil, T8= Sorghum extract @ 20 ml + powder @ 10 g kg⁻¹ soil, and T9= Sorghum extract @ 20 ml + 20 g kg⁻¹ soil.

Table 2: Phytotoxic efficacy of sorghum suppresses the seed germination and related growth traits of Carpet weed.

Treatments	SG (%)	RL (cm)	SL (cm)	FBS ⁻¹ (g)	DBS ⁻¹ (g)	VI	MC (%)
T ₁ = Control (Check)	94.43 a	10.90 a	10.00 a	9.96 a	6.11 a	1803.30 a	63.69 a
T ₂ = SE @ 20 ml kg ⁻¹ soil	66.60 c	8.10 c	8.23 c	8.04 c	4.89 c	887.70 c	56.29 c
T ₃ = SE @ 40 ml kg ⁻¹ soil	41.56 i	3.56 i	3.13 i	3.67 i	1.23 h	310.33 i	37.19 i
T ₄ = SP @ 20 g kg ⁻¹ soil	70.66 b	9.17 b	9.07 b	9.06 a	5.55 b	1050.33 b	59.22 b
T ₅ = SP @ 40 g kg ⁻¹ soil	60.40 e	5.55 e	6.27 e	6.03 e	3.83 d	631.80 e	51.28 e
T ₆ = E @ 10 ml + P @ 10 g kg ⁻¹ soil	64.25 d	7.50 d	7.13 d	7.10 d	4.14 d	803.90 d	54.25 d
T ₇ = E @ 10 ml + P @ 20 g kg ⁻¹ soil	52.77 f	4.96 f	5.79 f	5.10 f	3.43 e	498.33 f	48.56 f
T ₈ = E @ 20 ml + P @ 10 g kg ⁻¹ soil	49.21 g	4.55 g	5.03 g	4.51 g	2.73 f	434.80 g	45.95 g
T ₉ = E @ 20 ml + P @ 20 g kg ⁻¹ soil	46.22 h	4.03 h	4.10 h	4.00 h	2.27 g	372.67 h	41.14 h
p-value	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
S.E ±	0.8178	0.1570	0.1550	0.1547	0.1482	20.505	0.8967
LSD _{0.05}	1.7336	0.3329	0.3285	0.3279	0.3143	43.468	1.9010

SE, sorghum extract; SP, sorghum powder; E, extract, and P, powder. SG, seed germination; RL, root length; SL, shoot length; FBS⁻¹, fresh biomass per seedling, and DBS⁻¹, dry biomass per seedling. VI refers to the Vigour Index, and MC stands for Moisture Content. Asterisks (**) indicate statistical significance.

biomass seedling⁻¹, 434.80 vigour index and 45.95 % moisture content. Nonetheless, as expected control (check) treatment gave maximum seed germination (94.43 %), root length (10.90 cm), shoot length (10.00 cm), fresh biomass seedling⁻¹ (9.96 g), dry biomass⁻¹ (6.11 g), vigour index (1803.30) and moisture content (63.69 %). Hence, the results mentioned above clarify that sorghum allelopathic influence was specific to form and dose. Application of sorghum extract exhibited higher allelopathic efficacy than powder form. The linear increase in allelopathic effects was noticed as the levels of extracts or powder of sorghum were enhanced. Integrated application of sorghum extract and powder @ 20 ml + 20 g demonstrated higher phytotoxic efficiency when compared with the same dose (40 g) of powder applied as sole. For determination of allele-chemical properties of a plant, laboratory experiments are quite supportive (Tibugari *et al.*, 2020). The water extracts and powders of allelopathic crop (sorghum) retard the germination and seedling growth traits of weeds by affecting cell division and elongation process or by affecting the nutrients mobilizing enzymes involved in germination (Bàrberi, 2019). The phytotoxic potential of plants may differ from each other (Ali *et al.*, 2017). Sorghum (*Sorghum bicolor* L.) has ability to suppress weed in presence of hydrophilic compounds, phenolic acids, and their aldehyde as well as hydrophobic substances, such as sorgoleone (Czarnota *et al.*, 2003). Sorghum contains various secondary metabolites such as sorgoleone, protocatechuic acid gallic acid, vanillic acid,

syringic acid, benzoic acid, p-hydroxybenzoic acid and p-coumaric acid (Iqbal and Cheema, 2008).

Allelopathic impact of sorghum decreases the seed germination and succeeding growth of field bindweed (Convolvulus arvensis L.)

The collected data concerning field bindweeds' seed germination and seedling growth under the allelopathic impact of various sole and combined doses of sorghum extract and powder are shown in Table 3 and Figure 3. It is observable from the ANOVA that the extract and powder of sorghum used as allelopathic material caused significant ($P < 0.05$) effects on seed germination and growth traits of field bindweed. The findings indicate that lowest seed germination (39.57 %), root length (4.48 cm), shoot length (4.46 cm), fresh biomass seedling⁻¹ (2.00 g), dry biomass seedling⁻¹ (1.00 g), vigour index (514.33) and moisture content (34.18 %) were observed under application of sorghum extract @ 40 ml kg⁻¹ soil. Combined application of extract @ 20 ml + powder @ 20 g kg⁻¹ soil followed in allelopathic intensity resulting in 43.66 % seed germination, 5.25 cm root length, 5.49 cm shoot length, 2.54 g fresh biomass seedling⁻¹, 1.30 g dry biomass seedling⁻¹, 727.00 vigour index, and 37.80 % moisture content. Correspondingly, the combined application of extract @ 20 ml + powder @ 10 g kg⁻¹ soil graded 3rd in allelopathic prospective with 47.00 % seed germination, 6.00 cm root length, 6.27 cm shoot length, 2.99 g fresh biomass seedling⁻¹, 2.03 g dry biomass seedling⁻¹, 900.00 vigour index, and

Table 3: Allelopathic effects of sorghum extract and powder on germination and seedling growth of field bindweed.

