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# Evaluation of the efficacy of the plant-based fumigant Dominus in managing broadleaf and narrow-leaved weeds in onion (*Allium cepa* L.) cultivation

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**Abstract**

This study was conducted to assess the efficacy of the bio-herbicide Dominus (based on allyl isothiocyanate, applied at 280 L ha⁻¹) for weed management in onion production under both greenhouse and field conditions in the southern region of Kerman Province, Iran, during the 2021–2022 growing season. In the greenhouse experiment, the effect of Dominus application on seven weed species was investigated using a factorial experiment with a completely randomized design and five replications. At the same time, the field trial was arranged in a randomized complete block design with two treatments, Dominus application and a non-treated control, with three replications. Under greenhouse conditions, Dominus significantly reduced germination of all seven weed species, including *Malva neglecta* Wallr., *Amaranthus retroflexus* L., *Chenopodium album* L., *Lolium rigidum* Gaud., *Phalaris minor* Retz., *Avena ludoviciana* Durieu., and *Cuscuta campestris* L. at the 1% probability level. In the field, Dominus provided complete (100%) control of the dominant weed *Cyperus rotundus* L. and markedly decreased the biomass of the other weed species. Onion yield in the Dominus-treated plots (78 t ha⁻¹) did not differ significantly from the weed-free control (79 t ha⁻¹). In contrast, the untreated weedy check exhibited an 83% yield reduction, producing only 15.69 t ha⁻¹. However, Dominus® is a soil fumigant (allyl isothiocyanate) that poses specific, uncontrollable risks: off-target movement through air, high inhalation toxicity, requirement for complete protective gear (air-supplied respirators, chemical-resistant suits) and sophisticated closed-system injection equipment, and inherent unsuitability for open-field agriculture, especially near human dwellings. Therefore, despite its pronounced efficacy, the application of Dominus® is not advisable for onion production in the studied region or any open-field setting, and its use should not be recommended.

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## Introduction

Onion (*Allium cepa* L.) is one of the most important vegetables globally, ranking third after potato and tomato in terms of both cultivation area and production volume (Brice et al., 1997). Iran, as the world's fifth-largest onion producer, is a major contributor to global production (Roozkhosh et al., 2023). The onion cultivation area in the southern region of Kerman Province exceeds 13,000 hectares, and with an average annual production of approximately 589,000 tones, accounting for one-quarter of the national onion output, this region holds the foremost rank in the country (Anonymous, 2024). Owing to its inherently low seedling vigor and limited competitive ability during early growth stages, onion yield and quality are severely compromised by weed infestation (Al-Ebrahim et al., 2019). Weeds reduce onion productivity by competing for essential resources such as light, water, and nutrients (Zand et al., 2019). The most prevalent and problematic weeds in onion fields include purple nutsedge (*Cyperus rotundus* L.), yellow nutsedge (*Cyperus esculentus* L.), common mallow (*Malva neglecta* Wallr.), common purslane (*Portulaca oleracea* L.), and bitter apple (*Citrullus colocynthis* (L.) Schrad.) (Al-Ebrahim et al., 2019: Roozkhosh et al., 2025).

With growing awareness of the adverse environmental impacts of synthetic pesticides and increasing consumer demand for safe agricultural produce, plant-derived pesticides have attracted considerable attention from both researchers and growers. In this context, the plant-based product Dominus was introduced in 2009 by the Isagro Company and registered as a biopesticide by the United States Environmental Protection Agency (EPA) in the same year (Isagro, 2016). Following its initial successful outcomes, Dominus rapidly replaced methyl bromide in many developed countries. Dominus is a biofumigant derived from plant extracts, with allyl isothiocyanate (AITC) as its active ingredient. This compound is extracted from plants of the Brassicaceae family and is employed for pest management in both organic and conventional farming systems (Isagro, 2016; Yu et al., 2019). The application of Dominus in countries such as Mexico, Canada, Italy, Spain, Turkey, Morocco, Chile, Brazil, New Zealand, and Australia has resulted in the effective control of soilborne fungi, nematodes, and weeds (Wu et al., 2011). Furthermore, studies conducted on potato (*Solanum tuberosum* L.), ginseng (*Panax ginseng* C.A. Mey.), carrot (*Daucus carota* subsp. sativus (Hoffm.) Arcang.), strawberry (*Fragaria ananassa* (Weston) Duchesne), and tobacco (*Nicotiana tabacum* L.) have demonstrated that the use of this compound is safe for these crops (Buskov, 2002).

Considering the economic importance of onion in Iran, particularly in the southern region of Kerman Province, and the vulnerability of the crop due to its low competitive ability during early growth stages, effective weed management constitutes a cornerstone of successful onion production. Given the well-documented detrimental effects of chemical herbicides, the employment of naturally derived control agents such as bio-herbicides has received particular emphasis. Accordingly, the objective of the present study was to evaluate the efficacy of the bio-herbicide Dominus (active ingredient: allyl isothiocyanate) in controlling major weeds of onion fields namely common mallow (*Malva neglecta* Wallr.), amaranth (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), annual ryegrass (*Lolium rigidum* Gaud.), littleseed canarygrass (*Phalaris minor* Retz.), winter wild oat (*Avena ludoviciana* Durieu.), and field dodder (*Cuscuta campestris* L.) under both controlled greenhouse and field conditions. This study aims to provide a non-chemical, environmentally compatible weed management strategy, thereby contributing to reduced reliance on synthetic herbicides, the preservation of agroecosystem health, and the attainment of a sustainable agricultural system in onion cultivation (Ji et al., 2025).

## Material and Methods

### Geographical location

This study was conducted under both greenhouse and field conditions at the Agricultural Research, Education and Extension Center and the Jiroft Agro-Industry, located in the southern region of Kerman Province, Iran, during 2021 and 2022. The experimental site lies at 28°37′ N latitude, 57°41′ E longitude, and an elevation of 624 m above sea level. The region features a semi-arid climate characterized by hot summers and mild winters**.**

Prior to land preparation at the field site, the physical and chemical properties of the soil were determined by sampling from a depth of 0–30 cm. The results of the soil analyses for both years are presented in Table 1.

