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 allele chemicals into the environment (Golmaei *et al*., 2023). Sorgoleone, an excellent allele-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 portulacstrum* 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 allele-chemicals 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 herbages 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 (*Concolvulus arvensis* L.), and Purple nutsedge (*Cyperus rotundus* L.) were sown into the respective sandboxes separately. The sowing was done during 2$^{nd}$ 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 2$^{nd}$ 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

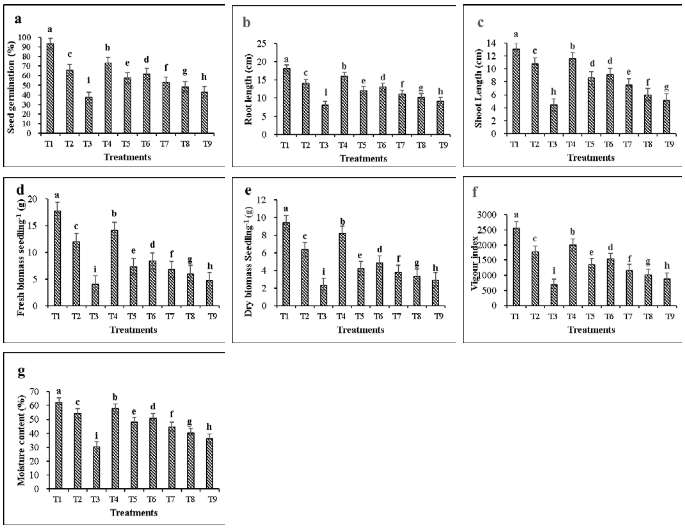

**Figure 1:** The phytotoxic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling$^{-1}$; e, Dry biomass seedling$^{-1}$; f, Vigour index, and g. Moisture content of False amaranth. Whereas, T1= Control (check), T2= Sorghum extract @ 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 3$^{rd}$ 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 seeling$^{-1}$, 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 seeling$^{-1}$ (17.83 g), dry biomass seeling$^{-1}$ (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 2$^{nd}$ in phytotoxic potential where 46.22 % seed germination, 4.03 cm root length, 4.10 cm shoot length, 4.00 g fresh biomass seegling$^{-1}$, 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

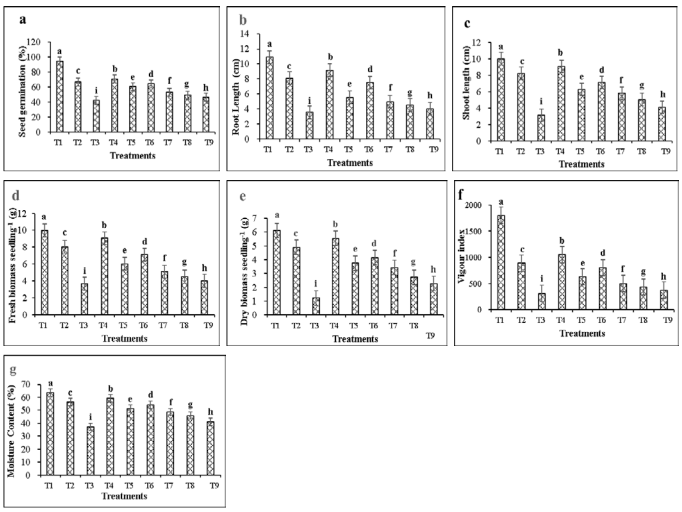


**Figure 2:** Allelopathic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling$^{-1}$; e, Dry biomass seedling$^{-1}$; f, Vigour index, and g. Moisture content of Carpet weed. Whereas, T1= Control (check), T2= Sorghum extract @ 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 supress 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, protocateuic acid gallic acid, vanillic acid, syringic acid, benzoic acid, p-hydroxybezoic 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.

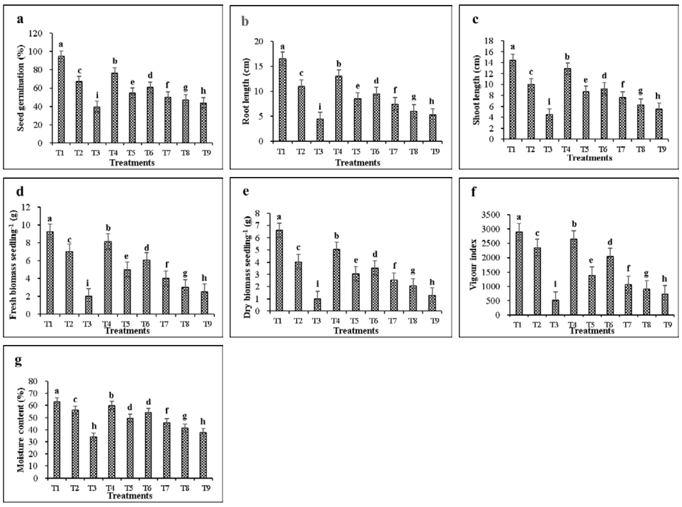

**Figure 3:** Allelopathic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling$^{-1}$; e, Dry biomass seedling$^{-1}$; f, Vigour index, and g, Moisture content of Field bindweed. Whereas, T1= Control (check), T2= Sorghum extract @ 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*., 3003), 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$^{-1}$,

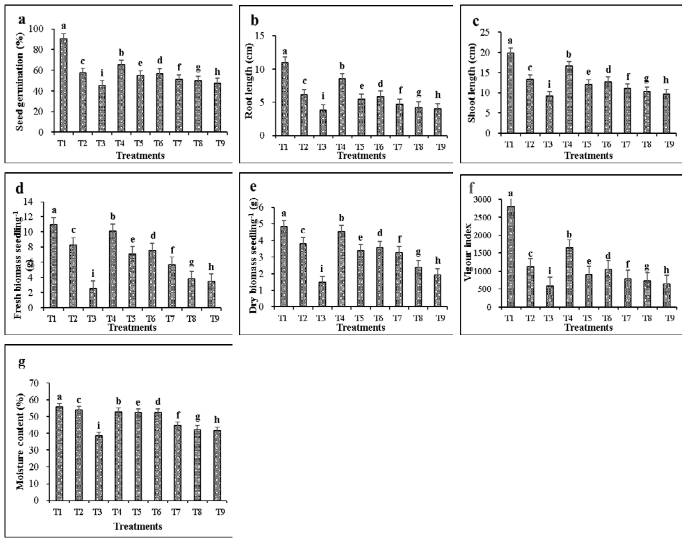


**Figure 4:** The phytotoxic effects of sorghum (*Sorghum bicolor* L.) on a, Seed germination; b, Root length; c, Shoot length; d, Fresh biomass seedling$^{-1}$; e, Dry biomass seedling$^{-1}$; f, Vigour index, and g. Moisture content of Purple nutsedge. Whereas, T1= Control (check), T2= Sorghum extract @ 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 3$^{rd}$ 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.

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