KSÜ Tarım ve Doğa Derg 27 (Ek Sayı 1), 74-87, 2024
KSU J. Agric Nat 27 (Supp l), 74-87, 2024
https://doi.org/10.18016/ksutarimdoga.vi.1431385

Allelopathic Effects of Black Radish (*Raphanus sativus* L. var. *niger* J. Kern.) and Garden Cress (*Lepidium sativum* L.) Plants on Johnsongrass (*Sorghum halepense* (L.) Pers.) Plant in Tomato Cultivation

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ABSTRACT

This study aimed to investigate the effectiveness of black radish and garden cress as pre-plant in field trials and their aqueous extracts under greenhouse conditions to control johnsongrass. In the field experiment, black radish and garden cress were grown as a pre-plant, then mixed with the soil and used with and without mulch against johnsongrass. The effects of these applications on johnsongrass development and tomato yield and quality were evaluated. Different concentrations of pre-plant extracts (2, 5, and 10%) were also investigated on johnsongrass and tomato seedling growth in greenhouse conditions. The lowest johnsongrass density was recorded in black radish and garden cress with mulch (106.7 and 97.2 number m^{-2}). Black radish and garden cress with mulch achieved johnsongrass control efficiency of 80.2 and 84.0% compared to those without mulch 56.8 and 58.2%. The effect of all treatments was positive in increasing the quantity and improving the quality of tomato production. The results of greenhouse experiments showed that high concentrations (10%) of black radish and garden cress extracts achieved high levels in preventing the germination and growth of johnsongrass. In these treatments, johnsongrass seeds and rhizomes germination rates were 17.5 and 7.5%, 20.0 and 12.5% respectively. GC-MS analysis showed that five isothiocyanates (ITCs) were in black radish, and their total percentages were 40.4%. In the garden cress, it was found that there is only one ITC with a percentage of 61.0%. Black radish and garden cress effectively inhibit the germination and growth of Johnsongrass due to their allelopathy effects. Sustainable management of johnsongrass can be achieved by introducing these plants into a crop rotation which may be an alternative or reduce the use of herbicides.

Herbology

Research Article

Article History
Received: 08.02.2024
Accepted: 18.07.2024

Keywords
Black radish (*Raphanus sativus* L. var. *niger* J. Kern.)
Garden cress(*Lepidium sativum* L.)
Johnsongrass (*Sorghum halepense* (L.) Pers.)
Tomato
Allelopathy

Domates Yetiştiriciliğinde Siyah Turp (*Raphanus sativus* L. var. *niger* J. Kern.) ve Tere (*Lepidium sativum* L.) Bitkilerinin Geliç (*Sorghum halepense* (L.) Pers.) Bitkisi Üzerine Allelopatik Etkileri

ÖZET

Bu çalışma, geliç mücadelede tarla denemelerinde ön bitki ve sera koşullarında sulu özüt olarak siyah turp ve tere etkinliğini araştırmayı amaçlamıştır. Tarla denemesinde siyah turp ve tere ön bitki olarak tarlada yetiştirildikten sonra toprağa karıştırılarak geliç'e karşı malçlı ve malçsız olarak kullanılmıştır. Bu uygulamaların geliç'in gelişmesine ve domates verim ve kalitesine etkileri değerlendirilmiştir. Sera koşullarında ön bitki özütlerinin farklı konsantrasyonlarının (%2, 5 ve 10), geliç ve domates fide büyümesi üzerine etkileri de araştırılmıştır. En düşük geliç yoğunluğu malçlı siyah turp ve tere uygulamalarda kaydedilmiştir (106.7 ve 97.2 adet m^{-2}). Malçlı siyah turp ve tere uygulamalarda geliç'in mücadele etkinliği %80.2 ve %84.0 olurken malçsız uygulamalarda %56.8 ve %58.2 kayıt edilmiştir. Tüm uygulamaların etkisi domates üretim miktar ve kalitesinin arttırılmasında olumlu olarak değerlendirilmiştir. Sera deneme sonuçları, siyah turp ve tere özütleri yüksek konsantrasyonlarının (%10) geliçin çimlenme ve büyümesini önlemede yüksek seviyede etkili

Herboloji

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 08.02.2024
Kabul Tarihi : 18.07.2024