**Table 1.** Soil analysis results (physical and chemical properties) of the test site

| Year | Soil depth (cm) | Soil texture | Electrical conductivity (dS/m) | Absorbable potassium (PPM) | Absorbable phosphorus (PPM) | Total Nitrogen (%) | Organic carbon (%) | pH |
|---|---|---|---|---|---|---|---|---|
| 2021 | 0-30 | Sandy loam | 1.66 | 368.63 | 8.2 | 0.023 | 0.115 | 7.6 |
| 2022 | 0-30 | Sandy loam | 1.59 | 348.12 | 8.3 | 0.024 | 0.119 | 7.4 |

## Plant species

Seeds of common mallow (*Malva neglecta* Wallr.) were obtained from the Iranian Research Institute of Plant Protection. Seeds of the other weed species under investigation, namely common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), field dodder (*Cuscuta campestris* L.), annual ryegrass (*Lolium rigidum* Gaud.), littleseed canarygrass (*Phalaris minor* Retz.), and winter wild oat (*Avena ludoviciana* Durieu), were collected from naturally infested fields in the region. Following collection, the seeds were cleaned, sorted, and stored in paper bags under dry, cool ambient conditions until the commencement of the experiments.

## Greenhouse experiment

To evaluate the efficacy of the bio-herbicide Dominus, a factorial experiment based on a completely randomized design with five replications was conducted under controlled greenhouse conditions. The first factor was the weed species, and the second factor was the application or non-application of Dominus. The effect of Dominus was assessed on seven weed speciesfield *C. campestris*, *L. rigidum*, *M. neglecta*, *A. retroflexus*, *Ch. album*, *A. ludoviciana*, and *P. minor* in the presence of onion. The treatments in both treated and untreated (control) components consisted of the application of Dominus at the recommended rate of 280 L $ha^{-1}$.The experiment was arranged as a 7 (weed species) × 2 (Dominus application) factorial in a completely randomized design with four replications (baskets) per treatment combination, giving a total of 56 experimental units. The error degrees of freedom in the ANOVA (df= 56) correspond to this replication.

## Substrate preparation and treatment application

For each weed species, ten cultivation baskets (50 × 50 × 30 cm) were allocated and filled with field soil with a clay loam texture. To overcome seed dormancy in certain species, specific pre-treatments were applied. Dormancy in *M. neglecta* seeds were broken by immersion in concentrated sulfuric acid (98%) for 3 min, rinsing with distilled water, and subsequent cold stratification at 4°C for 21 days (Mondani et al., 2018). *Ph. minor* seeds were treated with sulfuric acid (98%) for 2.5 min and then thoroughly rinsed with distilled water (Gherekhloo et al., 2010). *A. ludoviciana* seeds were first dehulled by removing the lemma and palea, and then stratified at 4°C for 96h (Zand et al., 2024). Following these pre-treatments, 30 non-dormant seeds of each species were sown at a depth proportional to seed size (five times the seed diameter).

Soil moisture was adjusted to 90% field capacity (FC) one day prior to treatment application. To achieve this, the baskets were irrigated by flooding and weighed twice daily until a constant weight was attained in two consecutive measurements; this point was designated as field capacity. Throughout the experiment, soil water status was monitored by randomly weighing the baskets. Daily water loss was estimated from six randomly selected baskets, and the depleted water was replenished to maintain soil moisture at field capacity (Miller & Donahue, 1990). Dominus was applied at a rate of 280 L $ha^{-1}$ equivalent to 7 mL per basket with a surface area of 0.25 $m^2$ diluted in 500 mL of water, and uniformly sprayed over the surface of each basket. Immediately after application, the baskets were covered with thick plastic sheeting for ten days to prevent volatilization of the active ingredient**.**

After ten days, the plastic cover was removed, and the baskets were aerated for 72 h. Onion (cv. Minerva) was then planted using onion sets (bulblets), with six sets per basket. Irrigation was continued according to the crop water requirement, maintaining soil moisture at field capacity until harvest (Miller & Donahue, 1990). Emerged weed seedlings of each species were counted weekly for a period of eight weeks. At the end of the eighth week, the fresh and dry weights (after oven-drying at 70°C for 48h) of each species were determined separately and recorded

## Field experiment

The field component of the study was conducted as a randomized complete block design with three replications. Treatments were application and non-application of the biofumigant Dominus to evaluate the effect of Dominus on *C. rotundus* and the naturally occurring weed flora in an onion field. In addition to these two treatments, each block contained one plot designated as a weed-free control, which was kept free of weeds throughout the growing season by hand weeding and was used for assessing onion yield parameters, and a weedy check with no weed control**.** During the 10-day fumigation period, soil temperature at 10 cm depth averaged 22.3 ± 1.5°C (field) and 24.1 ± 1.2°C (greenhouse). Soil moisture was maintained at 90% of field capacity (field: 18.5% gravimetric water content; greenhouse mix: 22.3%). These conditions were within the optimal range for AITC volatility (20–25°C, >70% FC).

## Field preparation and planting

In September 2022, a field with a known history of infestation by various weed species, particularly *C. rotundus*, was selected. Land preparation operations included plowing, disking, application of farmyard manure (20–30 t $ha^{-1}$) and chemical fertilizers (based on the soil test results presented in Table 1), construction of ridges and furrows, and installation of a drip irrigation system. Plots measuring 8 m in length and consisting of five ridges with 50 cm spacing were established. Onion (cv. Minerva) was planted using sets in four rows per ridge on 15 September.

## Treatment application and sampling

The Dominus treatment was applied according to the procedure described for the greenhouse experiment at a rate of 280 L $ha^{-1}$, and the field surface was immediately covered with plastic sheeting for ten days. Weed sampling was carried out at two time points 30 and 45 days after application. In each plot, three 50 × 50 cm quadrats were sampled in both the treated and untreated sections. Within each sample, weed density, the number of tubers (for *C. rotundus*), and weed dry weight were recorded. At the end of the growing season, onion yield was harvested from a 2.5 m² area in each plot and converted to tones per hectare.

## Statistical analysis

Analysis of variance (ANOVA) was performed using SAS statistical software version 9.4. Mean comparisons were conducted at the 5% probability level using the Least Significant Difference (LSD) test. Graphs were generated using Microsoft Excel.

## Results

## Greenhouse experiment: weed seedling count

The results of the analysis of variance (ANOVA) for the effects of the biofumigant Dominus and weed species on the number of emerged weed seedlings over the eight-week monitoring period in onion are presented in Table 2. The analysis revealed that the main effects of Dominus treatment, weed species, and their interaction on the mean seedling count across all evaluation weeks were highly significant at the 1% probability level ($P \leq 0.01$).