Treatments	SG (%)	RL (cm)	SL (cm)	FBS ⁻¹ (g)	DBS ⁻¹ (g)	VI	MC (%)
T ₁ = Control (Check)	94.86 a	16.53 a	14.43 a	9.25 a	6.60 a	2891.50 a	63.10 a
T ₂ = SE @ 20 ml kg ⁻¹ soil	67.09 c	11.03 c	10.00 c	7.01 c	4.03 c	2353.33 c	56.22 c
T ₃ = SE @ 40 ml kg ⁻¹ soil	39.57 i	4.48 i	4.44 i	2.00 i	1.00 i	514.33 i	34.18 i
T ₄ = SP @ 20 g kg ⁻¹ soil	76.38 b	13.00 b	12.86 b	8.15 b	5.03 b	2650.33 b	59.97 b
T ₅ = SP @ 40 g kg ⁻¹ soil	54.33 e	8.46 e	8.61 e	5.00 e	3.03 e	1385.20 e	49.55 e
T ₆ = E @ 10 ml + P @ 10 g kg ⁻¹ soil	60.56 d	9.46 d	9.22 d	6.06 d	3.52 d	2032.30 d	54.16 d
T ₇ = E @ 10 ml + P @ 20 g kg ⁻¹ soil	50.03 f	7.45 f	7.58 f	4.00 f	2.51 f	1056.47 f	45.92 f
T ₈ = E @ 20 ml + P @ 10 g kg ⁻¹ soil	47.00 g	6.00 g	6.27 g	2.99 g	2.03 g	900.00 g	41.40 g
T ₉ = E @ 20 ml + P @ 20 g kg ⁻¹ soil	43.66 h	5.25 h	5.49 h	2.54 h	1.30 h	727.00 h	37.80 h
p-value	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
S.E ±	0.9242	0.2188	0.2363	0.1873	0.1303	67.159	1.1716
LSD _{0.05}	1.9593	0.4637	0.5009	0.3971	0.2763	142.37	2.4836

SE, sorghum extract; SP, sorghum powder; E, extract, and P, powder. SG, seed germination; RL, root length; SL, shoot length; FBS⁻¹, fresh biomass per seedling, and DBS⁻¹, dry biomass per seedling. VI refers to the Vigour Index, and MC stands for Moisture Content. ** indicates significant results.

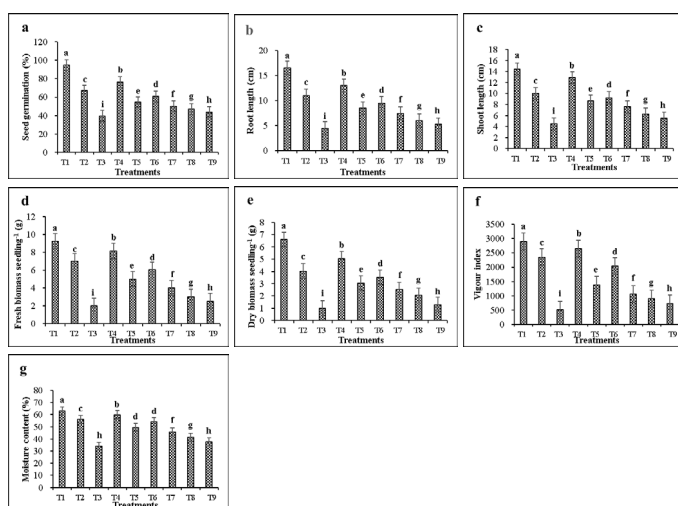


Figure 3: Allelopathic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling⁻¹; e, Dry biomass seedling⁻¹; f, Vigour index, and g, Moisture content of Field bindweed. Whereas, T₁= Control (check), T₂= Sorghum extract @ 20 ml kg⁻¹ soil, T₃= Sorghum extract @ 40 ml kg⁻¹ soil, T₄= Sorghum powder @ 20 g kg⁻¹ soil, T₅= Sorghum powder @ 40 g kg⁻¹ soil, T₆= Sorghum @ 10 ml + powder @ 10 g kg⁻¹ soil, T₇= Sorghum extract 10 ml + powder 20 g kg⁻¹ soil, T₈= Sorghum extract @ 20 ml + powder @ 10 g kg⁻¹ soil, and T₉= Sorghum extract @ 20 ml + 20 g kg⁻¹ soil.