Anahtar Kelimeler
Siyah turp (*Raphanus sativus* L. var. *niger* J. Kern.)
Tere (*Lepidium sativum* L.)
Geliç (*Sorghum halepense* (L.) Pers.)
Domates
Allelopati

olduğunu göstermiştir. Bu uygulamalarda geliç tohum ve rizomlarının çimlenme oranları sırasıyla %17.50 ve %7.50, %20.00 ve %12.50 olarak tespit edilmiştir. GC-MS analizine göre siyah turpta beş isotiyosiyanat (ITC) bileşen bulunduğu, toplam oranları ise %40.4 olarak tespit edilmiştir. Terede ise %61.0 oranında sadece bir ITC'nin bulunmuştur. Siyah turp ve tere, allelopati etkileri nedeniyle geliçin çimlenme ve büyümesini etkili bir şekilde engellemiştir. Sürdürülebilir geliç yönetimi, bu bitkilerin, herbisitlerin kullanımına alternatif olabilecek veya kullanımını azaltabilecek bir ürün rotasyonuna dahil edilmesiyle sağlanabilir.

Atıf Şekli: Elsekran, M. & Üstüner, T. (2024) Domates yetiştiriciliğinde siyah turp (*Raphanus sativus* L. var. *niger* J. Kern.) ve tere (*Lepidium sativum* L.) bitkilerinin geliç (*Sorghum halepense* (L.) Pers.) bitkisi üzerine allelopatik etkileri . *KSÜ Tarım ve Doğa Derg 27* (Ek Sayı 1), 74-87. https://doi.org/10.18016/ksutarimdoga.vi. 1431385

To Cite : Elsekran, M. & Üstüner, T. (2024) Allelopathic effects of black radish (*Raphanus sativus* L. var. *niger* J. Kern.) and garden cress (*Lepidium sativum* L.) plants on johnsongrass (*Sorghum halepense* (L.) Pers.) plant in tomato cultivation. *KSU J. Agric Nat 27* (Supp l), 74-87. https://doi.org/10.18016/ksutarimdoga.vi.1431385

INTRODUCTION

Johnsongrass (*Sorghum halepense* (L.) Pers.) is a perennial weed native to the Mediterranean region, belongs to the Poaceae family, and reproduces by seeds and rhizomes (Warwick & Black, 1983; Davis, 1988). Johnsongrass causes yield loss of up to 88% in economically important crops (Peerzada et al., 2017). Chemical herbicides are widely used to reduce the damage caused by johnsongrass. Herbicides cause damage to the environment and human health. They persist for many years in the soil, and weeds are developing resistance to them. Therefore, it is necessary to find alternative and healthy control methods to achieve sustainable agriculture (Ustuner et al., 2020; Yazlik & Uremis, 2022).

Some plants contain allelochemicals produced through secondary metabolite reactions. These substances affect the germination and growth of other plants positively or negatively. Allelopathic negative effects can benefit weed control, while positive effects can be used as growth regulators. In addition, the synergistic effect between plants can be benefited by taking it into the appropriate agricultural rotation system (Bellostas et al., 2007; Jabran, 2017; Acar et al., 2019). Several studies showed the allelopathic potential of many plants of the cruciferous family and their efficiency in weed control (Uremis et al., 2009; Bangarwa et al., 2011; Jabran et al., 2015; Elsekran, 2022; Elsekran & Ustuner, 2024). It was reported that when the *Brassica napus* plant was incorporated into the soil, it inhibited weed biomass by 96% in subsequent potato production (Boydston & Hang, 1995). In the tomato (*Lycopersicon esculentum* L.) field, *B. rapa*, *B. juncea*, and *Sinapis alba* were used as cover crops, in combination with polyethene mulch, to control johnsongrass. Brassicaceae cover crops achieved johnsongrass control of 46% two weeks after planting (Bangarwa & Norsworthy, 2014). Malik et al. (2008), reported that incorporating wild radish into the soil before the cultivation of corn significantly reduces the density of *Digitaria sanguinalis*. The allelopathic potential of six species of cruciferous plants was evaluated in laboratory and field conditions. According to this study, all species inhibited the development of johnsongrass while black radish (*Raphanus sativus* L. var. *niger* J. Kern.) was the most efficient (Uremis et al., 2009). According to Qasem (1994), aqueous extracts of wild cress (*Lepidium draba*) leave inhibited wheat and barley seed germination rate (36% and 75%), coleoptile elongation (52% and 85%), and root length (63% and 94%). The aqueous extract of the wild cress plant increased the germination and root development of barley seeds at 1% concentration, and the germination rate decreased when the concentration was increased to 3% (Erez, 2009). Allelochemicals in garden cress (*Lepidium sativum* L.) seeds and seedlings were reported to be effective in reducing seedling growth in *Amaranthus caudatus* and lettuce (Iqbal & Fry, 2012).