**Table 2.** Analysis of variance of the effects of experimental factors on the mean number of weed plants counted over eight weeks of investigation.

| S.O.V | df | MS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Week1 | Week2 | Week3 | Week4 | Week5 | Week6 | Week7 | Week8 |
| Herbicide treatment | 1 | 788.93** | 1033.73** | 654.23** | 526.63** | 521.16** | 288.06** | 284.01** | 252.7** |
| Weed | 6 | 93.53** | 107.31** | 189.82** | 218.10** | 230.4** | 302.96** | 292.41** | 248.4** |
| Interaction | 6 | 93.53** | 91.36** | 75.19** | 59.30** | 65.66** | 75.72** | 68.61** | 72.17** |
| Error | 56 | 0.12 | 0.14 | 0.57 | 0.73 | 0.64 | 0.36 | 0.91 | 1.12 |
| CV(%) | | 10.38 | 8.98 | 14.46 | 14.1 | 12.39 | 8.45 | 12.85 | 13.65 |

ns, ** and *: non-significant, significant at $P \leq 0.01$ and $P \leq 0.05$, respectively

The results of the interaction effect between the biofumigant Dominus and weed species on the mean number of emerged weed seedlings over the eight-week experimental period are presented in Table 3. Overall, the absence of Dominus application led to a substantial increase in weed density across all species examined. In the untreated control, weed emergence was notably higher for certain species, including *A. retroflexus*, *M. neglecta*, *Ch. album*, and *A. ludoviciana*, reaching a maximum of 13 emerged seedlings during the first and second weeks.

In contrast, the application of the biofumigant Dominus exhibited a pronounced inhibitory effect on the germination of *Ph. minor* and *A. ludoviciana*, such that the number of emerged seedlings per basket did not exceed two even by the eighth week. The data further demonstrated that Dominus significantly suppressed the germination of *L. rigidum* (up to the fifth week) and *C. campestris* (up to the eighth week). In other words, during the critical early-season period when onion is highly sensitive to weed interference, Dominus effectively prevented the germination of *L. rigidum* and *C. campestris* seeds.

Another noteworthy finding was that the application of Dominus provided effective control of the majority of weed species during the initial two-week period. With the exception of *M. neglecta* and *L. rigidum*, the mean number of emerged seedlings of all other species did not exceed four per basket by the third week.

With regard to *M. neglecta*, results indicated that its seedlings began to emerge approximately 15 days after Dominus application. The use of the biofumigant during the early growth stage of onion markedly suppressed *M. neglecta* seed germination. Although the number of emerged seedlings in the Dominus-treated baskets increased slightly over time, the ANOVA results (Table 2) revealed that the difference in *M. neglecta* density between the treated and untreated treatments was statistically significant (P $\leq$ *0.01*). In other words, Dominus application led to a significant reduction in *M. neglecta* density compared to the untreated control.

**Table 3.** Mean comparison of the interaction effect between Dominos biofumigant and weed species on the plant count per week.

| Interaction | | MS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Weed species | Week1 | Week2 | Week3 | Week4 | Week5 | Week6 | Week7 | Week8 |
| With Dominos application | *Phaiaris minor* | $0.00^{d}$ | $0.40^{d}$ | $0.40^{e}$ | $0.60^{e}$ | $0.60^{e}$ | $0.60^{d}$ | $0.60^{dc}$ | $0.60^{e}$ |
| | *Amaranthus retroflexus* | $0.00^{d}$ | $0.00^{d}$ | $0.80^{e}$ | $7.60^{c}$ | $8.40^{c}$ | $12.80^{a}$ | $12.60^{a}$ | $12.60^{a}$ |
| | *Malva neglecta* | $0.00^{d}$ | $0.00^{d}$ | $10.40^{b}$ | $10.40^{b}$ | $11.00^{b}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| | *Chenopodium album* | $0.00^{d}$ | $2.20^{c}$ | $3.60^{d}$ | $4.60^{d}$ | $6.20^{d}$ | $8.80^{c}$ | $10.60^{b}$ | $11.00^{b}$ |
| | *Avena ludoviciana* Durieu | $0.00^{d}$ | $0.00^{d}$ | $0.00^{e}$ | $0.00^{e}$ | $0.00^{e}$ | 0.60d | $1.00^{cd}$ | $1.00^{de}$ |
| | *Cuscuta campestris* | $0.00^{d}$ | $0.00^{c}$ | $0.00^{c}$ | $0.00^{c}$ | $0.00^{b}$ | $0.00^{b}$ | $1.4^{b}$ | $2.2^{c}$ |
| | *Lolium rigidum* | 2.20b | $3.00^{b}$ | $5.4^{b}$ | $5.4^{b}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| Without Dominos application | *Phaiaris minor* | $2.20^{c}$ | $4.80^{b}$ | $5.80^{b}$ | $9.40^{b}$ | $11.80^{b}$ | $11.80^{b}$ | $11.80^{b}$ | $11.80^{b}$ |
| | *Amaranthus retroflexus* | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| | *Malva neglecta* | $12.60^{a}$ | $12.60^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| | *Chenopodium album* | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| | *Avena ludoviciana Durieu* | $6.20^{b}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |
| | *Cuscuta campestris* | $0.00^{c}$ | $0.00^{c}$ | $0.00^{c}$ | $0.00^{c}$ | $0.00^{b}$ | $0.00^{b}$ | $2.6^{b}$ | $6.2^{b}$ |
| | *Lolium rigidum* | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ | $13.00^{a}$ |

The columns with the same letter are not significantly different at 5% level (LSD)

The highest mean weed seedling counts over the study period were recorded for *M. neglecta*, *A. retroflexus*, and *Ch. album*, which surpassed the other species in both germination speed and the total number of emerged seedlings. A notable feature of the germination pattern was that *A. ludoviciana* seeds ceased germination entirely after the second week of the experiment, whereas species such as *M. neglecta*, *A. retroflexus*, and *Ch. album* continued to germinate throughout the entire experimental period. This characteristic may explain the ability of these species to escape control by post-emergence herbicides, resulting in subsequent seed replenishment in the field following herbicide application

## Weed fresh and dry weight

The ANOVA results for the effects of the experimental treatments on weed fresh and dry weights are presented in Table 4. The analysis revealed that the main effects of the biofumigant Dominus and weed species, as well as their interaction, on both fresh and dry weights were highly significant (P $\leq$ *0.01*). This significant interaction indicates differential responses among weed species to the Dominus treatment.

The mean comparison of the interaction effect between the biofumigant Dominus application and weed species on the fresh weight of the various weed species is illustrated in Fig. 1. Overall, the mean fresh weight of weeds in the untreated control was higher than that in the Dominus-treated plots. The mean comparison revealed that in both treatments (with and without Dominus), the fresh weights of *Ch. album* and *A. retroflexus* were greater than those of the other species. Nonetheless, a significant difference was observed between the Dominus-treated and untreated conditions for these two species; specifically, the application of the biofumigant Dominus substantially reduced the fresh weight of both *Ch. album* and *A. retroflexus*. Conversely, the lowest fresh weights among the species were recorded for *Ph. minor*, *A. ludoviciana*, and *C. campestris*.