41.40 % moisture content. Although, the highest seed germination (94.86 %), root length (16.53 cm), shoot length (14.43 cm), fresh biomass biomass⁻¹ (9.25 g), dry biomass seedling⁻¹ (6.60 g), vigour index (2891.50)

and moisture content (63.10 %) were observed under control (check) condition. Furthermore, the overall results suggested that allelopathic effects of sorghum were form and dose-specific. Extract of sorghum was found more allelopathic as compared to its powder. Higher doses either in the form of extract or powder caused significantly greater allelopathic effect over lower dose. Integration of extract @ 20 ml + powder @ 20 g proved more allelopathic in contrast to the same dose (40 g) of powder. The efficacy of allelopathic compounds present in sorghum might be directly decreased the growth of various weed species (Jesudas *et al.*, 2014). Research studies highlighted that combined dose of water extract from sorghum, sunflower, and rice with reduced dose of pre-emergence herbicide reduce weed growth by 60-70 % and decreased herbicide rate by 20-60 % (Rehman *et al.*, 2010). Incorporation of phytotoxic plants extracts in soil ascertained the allelopathic and adversely affected sprouting as well as succeeding seedling growth of tested weeds (Chen and Zhang, 2021). Many researcher reported the phytotoxic effects of various secondary metabolites on germination and growth of plants. The root development due to adventitious root formation stimulated by phytohormones (Kuroha *et al.*, 2002), extra nutrient obtaining capability of different plants attributed to more adventitious roots (Oda *et al.*, 2003), decrement in root as well as shoot growth of weeds might have been due to decreasing the level of growth-promoting hormones such as Auxin, Indole Acidic Acid, Gibberellic Acid, and DNA

under allele-chemical stresses (Wahyuni *et al.*, 2003). Decrease in germination and seedling growth of weeds due to extracts of sorghum might be associated and in presence of soluble allelopathic compounds in water extracts with allelo-chemicals potentiality (Hassan *et al.*, 2012). Allelochemicals reduce water and mineral uptake by roots and as a consequence inhibitory effect on photosynthesis, respiration, protein synthesis, cell division, and thickness of seminal roots (Jafariehyazdi and Javidfar, 2011).

Allelopathic efficacy of Sorghum prohibits seed germination and succeeding seedling growth of purple nutsedge (*Cyperus rotundus* L.)

The data revealed that sorghum extract and powder caused significant suppression of seed germination and seedling growth of purple nutsedge as compared to control (check) treatment are presented in Table 4 and Figure 4. The ANOVA illustrated that sorghum extract and powder was significantly inhibitory ($P<0.05$) on seed germination and related growth traits of test weed purple nutsedge. The findings exhibited that minimum seed germination (39.67 %), root length (2.23 cm), shoot length (4.96 cm), fresh biomass seedling⁻¹ (2.10 g), dry biomass seedling⁻¹ (1.28 g), vigour index (519.00) and moisture content (32.29 %) were recorded under application of sorghum extract @ 40 ml kg⁻¹ soil. It is also apparent from the results of experiment that Integrated application of extract @ 20 ml + powder @ 20 g kg⁻¹ soil followed in allelopathic efficacy resulting in

44.80 % seed germination, 3.50 cm root length, 6.40 cm shoot length, 2.55 g fresh biomass seedling⁻¹,

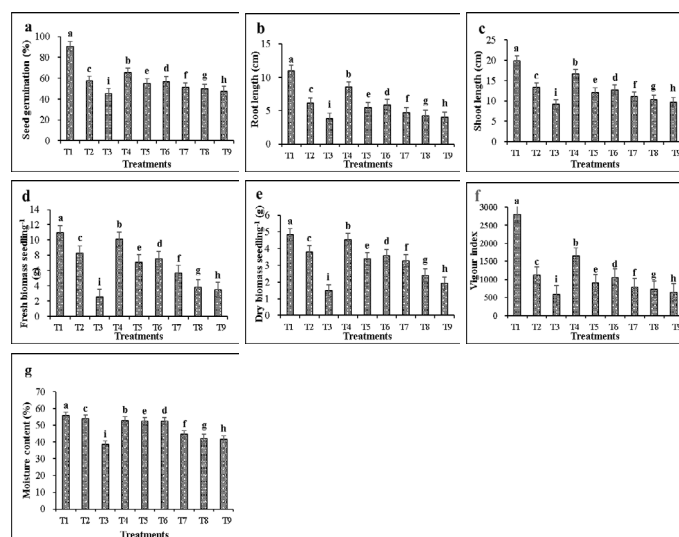


Figure 4: The phytotoxic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling⁻¹; e, Dry biomass seedling⁻¹; f, Vigour index, and g. Moisture content of Purple nutsedge. Whereas, T1= Control (check), T2= Sorghum extract @ 20 ml kg⁻¹ soil, T3= Sorghum extract @ 40 ml kg⁻¹ soil, T4= Sorghum powder @ 20 g kg⁻¹ soil, T5= Sorghum powder @ 40 g kg⁻¹ soil, T6= Sorghum @ 10 ml + powder @ 10 g kg⁻¹ soil, T7= Sorghum extract 10 ml + powder 20 g kg⁻¹ soil, T8= Sorghum extract @ 20 ml + powder @ 10 g kg⁻¹ soil, and T9= Sorghum extract @ 20 ml + 20 g kg⁻¹ soil.

Table 4: Allelopathic effect of sorghum extract and powder on germination and seedling growth of purple nutsedge.