**Table 4.** Analysis of variance of the effects of experimental factors on the mean fresh and dry biomass of different weed species.

| S.O.V | df | MS | |
|---|---|---|---|
| | | Fresh weed biomass | Dry weed biomass |
| Herbicide treatment | 1 | 4645.18** | 35.81** |
| Weed | 6 | 3297.07** | 33.01** |
| Interaction | 6 | 1329.47** | 8.82** |
| Error | 56 | 4.09 | 0.10 |
| CV (%) | | 11.47 | 15.71 |

ns, ** and *: non-significant, significant at P ≤ *0.01* and P ≤ *0.05*, respectively

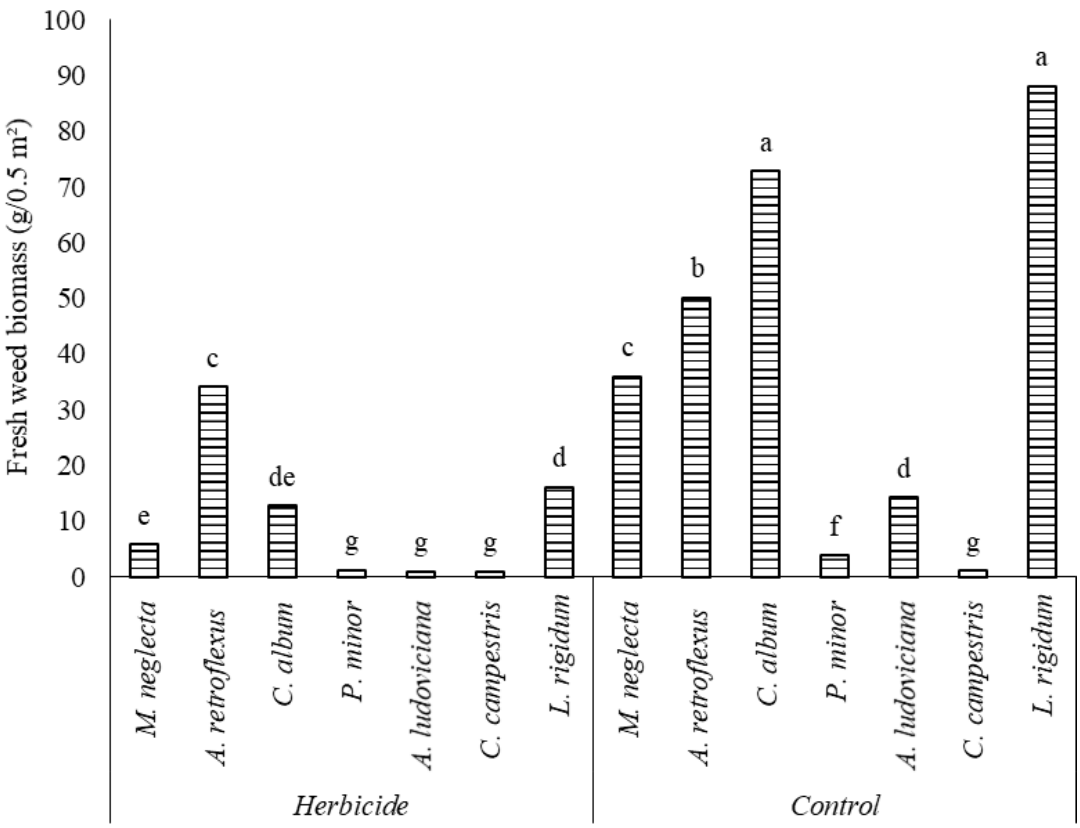


**Fig. 1.** Interaction effect of Dominos biofumigant application and weed species type on fresh weed biomass of different weed species.

The mean comparison of the interaction effect between the biofumigant Dominus application and weed species on weed dry weight is illustrated in Fig. 2. The results indicate that in the untreated control, weed dry weight was significantly higher across all species. The highest dry weight was recorded for *Ch. album*, which differed significantly from the other species. In contrast, the lowest dry weights were obtained for *L. rigidum*, *A.*

*ludoviciana*, and *Ph. minor* in the Dominus-treated plots. Given that *A. retroflexus* exhibited relatively good germination in both the control and Dominus treatments, it can be concluded that the most pronounced reduction in both fresh and dry weight following Dominus application occurred in *Ch. Album*.

## Field experiment

The weed survey conducted in the onion field revealed the presence of a total of 12 weed species, as detailed in Table 5. The assessments indicated that the highest weed densities were recorded for *C. rotundus*, bitter apple (*Citrullus colocynthis* (L.) Schrad.), and field bindweed (*Convolvulus arvensis* L.), in descending order.

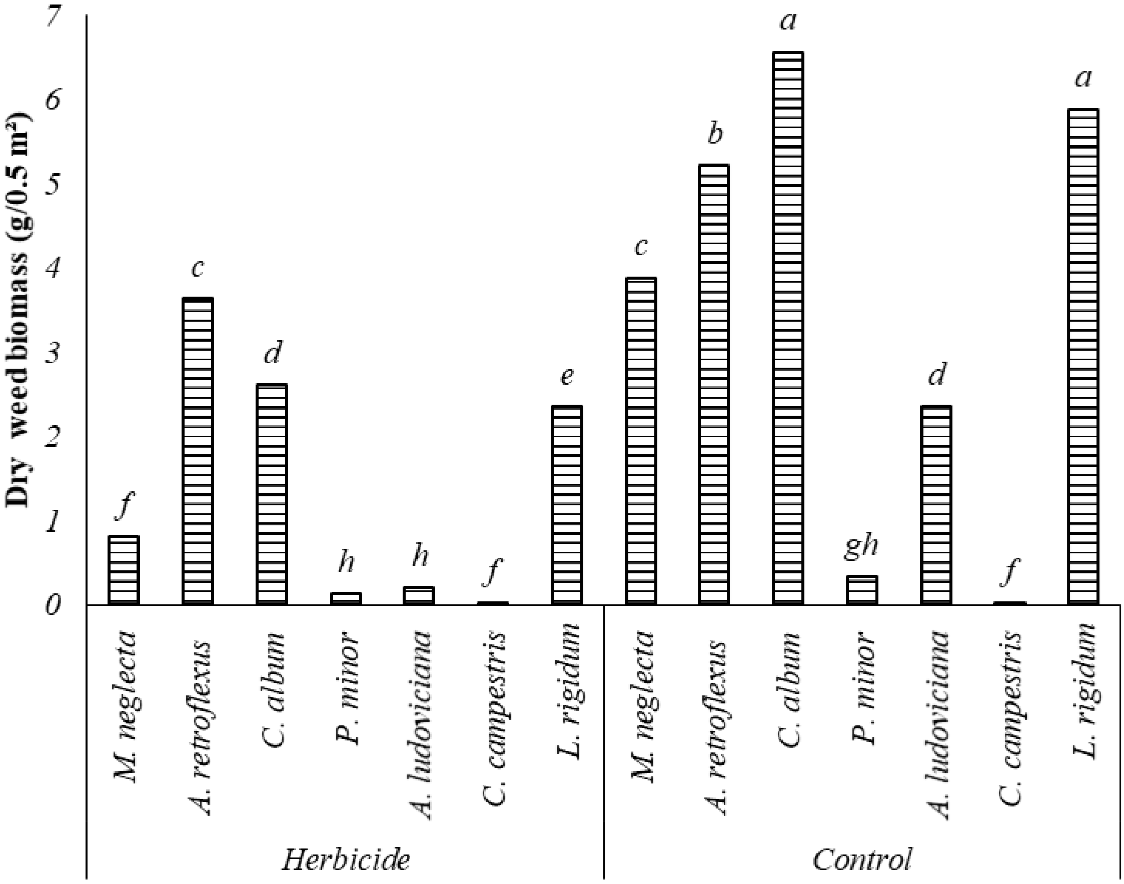


**Fig. 2.** Interactive effect of Dominos biofumigant application on dry weed biomass of different weed species.

**Table 5.** Dominant weed species observed in the onion field.

| Family | Efficacy[a] | Scientific Name | Common name |
|---|---|---|---|
| *Cucurbitaceae* | **** | *Citrullus colocynthis* (L.) Schrad. | Colocynth |
| *Amaranthaceae* | ** | *Amaranthus retroflexus* L. | Pigweed |
| *Cyperaceae* | **** | *Cyperus rotundus* L. | Purple nutsedge |
| *Portulacaceae* | *** | *Portulaca oleracea* L. | Portulaca |
| *Convolvulaceae* | * | *Convolvulus arvensis* L. | field bindweed |
| *Brassicaceae* | * | *Sinapsis arvensis* L. | Wild mustard |
| *Asteraceae* | *** | *Heliotropium europaeum* L. | European turn-sole |
| *Poaceae* | ** | *Echinochloa crus-gali* L. Beauv | cockspur |
| *Poaceae* | *** | *Sorghum halepense* (L.) Pers. | Johnson grass |
| *Malvaceae* | *** | *Malva neglecta* Wallr. | Common mallow |
| *Poaceae* | ** | *Cynodon dactylon* (L.) Pers | Scutch grass |
| *Chenopodiaceae* | * | *Chenopodium album* L. | Common lambsquarters |

a: *Low density; ** Medium density; *** High density; ****Very high density

## Fresh and dry weight of different weed species

The results of the analysis of variance for the effects of the experimental factors on the fresh and dry weights of the various weed species examined in this experiment are presented in Table 6. Accordingly, the simple effects of the biofumigant Dominus application, weed species, and their interaction on both fresh and dry weed weights were significant at the 1% probability level.

The mean comparison results for the interaction effect of the biofumigant Dominus application and weed species on the fresh and dry weights of the different weed species are presented in Fig. 3 and Fig. 4, respectively. The mean comparisons revealed that Dominus application reduced both fresh and dry weights across all weed species examined in this experiment, with a statistically significant difference observed between the treated and untreated conditions. Moreover, significant differences were detected among the weed species with respect to fresh and dry weights, as illustrated in Fig. 3 and Fig. 4.

**Table 6.** Analysis of variance of the effects of experimental factors on the mean fresh and dry weed biomass.

| S.O.V | df | MS | |
|---|---|---|---|
| | | fresh weed biomass | dry weed biomass |
| Replication | 3 | 8406.85** | 196.38** |
| treatment | 2 | 308334.67** | 9576.02** |
| Error | 6 | 36.90 | 2.50 |
| CV (%) | | 10.72 | 15.82 |

ns, ** and *: non-significant, significant at P ≤ *0.01* and *P ≤ 0.05*, respectively

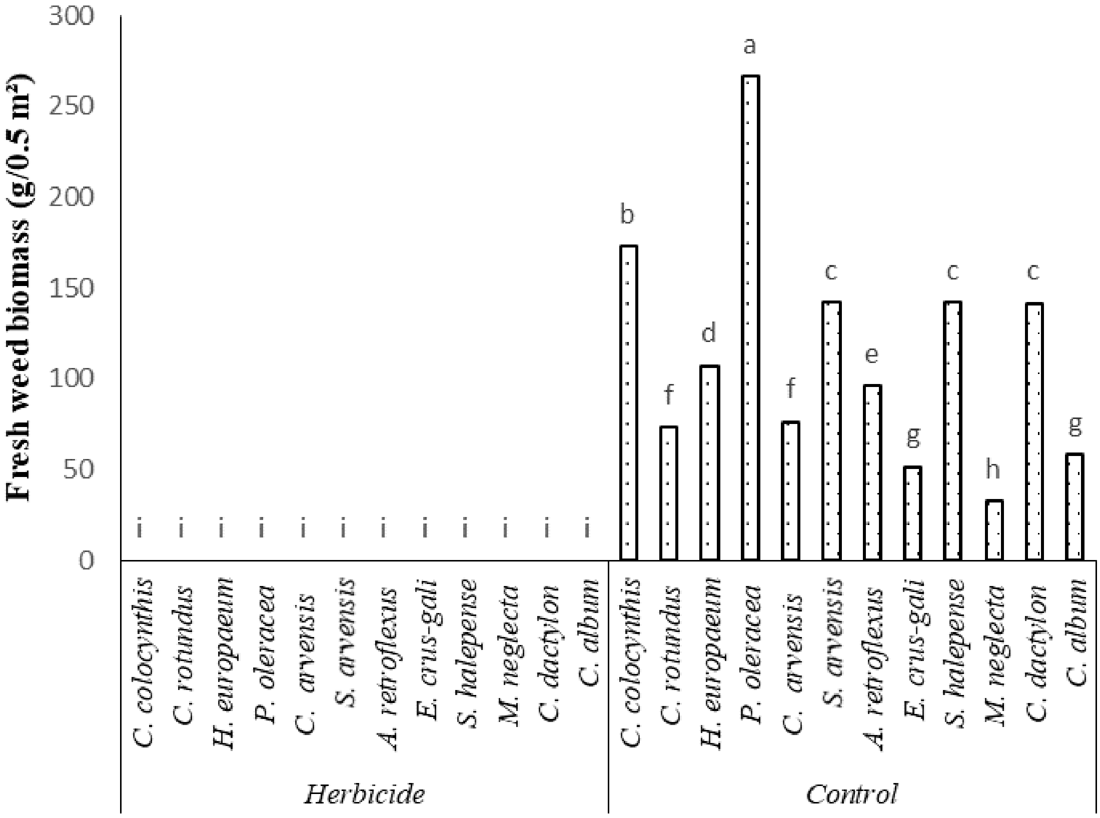


**Fig. 3.** Interaction effect of Dominos biofumigant application and weed species type on fresh weed biomass in onion field.