Treatments	SG (%)	RL (cm)	SL (cm)	FBS ⁻¹ (g)	DMS ⁻¹ (g)	VI	MC (%)
T ₁ = Control (Check)	93.27 a	12.00 a	19.90 a	11.95 a	5.62 a	2801.61 a	61.51 a
T ₂ = SE @ 20 ml kg ⁻¹ soil	69.80 c	8.13 c	14.00 c	9.03 c	4.53 c	2311.30 c	52.73 c
T ₃ = SE @ 40 ml kg ⁻¹ soil	39.67 i	2.23i	4.96 i	2.10 i	1.28 i	519.00 i	32.29 i
T ₄ = SP @ 20 g kg ⁻¹ soil	74.46 b	10.00 b	17.70 b	10.48 b	4.80 b	2558.71 b	56.96 b
T ₅ = SP @ 40 g kg ⁻¹ soil	59.96 e	4.63 e	10.66 e	6.10 e	3.75 e	1763.73 e	47.37 e
T ₆ = E @ 10 ml + P @ 10 g kg ⁻¹ soil	64.90 d	6.53 d	12.66 d	7.20 d	4.06 d	2148.70 d	49.95 d
T ₇ = E @ 10 ml + P @ 20 g kg ⁻¹ soil	53.13 f	3.93 f	9.53 f	4.68 f	3.43 f	1348.00 f	43.91 f
T ₈ = E @ 20 ml + P @ 10 g kg ⁻¹ soil	48.58 g	3.50 g	7.69 g	3.52 g	2.96 g	1094.56 g	40.27 g
T ₉ = E @ 20 ml + P @ 20 g kg ⁻¹ soil	44.80 h	3.03 h	6.40 h	2.55 h	2.10 h	648.67 h	35.38 h
p-value	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
S.E ±	0.8232	0.1780	0.3799	0.2658	0.0935	53.756	0.8426
LSD _{0.05}	1.7451	0.3772	0.8053	0.5635	0.1982	113.96	1.7862

SE, sorghum extract; SP, sorghum powder; E, extract, and P, powder. SG, seed germination; RL, root length; SL, shoot length; FBS⁻¹, fresh biomass per seedling, and DBS⁻¹, dry biomass per seedling. VI refers to the Vigour Index, and MC stands for Moisture Content. Significant results are indicated by an asterisk (**).

2.10 g dry biomass seedling⁻¹, 648.67 vigour index and 35.38 % moisture content. Similarly, the combined application of extract @ 20 ml + powder @ 10 g kg⁻¹ soil ranked 3rd in phytotoxic potential having 48.58 % seed germination, 3.50 cm root length, 7.69 cm shoot length, 3.52 g fresh biomass seedling⁻¹, 2.96 g dry biomass seedling⁻¹, 1094.56 vigour index and 40.27 % moisture content. Nevertheless, control (check) treatment recorded maximum seed germination (93.27 %), root length (12.00 cm), shoot length (19.90 cm), fresh biomass seedling⁻¹ (11.95 g), dry biomass seedling⁻¹ (5.62), vigour index (2801.61) and moisture content (61.51 %). Moreover, the overall results suggested that the inhibitory allelopathic effect of sorghum was form and dose-specific. Extract of sorghum was found more allelopathic as compared to its powder. Higher doses either in the form of extract or powder caused significantly greater allelopathic effect over lower dose. Combination of extract (20 ml) + powder (20 g) proved more allelopathic in contrast to same dose (40 g) of powder. These findings are in line with results of [Ashraf and Akhlaq \(2007\)](#) who recommended that water extract of phytotoxic plants exhibited considerable inhibitory effects on weeds growth. A wide range of research literature enlightens the sorghum plant's phytotoxic efficacy and highlights their role in various farming systems. The most important allelochemicals released by sorghum are hydrophobic *p* benzoquinone (sorgoleone), phenolics, and acyanogenic glycoside ([Abbas et al., 2021](#)). With 1, 4-dihydroxy form sorgoleone represents sorghum root exudates containing 90% compounds ([Glab et al., 2017](#)). An integrated line to sorghum cultivation shows sustainable potential treatment utilizing the secondary metabolites proven as principal combinations in finding series of herbicides ([Hussain et al., 2021](#)). Manipulation of allelopathy as an eco-friendly and safe means for weed management. [Kandhro et al. \(2015\)](#) investigated that water extract of allelopathic crops significantly reduced the germination and growth of tested weeds such as purple nutsedge (*Cyperus rotundus* L.), Bermuda grass (*Cynodon dactylon* L.) and jungle rice (*Echinochloa colonum* L.). In another research study the finding revealed that phytotoxic chemicals from the extracts of *Cynodon dactylon* reduces germination in several other species like cotton, corn and barnyard grass ([Vasilakoglou et al., 2005](#)). Sorghum and sunflower residues retarded the germination and growth of carpet weed and purple nutsedge ([Khaliq et al., 2011](#)).

Conclusions and Recommendations

The research findings concluded that under laboratory conditions sorghum (*Sorghum bicolor* L.) allelopathic material caused significant inhibitory effects of seed germination and seedling growth of tested weeds associated with sesame crop. The solitary application of sorghum extract at 40 ml kg⁻¹ soil demonstrated significant allelopathic effects as compared to sole doses of powder and combined doses extract and powder. The sole water extract of sorghum caused higher phytotoxic potential over soil incorporation of sorghum powder. The overall findings suggested that sole sorghum extract at 40 ml kg⁻¹ soil showed significant results as compared to solely applied doses of sorghum powder and integrated doses of sorghum extract and powder.