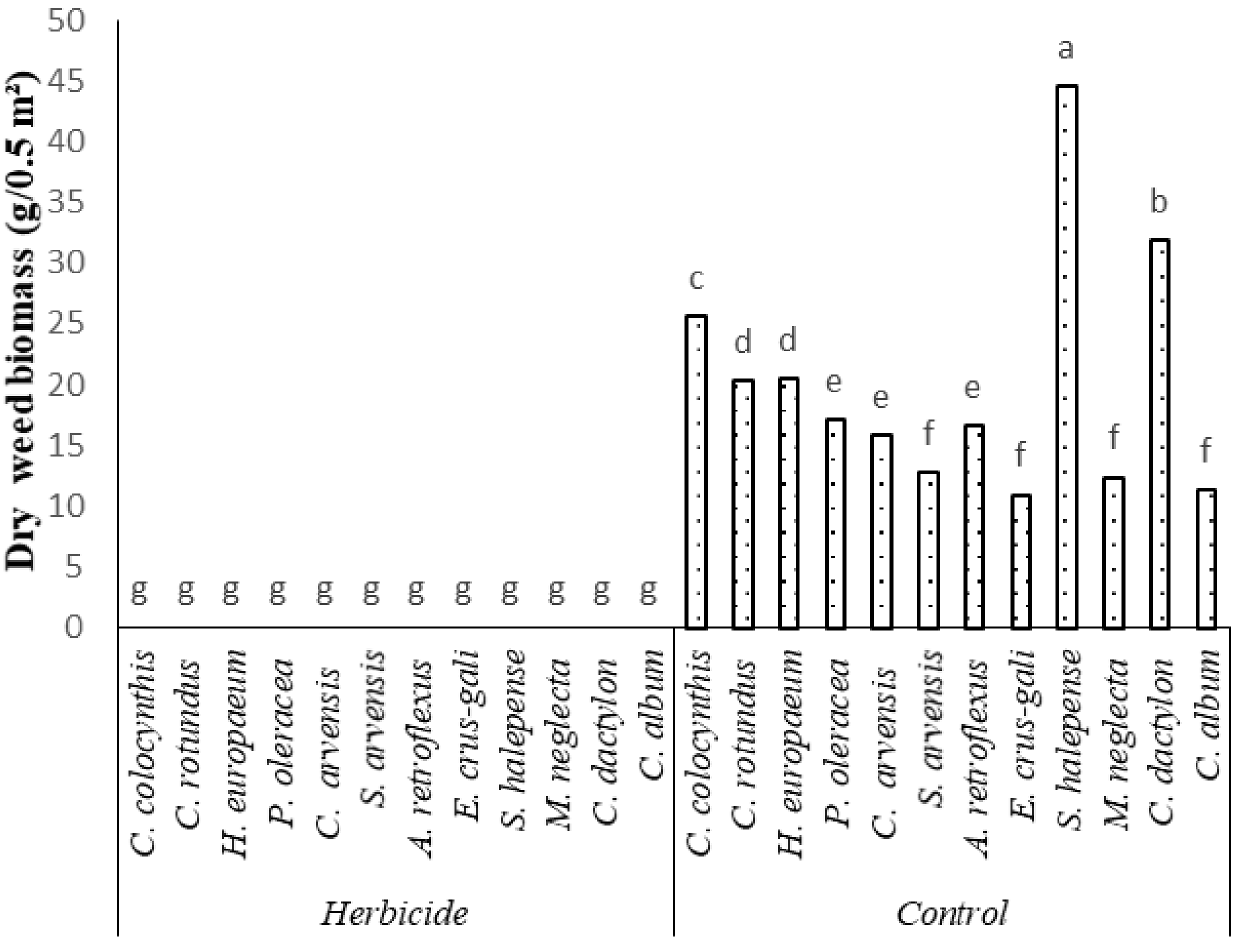


**Fig. 4.** Interaction effect of Dominos biofumigant application and weed species type on dry weed biomass in the onion field.

The application of the biofumigant Dominus resulted in complete (100%) control of *C. rotundus* density, which, as shown in Fig. 5, differed significantly from the untreated weedy check (Fig. 5). However, this control refers to the suppression of emerged shoots during the growing season and does not guarantee permanent eradication of tubers, as tuber viability and soil penetration depth were not assessed.

## Fresh and dry weight of purple nutsedge aerial parts

The analysis of variance indicated that Dominus application had a significant effect on the fresh and dry weight of *C. rotundus* aerial parts ($P \leq 0.01$) (Table 6). The mean comparison of aerial part fresh and dry weights (Fig. 3) revealed that the weed-free control (0 g $m^{-2}$) and the Dominus treatment (0 g $m^{-2}$) exhibited the lowest values among the experimental plots.

## Fresh and dry weight of purple nutsedge Underground organs (roots, rhizomes, and tubers)

The results demonstrated that Dominus application significantly affected the fresh and dry weight of *C. rotundus* underground organs (rhizomes and tubers) ($P \leq 0.01$). The mean comparison of underground organ fresh and dry weights showed that the weed-free control and the Dominus treatment had the lowest values in the experimental plots (Fig. 3). Specifically, the biofumigant Dominus reduced the fresh and dry weight of *C. rotundus* underground organs by 100% compared to the weedy check.

## Onion yield, bulb fresh weight, and neck diameter

The analysis of variance revealed that the application of the biofumigant Dominus significantly affected all measured onion traits, including neck diameter, bulb fresh weight, and onion yield (*P* ≤ *0.01*) (Table 7).