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Novelty Statement

The present research work investigated the allelopathic efficacy of sorghum in suppressing the germination and seedling growth of weeds in sesame crops for the first time under laboratory conditions. This could help in weed reduction and will open up the ways towards sustainable and eco-friendly agronomic practices for weed management and enhancing the overall productivity of crops in the future.

Author's Contribution

MSC planned the experiment, gathered data, and prepared the manuscript. MNK guided scholars as a whole from designing to writing of manuscript. BNM contributed to the collection of data and proofreading of the manuscript. ZHS helped in the interpretation of the results and editing of the manuscript. SAC contributed to the research material and data analysis.

Conflict of interest

The authors have declared no conflicts of interest.

References

Abbas, T., A. Ahmad, A. Kamal, M.Y. Nawaz,

- M.A. Jamil, T. Saeed, M.A. Abid, H.H. Ali and M. Ateeq. 2021. Ways to use allelopathic potential for weed management: A review. *Int. J. Food Sci. Agric.*, 5: 492-498. <https://doi.org/10.26855/ijfsa.2021.09.020>
- Ali, H.H., A.M. Peerzada, Z. Hanif, S. Hashim and B.S. Chauhan. 2017. Weed management using crop competition in Pakistan: A review. *Crop Prot.*, 95: 22-30. <https://doi.org/10.1016/j.cropro.2016.07.009>
- Ali, M., M.A. Ahmad, A. Sajjad and S. Sae. 2022. Effectiveness of native solitary bees in seed production of sesame (*Sesamum indicum* L.). *Sarhad J. Agric.*, 38(3): 10691075. <https://doi.org/10.17582/journal.sja/2022/38.3.1069.1075>
- Alsaadawi, I.S., M. Al-Ekelle and M. Al-Hamzawi. 2005. Allelopathic potential of *Sorghum bicolor* L. (Moench) genotypes against weeds. pp. 254-257.
- Ashraf, M. and M. Akhlaq. 2007. Effects of sorghum leaves, roots and stems water extract, hand weeding and herbicide on weeds suppression and yield of wheat. *Sarhad J. Agric.*, 23(2): 319.
- Aslam, F., S. Iqbal, M. Nasir and A.A. Anjum. 2019. White sesame seed oil mitigates blood glucose level, reduces oxidative stress, and improves biomarkers of hepatic and renal function in participants with type 2 diabetes mellitus. *J. Am. Coll. Nutr.*, 38(3): 235-246. <https://doi.org/10.1080/07315724.2018.1500183>
- Awan, I.U., M.A. Khan, M. Zareef and E.A. Khan. 2009. Weed management in sunflower with allelopathic water extract and reduced doses of an herbicide. *Pak. J. Weed Sci. Res.*, 15: 19-30.
- Ayana, N.G., 2015. Status of production and marketing of Ethiopian sesame seeds (*Sesamum indicum* L.). A review. *Agric. Biol. Sci. J.*, 1(5): 217-223.
- Azab, A.E.S., 2014. Hepatoprotective effect of sesame oil against lead induced liver damage in albino mice: Histological and biochemical studies. *Am. J. Bio-Sci.*, 12(2): 1-11. <https://doi.org/10.11648/j.ajbio.s.2014020602.11>
- Azhar, M., Z.A. Cheema and K. Abdul 2010. Evaluating the potential of allelopathic plant water extracts in suppressing horse purslane growth. *Int. J. Agric. Biol.*, 12(4): 581585.
- Bais, H.P., R. Vepachedu, S. Gilroy, R.M. Callaway and J.M. Vivanco. 2003. Allelopathy and exotic plant invasion from molecules and genes to species interactions. *Science*, 301(5638): 1377-1380. <https://doi.org/10.1126/science.1083245>
- Bàrberi, P., 2019. Ecological weed management in sub-Saharan Africa: Prospects and implications on other agroecosystem services. *Adv. Agron.*, 156: 219-264. <https://doi.org/10.1016/bs.agron.2019.01.009>
- Bersisa, G., G. Umoh, T. Tesema, N. Hundesa and S. Bedada. 2016. Survey of weeds in sesame in the major growing area of Ethiopia. *Ecol. Evol. Biol.*, 8(1): 1-13.
- Besançon, T.E., F.E. Dayan, T.W. Gannon and W.J. Everman. 2020. Conservation and divergence in sorgoleone production of sorghum species. *J. Environ. Qual.*, 49(2): 368-377. <https://doi.org/10.1002/jeq2.20038>
- Cheema, Z. and A. Khaliq. 2000. Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agric. Ecol. Environ.*, 79(23): 105-112. [https://doi.org/10.1016/S0167-8809\(99\)00140-1](https://doi.org/10.1016/S0167-8809(99)00140-1)
- Cheema, Z., 1988. Weed control in wheat through sorghum allelochemicals. PhD thesis, Department of Agronomy, University Agriculture, Faisalabad, Pakistan.
- Cheema, Z., A. Khaliq and S. Saeed 2004. Weed control in maize (*Zea mays* L.) through sorghum allelopathy. *J. Sustain. Agric.*, 23(4): 73-86. https://doi.org/10.1300/J064v23n04_07
- Cheema, Z.A., A. Khaliq and M. Farooq. 2008. Sorghum allelopathy for weed management in wheat. *Allelopat. Sus. Agric. For.*, pp. 255-270. https://doi.org/10.1007/978-0-387-77337-7_13
- Chen, S. and B. Zhang. 2021. Organ-specific transcriptome analysis identifies candidate genes involved in the stem specialization of bermudagrass (*Cynodon dactylon* L.). *Front. Genet.*, 12: 678673. <https://doi.org/10.3389/fgene.2021.678673>
- Couch, A., R.M. Gloaguen, D.R. Langham, G.J. Hochmuth, J.M. Bennett and D.L. Rowland. 2017. Non-dehiscent sesame (*Sesamum indicum* L.): Its unique production potential and expansion into the southeastern USA. *J. Crop Improv.*, 31(2): 101-172.
- Cruz, N.D., L.F.J. Do Nascimento, R.F. Santos, L.A.Z. Júnior, E. Cunha and E.O. Rocha. 2019. Characteristics and cultural practices of sesame (*Sesamum indicum* L.). *Rev. Brasil. Energ. Renov.*, 8(4): 665-675. <https://doi.org/10.5380/rber.v8i4.65757>

- Czarnota, M.A., R.N. Paul., L.A. Weston and S.O. Duke. 2003. Anatomy of sorgoleonesecreting root hairs of Sorghum species. Int. J. Plant Sci., 164(6): 861-866. <https://doi.org/10.1086/378661>
- Farooq, N., T. Abbas, A. Tanveer and K. Jabran. 2020. Allelopathy for weed management. Co-evolution of secondary metabolites, pp. 505-519. https://doi.org/10.1007/978-3-319-96397-6_16
- Gharby, S., H. Harhar, Z. Bouzoubaa, A. Asdadi, A. El-Yadini and Z. Charrouf. 2017. Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. J. Saudi Soc. Agric. Sci., 16(2): 105-111. <https://doi.org/10.1016/j.jssas.2015.03.004>
- Głab, L., J. Sowiński, R. Bough and F.E. Dayan. 2017. Allelopathic potential of sorghum (*Sorghum bicolor* (L.) Moench) in weed control: A comprehensive review. Adv. Agron., 145: 43-95. <https://doi.org/10.1016/bs.agron.2017.05.001>
- Golmaei, F., E.R. Petroudi, H.R. Mobasser and F.S. Shahmiri. 2023. Weed control using allelopathic properties of rapeseed residues and crop management. Rom. Agric. Res., 40. <https://doi.org/10.59665/rar4027>
- Hassan, M.M., H.M. Daffalla, S.O. Yagoub, M.G. Osman, M.E.A. Gani and A.E.D.E. Babiker. 2012. Allelopathic effects of some botanical extracts on germination and seedling growth of *Sorghum bicolor* L. Int. J. Agric. Technol., 8(4): 1423-1469.
- Hussain, M.I. and M.J. Reigosa. 2017. Evaluation of photosynthetic performance and carbon isotope discrimination in perennial ryegrass (*Lolium perenne* L.) under allelochemicals stress. Ecotoxicol., 26: 613-624. <https://doi.org/10.1007/s10646-017-1794-3>
- Hussain, M.I., S. Danish, A.M. Sánchez-Moreiras, O. Vicente, K. Jabran, U.K. Chaudhry, F. Branca and M.J. Reigosa. 2021. Unraveling sorghum allelopathy in agriculture: Concepts and implications. Plants, 10(9): 1795. <https://doi.org/10.3390/plants10091795>
- Iqbal, J. and Z.A. Cheema. 2008. Purple nutsedge (*Cyperus rotundus* L.) management in cotton with combined application of Sorgaab and s-metolachlor. Pak. J. Bot., 40(6): 2383-2391.
- Jabran, K., G. Mahajan, V. Sardana and B.S. Chauhan. 2015. Allelopathy for weed control in agricultural systems. Crop Prot., 72: 57-65. <https://doi.org/10.1016/j.cropro.2015.03.004>
- Jafariehyazdi, E. and F. Javidfar. 2011. Comparison of allelopathic effects of some brassica species in two growth stages on germination and growth of sunflower. Plant Soil Environ., 57(2): 52-56. <https://doi.org/10.17221/139/2010-PSE>
- Jesudas, P.A., S.J. Kingsley and S. Ignacimuthu. 2014. Sorgoleone from *Sorghum bicolor* as a potent bioherbicide. Res. J. Recent Sci., 3: 32-36.
- Jia, X., Q. Zhou, J. Wang, C. Liu, F. Huang and Y. Huang. 2019. Identification of key aroma-active compounds in sesame oil from microwaved seeds using E-nose and HS-SPME-GC× GC-TOF/MS. J. Food Biochem., 43(10): e12786. <https://doi.org/10.1111/jfbc.12786>
- Kandhro, M.N., M.A. Ansari, A. Naqi, M. Ibrahim and H.R. Memon. 2015. Laboratory studies on the allelopathic potential of sorghum and sunflower water extract and powder against narrow-leaf summer weeds. Gomal Univ. J. Res., 31: 10198180.
- Karnan, G., R. Pasala, B.B. Pandey, M. ChLn, R. Kt, R. Al and A. Guhey. 2023. Source and sink traits and their relationship under deficit soil moisture stress conditions in an indeterminate crop: Sesame (*Sesamum indicum* L.). Plant Prod. Sci., 26(2): 153-163. <https://doi.org/10.1080/1343943X.2023.2203404>
- Khalique, A., A. Matloob, M. Farooq, M. Mushtaq and M. Khan. 2011. Effect of crop residues applied isolated or in combination on the germination and seedling growth of horse purslane (*Trianthema portulacastrum*). Planta Daninha, 29: 121-128. <https://doi.org/10.1590/S0100-83582011000100014>
- Khamare, Y., J. Chen and S.C. Marble. 2022. Allelopathy and its application as a weed management tool: A review. Front. Plant Sci., 13: 1034649. <https://doi.org/10.3389/fpls.2022.1034649>
- Khan, E.A., A.A. Khakwani and M. Munir. 2015. Effects of allelopathic chemicals extracted from various plant leaves on weed control and wheat crop productivity. Pak. J. Bot., 47(2): 735-740.
- Kobayashi, K., D. Itaya, P. Mahatamnuchoke and T. Pornprom. 2008. Allelopathic potential of it chgrass (*Rottboellia exaltata* L. f.) powder incorporated into soil. Weed Biol. Manage., 8(1): 64-68. <https://doi.org/10.1111/j.1445-6664.2007.00275.x>