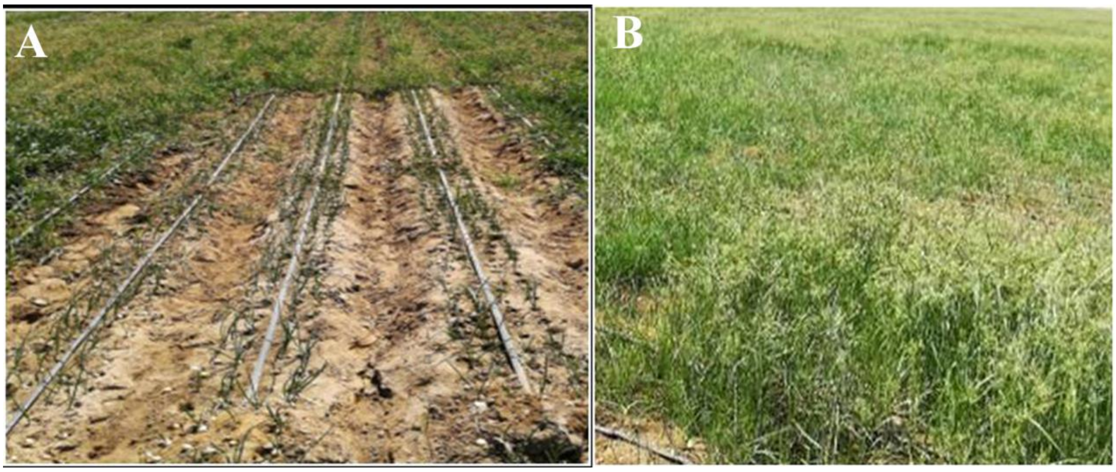


**Fig. 5.** Comparison of purple nutsedge (*Cyperus rotundus*) and other weed infestations in the onion field at Jiroft Agro-Industry between the weedy control treatment (A) and Dominos biofumigant application (B).

**Table 7.** Analysis of variance of onion yield and neck diameter.

| S.O.V | | MS | | |
|---|---|---|---|---|
| | df | onion yield | Onion bulb weight | neck diameter |
| Replication | 3 | 19934574 | 3163.68 | 0.168 |
| treatment | 2 | 13331113158** | 682899** | 261.7** |
| Error | 6 | 3532953.78 | 17775.49 | 0.22 |
| CV (%) | | 2.02 | 10.3 | 2.24 |

ns, ** and *: non-significant, significant at p ≤ *0.01* and p ≤ *0.05*, respectively

## Onion yield

The mean comparison among the experimental treatments indicated no significant difference in onion yield between the weed-free control and the Dominus treatment. The highest yields were recorded for the weed-free control (79 $t\ ha^{-1}$) and the pre-planting application of the biofumigant Dominus as a herbicide (78 $t\ ha^{-1}$) (Fig. 6). The superior yield performance of the Dominus treatment was attributed to complete weed suppression. In contrast, the unweeded weedy check produced a yield of only 15.69 $t\ ha^{-1}$, corresponding to an 80.1% and 79.9% reduction relative to the weed-free control and the Dominus treatment, respectively. These findings demonstrate that the biofumigant Dominus can be effectively employed as a pre-planting herbicide for weed control in onion production without any adverse effect on crop yield.

## Efficacy of the biofumigant Dominus

The findings of this study demonstrated that the biofumigant Dominus effectively suppressed the germination of all seeds present in the soil seed bank throughout the onion growing season (Table 8). Furthermore, the results indicated that the efficacy of Dominus under greenhouse conditions, in pots with a prepared seedbed, was lower than that observed under field conditions. Based on the observations, it can be inferred that the seeds of annual weed species exhibited greater susceptibility to Dominus application compared to those of biennial or perennial weed species.

## Discussion

A constraint of this study is that perennial and parasitic weeds dominant in the field (e.g., C. *rotundus*, C. *colocynthis*) could not be tested in the greenhouse due to their clonal propagation and seed dormancy characteristics; therefore, extrapolation of greenhouse results to these species should be made with caution. The findings of this study clearly demonstrated that the bio-herbicide Dominus, formulated with allyl isothiocyanate (AITC), effectively suppressed the germination and growth of a broad spectrum of broadleaf and narrow-leaved weeds in onion cultivation.

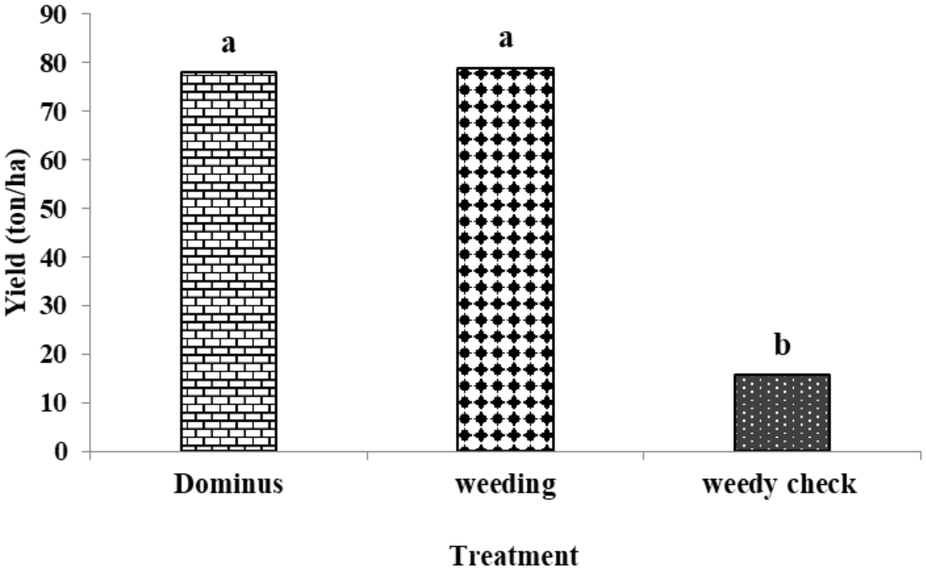


**Fig. 6.** Effect of different experimental treatments on onion yield. Means with at least one common letter based on LSD test are not significantly different.

**Table 8.** Efficacy rating of Dominos biofumigant as an herbicide on different weed species under field and greenhouse conditions.

| Common name | Scientific name of weed | Field | Greenhouse |
|---|---|---|---|
| Colocynth | *Citrullus colocynthis* L. | *** | – |
| Redroot pigweed | *Amaranthus retroflexus* L. | *** | ** |
| Purple nutsedge | *Cyperus rotundus* L. | ** | – |
| Common purslane | *Portulaca oleracea* L. | *** | – |
| Field bindweed | *Convolvulus arvensis* L. | ** | – |
| Wild mustard | *Sinapis arvensis* L. | *** | – |
| European heliotrope | *Heliotropium europaeum* L. | *** | – |
| Cockspur grass | *Echinochloa crus-galli* L. Beauv | *** | – |
| Johnsongrass | *Sorghum halepense* (L.) Pers | *** | – |
| Common mallow | *Malva neglecta* Wallr. | *** | ** |
| Bermuda grass | *Cynodon dactylon* (L.) Pers | ** | – |
| Common lambsquarters | *Chenopodium album* L. | *** | ** |
| Annual ryegrass | *Lolium rigidum* Gaud | – | *** |
| Littleseed canarygrass | *Phalaris minor* Retz | – | *** |
| Winter wild oat | *Avena ludoviciana* Durieu | – | *** |
| Field dodder | *Cuscuta campestris* L. | – | * |

***Good control, ** Moderate control, * Poor control, – Species not evaluated

Each species was only evaluated in one environment.