- Kouighat, M., M. El-Harfi, H. Hanine M. El-Fechali and A. Nabloussi. 2022. Moroccan sesame: Current situation, challenges, and recommended actions for its development. *Oils Fat Crop Li.*, 29: 27. <https://doi.org/10.1051/ocl/2022022>
- Kumar, M., D. Sah, S. Yadav, V. Singh, R. Kumar and K. zam. 2023. Structure, composition and importance value index of weeds in major rabi crops of Banda district of UP Bundelkhand. *Pharm. Innov. J.*, 12(9): 2985-2990.
- Kuroha, T., H. Kato, T. Asami, S. Yoshida, H. Kamada and S. Satoh. 2002. A trans-zeatin riboside in root xylem sap negatively regulates adventitious root formation on cucumber hypocotyls. *J. Exp. Bot.*, 53(378): 2193-2200. <https://doi.org/10.1093/jxb/erf077>
- Lahmod, N.R. and I.S. Alsaadawi. 2014. Weed control in wheat using sorghum residues and less herbicide. *Allelopathy J.*, 34(2): 277.
- Lee, J.Y., S.E. Lee and D.W. Lee. 2022. Current status and future prospects of biological routes to bio-based products using raw materials, wastes, and residues as renewable resources. *Crit. Rev. Environ. Sci. Technol.*, 52(14): 2453-2509. <https://doi.org/10.1080/10643389.2021.1880259>
- Matos, F.S., B.N. Furtado, M.R. dos Santos, V.A. Amorim and L.P. Borges. 2020. Biorational agriculture: Herbicidal activity of sorghum extract in control of *Cyperus rotundus* L. *Magistra*, 31: 675-682.
- Mujtaba, M., H.M. Cho, H. Masjuki, M. Kalam, H.C. Ong, M. Gul, M. Harith and M. Yusoff. 2020. Critical review on sesame seed oil and its methyl ester on cold flow and oxidation stability. *Energy Rep.*, 6: 40-54. <https://doi.org/10.1016/j.egy.2019.11.160>
- Nakamura, Y., H. Okumura, Y. Ono, Y. Kitagawa, T. Rogi and H. Shibata. 2020. Sesame lignans reduce LDL oxidative susceptibility by downregulating the platelet-activating factor acetyl hydrolase. *Eur. Rev. Med. Pharmacol. Sci.*, 24(4): 2151-2161.
- Nawaz, A. and M. Farooq. 2016. Weed management in resource conservation production systems in Pakistan. *Crop Prot.*, 85: 89-103. <https://doi.org/10.1016/j.cropro.2016.04.002>
- Nazir, A., M.A. Bhat, T.A. Bhat, S. Fayaz, M.S. Mir, U. Basu, S.A. Ahanger, S. Altaf, B. Jan and B.A. Lone. 2022. Comparative analysis of rice and weeds and their nutrient partitioning under various establishment methods and weed management practices in temperate environment. *Agron.*, 12(4): 816. <https://doi.org/10.3390/agronomy12040816>
- Nematian, T., M. Fatehi, M. Hosseinpour and M. Barati. 2021. One-pot conversion of sesame cake to low N-content biodiesel via nanocatalytic supercritical methanol. *Renew. Energy*, 170: 964-973. <https://doi.org/10.1016/j.renene.2021.02.042>
- Oda, A., C. Sakuta, S. Masuda, T. Mizoguchi, H. Kamada and S. Satoh. 2003. Possible involvement of leaf gibberellins in the clock-controlled expression of XSP30, a gene encoding a xylem sap lectin, in cucumber roots. *Plant Physiol.*, 133(4):1779-1790. <https://doi.org/10.1104/pp.103.030742>
- Ofosu, R., E.D. Agyemang, A. Márton, G. Pásztor, J. Taller and G. Kazinczi. 2023. Herbicide resistance: managing weeds in a changing world. *Agron.*, 13(6): 1595. <https://doi.org/10.3390/agronomy13061595>
- Ogunsola, O. and T. Fasola. 2014. The antibacterial activities of *Sesamum indicum* L. leaf extracts methods. *Adv. Life Sci. Tech.*, 18: 28-32.
- Rajpurohit, D.S., L. Arvadia and R. Jangir. 2017. Growth and yield of summer sesamum (*Sesamum indicum* L.), dry weight of weeds and weed control efficiency influence by different row spacing and weed management under south Gujarat condition. *Int. J. Curr. Microbiol. Appl. Sci.*, 6(8): 2493-2501. <https://doi.org/10.20546/ijcmas.2017.608.295>
- Rehman, A., Z. Cheema, A. Khaliq, M. Arshad and S. Mohsan. 2010. Application of sorghum, sunflower and rice water extract combinations helps in reducing herbicide dose for weed management in rice. *Int. J. Agric. Biol.*, 12(6): 901-906.
- Sarić-Krsmanović, M., J. Gajić Umiljendić, L. Radivojević, L. Šantrić, I. Potočnik and R. Urović-Pejčev. 2019. Bio-herbicidal effects of five essential oils on germination and early seedling growth of velvetleaf (*Abutilon theophrasti* Medik.). *J. Environ. Sci. Health Part B*, 54(4): 247-251. <https://doi.org/10.1080/03601234.2018.1550309>
- Shayo, P., 2023. Distribution, characterization and propagation methods for conservation and utilization of oyster nuts *Telfairia pedata* in

- Tanzania. NM-AIST.
- Singh, R.K. and B.D. Chaudhary. 1985. Biometrical methods in quantitative genetics analysis: Kalyani Publishers.
- Tibugari, H., C. Chiduzza, A. Mashingaidze and S. Mabasa. 2020. High sorgoleone autotoxicity in sorghum (*Sorghum bicolor* (L.) Moench) varieties that produce high sorgoleone content. S. Afr. J. Plant soil., 37(2): 160-167. <https://doi.org/10.1080/02571862.2020.1711539>
- Uddin, M.R., K.W. Park, J.Y. Pyon and S.U. Park. 2013. Combined herbicidal effect of two natural products (sorgoleone and hairy root extract of tartary buckwheat) on crops and weeds. Aust. J. Crop Sci., 7(2): 227-233.
- Ullah, R., Z. Aslam, M. Maitah, Q.U. Zaman, S. Bashir, W. Hassan and Z. Chen. 2020. Sustainable weed control and enhancing nutrient use efficiency in crops through Brassica (*Brassica campestris* L.) allelopathy. Sustainability, 12(14): 5763. <https://doi.org/10.3390/su12145763>
- Vasanthi, E. and D. Rajavel. 2021. Biopesticidal effect of sesamin on subterranean termite, *Odontotermes Obesus* (*Termitidae, isoptera*). J. Entomol. Res., 45(3): 444-446. <https://doi.org/10.5958/0974-4576.2021.00069.4>
- Vashisht, P., N. Yadav, R. Kumar, P. Jangra and J. Indora. 2023. Management strategies for charcoal rot of sesame: A review. Int. J. Plant Sci., 35(19): 2255-2264. <https://doi.org/10.9734/ijpss/2023/v35i193777>
- Vasilakoglou, I., K. Dhima and I. Eleftherohorinos. 2005. Allelopathic potential of bermudagrass and johnsongrass and their interference with cotton and corn. Agron. J., 97(1): 303-313. <https://doi.org/10.2134/agronj2005.0303a>
- Wahyuni, S., U.R. Sinniah, R. Amarthalingam and M.K. Yusop. 2003. Enhancement of seedling establishment in rice by selected growth regulators as seed treatment. J. Penelit. Pertanian. Pangan., 22(1): 51-55.
- Wei, P., F. Zhao, Z. Wang, Q. Wang, X. Chai, G. Hou and Q. Meng. 2022. Sesame (*Sesamum indicum* L.): A comprehensive review of nutritional value, phytochemical composition, health benefits, development of food, and industrial applications. Nutrient, 14(19): 4079. <https://doi.org/10.3390/nu14194079>
- Wei, X., K. Liu, Y. Zhang, Q. Feng, L. Wang, Y. Zhao, D. Li, Q. Zhao, X. Zhu and X. Zhu. 2015. Genetic discovery for oil production and quality in sesame. Nat. Commun., 6(1): 8609. <https://doi.org/10.1038/ncomms9609>
- Weldemichael, M.Y. and H.M. Gebremedhn. 2023. QTL Mapping in Sesame (*Sesamum indicum* L.): A review. J. Biotech., 376: 11-23. <https://doi.org/10.1016/j.jbiotec.2023.09.003>
- Yadav, R., S. Kalia, P. Rangan, G.P. Rao, V. Kaur, R. Pandey, V. Rai, S. Langyan, V.S. Rana and H. Vishwakarma. 2022. Current research trends and prospects for yield and quality improvement in sesame, an important oilseed crop. Front. Plant Sci., 13: 863521. <https://doi.org/10.3389/fpls.2022.863521>
- Yarnia, M., M.K. Benam and E.F.M. Tabrizi. 2009. Allelopathic effects of sorghum extracts on *Amaranthus retroflexus* seed germination and growth. J. Food Agric. Environ., 7(4): 770-774.
- Yin, W.T., X-T. Ma and X.D. Wang. 2019. Volatile composition and sensory evaluation of sesame oils extracted by different processes. China Oils Fats, 44(12): 8-13.
- Zenawi, G. and A. Mizan. 2019. Effect of nitrogen fertilization on the growth and seed yield of sesame (*Sesamum indicum* L.). Int. J. Agron., 2019: 7. <https://doi.org/10.1155/2019/5027254>