The greenhouse results indicated a significant effect ($P < 0.01$) of Dominus application on reducing the germination of all seven weed species examined, such that in *Ph.minor* and *A. ludoviciana*, the number of emerged seedlings was limited to fewer than two per basket even by the eighth week. These results are consistent with previous studies that have confirmed the efficacy of AITC in controlling various weeds, including black medick (*Medicago lupulina* L.), common chickweed (*Stellaria media* (L.) Vill.), *M. neglecta*, *P. oleracea*, *C. arvensis*, morning glory (*Ipomoea* spp.), prostrate knotweed (*Polygonum aviculare* L.), *C. rotundus*, and *C. esculentus* (Buskov *et al.*, 2002; Isagro, 2016).

Under field conditions, Dominus achieved complete (100%) control of the dominant weed *C. rotundus* and significantly reduced the biomass of other weed species. This is particularly noteworthy given that previous attempts to control *C. rotundus* in onion fields using conventional herbicides have not been entirely successful (Babaei nejad et al., 2017). For instance, in a study conducted on autumn-transplanted onion in Hormozgan Province, Iran, the evaluation of mechanical and chemical weed control methods revealed that the herbicide oxadiazon reduced *C. rotundus* density and dry weight by only 60% and 59%, respectively. Conflicting results have been reported for bentazon; Hermann et al. demonstrated that although bentazon provided effective control of *C. esculentus*, it caused serious crop injury to onion. In an investigation on the efficacy of oxadiazon and bentazon for *C. rotundus* management in southern Kerman, the lowest *C. rotundus* biomass was observed in the treated plots relative to the weedy check (Rafiee Sarbijan Nasab et al., 2020: Rafiee Sarbijan Nasab et al., 2019).

One of the most salient findings of this study was the lack of a statistically significant difference in onion yield between the Dominus treatment (130.75 t ha$^{-1}$) and the weed-free control (131.55 t ha$^{-1}$), whereas the weedy check exhibited an 83% reduction in yield. This demonstrates that Dominus, by creating a competition-free window during the critical weed control period of onion—which has been reported to range from 10 to 60, and even up to 90, days after emergence—allows the crop to establish without competition and to achieve its full yield potential (Rafiee Sarbijan Nasab et al., 2020). The larger neck diameter observed in the superior Dominus and hand-weeded treatments was attributable to complete weed control and enhanced nutrient uptake. Similar studies in southern Kerman have reported that season-long weed control increases onion neck diameter, dry matter accumulation, and ultimately crop yield (Rafiee Sarbijan Nasab et al., 2020; Tel et al., 1996). The reduced neck diameter in the unweeded treatment was attributed to intense competition between weeds and onion for nutrients, particularly nitrogen, and shading under high weed densities (Rafiee Sarbijan Nasab et al., 2020; Khokhar et al., 2006). Previous research has confirmed the effectiveness of Dominus in controlling weeds, especially *C. rotundus* and *C. esculentus* (Bangarwa et al., 2011; Devkota and Norsworthy, 2014; Jialin et al., 2019).

At the molecular level, the mode of action of AITC as a potent "antimetabolite" involves the disruption of key enzyme activities and respiratory processes in weed seeds and vegetative propagules, thereby inhibiting germination and growth (US EPA, 2013). The high volatility of this molecule and its diffusion through the soil pore space enable uniform penetration and activity against the underground organs of perennial weeds such as *C. rotundus* (Bangarwa et al., 2011). Other studies have demonstrated that cover crops and allelopathic species such as rye and various legumes can suppress weed seed germination and contribute to improved quantitative and qualitative traits of crop plants (Pourheydar Ghafarbi et al., 2007; Shilling et al., 1985; Moonen & Barberi, 2004; Blackshaw et al., 2001; Davis & Liebman, 2003). Future research should include a dose-response study (e.g., 140, 210, 280, 350 L ha$^{-1}$) to determine the minimum effective rate for different weed spectra. A preliminary cost-benefit analysis based on current market prices (Dominus: ≈$1,200 ha$^{-1}$, onion yield increase: ≈115 t ha$^{-1}$ worth ≈$11,500) suggests that even at the tested rate, Dominus is economically viable, but lower rates might improve the margin. This is now mentioned as an avenue for further work.

## Conclusion

In conclusion, the findings of this study demonstrated that Dominus, a biofumigant formulated with allyl isothiocyanate, possesses considerable potential for managing a broad spectrum of broadleaf, narrow-leaved, and even parasitic weeds, representing an efficacious and environmentally compatible option for onion cultivation. It must be emphasized that the "100% control" reported here is limited to the absence of emerged *C. rotundus* shoots during the experimental growing season; long-term eradication was not demonstrated. The relatively consistent performance of this compound across both greenhouse and field conditions including the complete suppression of *C. rotundus*, the marked reduction in the density and biomass of problematic species such as *Ch. album* and *A. retroflexus*, and the inhibition of germination of difficult-to-control species like *C. campestris* and *L. rigidum* during the critical growth stages of onion indicates that Dominus can substantially address the existing gap in effective non-chemical weed control without compromising crop yield. Nevertheless, given its fumigant nature and the associated safety hazards, the application of Dominus is strictly recommended under the direct supervision of trained professionals and in full compliance with protective guidelines. For particularly recalcitrant weed species for which virtually no effective management strategy exists, targeted, spot-application of Dominus following a thorough assessment of soil conditions, moisture, and ambient temperature may serve as a reliable option. In greenhouse environments, the application of Dominus prior to planting and before the installation of plastic mulch offers an effective means of substrate sterilization and reduction of the weed seed bank, provided that all procedures are carried out by experienced personnel with rigorous monitoring of ventilation and safety protocols.

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## Ethical Approval and Consent

This article does not contain any studies involving human participants or animals performed by any of the authors.

## CRediT author statement

**N. Sohrabzadeh:** Investigation & methodology, **M**. **Amirinejad**: Investigation, writing – review & editing. **B. Khalil Tahmasebi:** Conceptualization, funding acquisition, Investigation, Methodology, Data analysis, Writing – review & editing. **M**. **Eshraghi-Nejad:** Data analysis, Writing – review & editing. **M**. **Esmaeilzade-Moridani:** Writing – review & editing,

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## Data Availability

All datasets generated during this study are available from the corresponding author upon request.

### Conflict of interest

The authors have no competing interests.

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