The allelopathic effects of cruciferous plants are attributed to compounds called isothiocyanates (ITCs). These compounds, which are characterized by high bioactivity, do not exist in healthy plants but result from the hydrolysis of glucosinolates (GSLs) by the enzyme myrosinase (β-thioglucosidase). GSLs are secondary metabolites and do not have toxic effects (Rask et al., 2000; Jafariehyazdi & Javidfar, 2011). GSLs are divided into three classes namely aliphatic GSLs, aromatic GSLs, and indole GSLs based on the difference in the side chain of their structure. Therefore, the ITCs differ based on these GSL types and their effects on weeds (Graser et al., 2000; Norsworthy & Meehan, 2005).

This study aimed to determine the level of control of johnsongrass using black radish and garden cress as pre-plants, with and without black plastic mulch. Additionally, the study aimed to evaluate the allelopathic effects of these plants on biomarkers of johnsongrass growth and development under both field and greenhouse conditions. The effect of these treatments on the quantity and quality of the tomato crop was also estimated. The greenhouse experiments aimed to study the effect of aqueous extracts of black radish and garden cress at different concentrations (2, 5, and 10%) on the germination and growth of johnsongrass seeds and rhizomes in pots.

MATERIALS and METHODS

Fields Experiments

Experiment site and climatic characteristics

The experiments were performed in the fields of the faculty of Agriculture at Kahramanmaraş Sütçü Imam University, Türkiye (37°35′37.3″ N 36°48′53.0″ E) in 2019 and 2020. The soil analysis of the experiment area showed that the texture of the soil was clay loam, pH neutral (7.04), slightly salty (0.30%), organic matter ratio of 3.32%, and potassium and phosphorus content moderate. According to the meteorological data of the field trial area, it was observed that the hottest months are July and August, and the coldest is January. In addition, the highest precipitation was in January, while the rains were absent or infrequent in June, July, August, and September (Table 1).

Experiment design and treatments

The experiment was set up in three replications (blocks) according to the randomized complete block design. In each block, there were 7 applications, weed-free control (Cnt 1), black radish (BR), garden cress (GC), black polyethylene mulch 100 microns thick and had UV additives (mulch), black radish + mulch (BR+M), garden cress + mulch (GC+M), and johnsongrass control (Cnt 2). The dimensions of the experimental plots in the field experiment were 2 × 5 m. While a distance of 1 m was left between the plots, 1.5 m between the blocks, and 1.5 m as side effects areas around the experimental areas. All experiments were repeated twice throughout 2019 and 2020.

BR and GC were planted first as pre-plants, and then tomato seedlings were planted. The varieties used in this experiment were BT- Bur Siyah for BR Zeybek for GC, and F1 Ege pembesi for tomato. The seeds of these plants were obtained from the Teta-Tohumculuk-seed company in Türkiye. There was no need for infection with johnsongrass because the experiment area was a natural area for it (Figure 1).

Figure 1. Johnsongrass spread in the experiment area naturally

Şekil 1. Geliç bitkisinin deneme alanında doğal olarak yayılması

Table 1. Meteorological data of Kahramanmaraş province for 2019 and 2020*

*Çizelge 1. Kahramanmaraş ili 2019 ve 2020 yılına ait meteorolojik verileri**

Months	Minimum temperature (°C)		Maximum temperature (°C)		Average relative humidity (%)		Total precipitation (mm)	
	2019	2020	2019	2020	2019	2020	2019	2020
January	-5.0	-4.2	16.1	14.1	84.5	82.3	265.8	105.8
February	-0.9	-3.2	19.5	18.7	83.0	78.1	111.6	75.2
March	-0.3	0.3	23.9	25.9	69.4	74.6	143.4	4.6
April	0.8	0.4	29.5	30.9	72.2	66.1	32.2	33.0
May	1.7	7.5	41.3	41.2	47.5	54.4	3.6	23.0
June	10.3	11.4	39.9	41.0	50.1	50.2	5.2	0.0
July	18.9	18.5	41.1	44.6	49.8	46.4	0.2	0.0
August	14.7	15.9	39.7	45.0	43.3	40.9	0.0	0.0
September	11.1	11.8	36.2	37.6	48.6	48.2	0.0	0.0

*Kahramanmaraş meteorology station

Before sowing seeds of BR and GC, the soil of the trial area was ploughed twice. NPK fertilizer, which is a mixture containing 15% nitrogen, 15% phosphorus, and 15% potassium at a rate of 500 kg ha^{-1}, was applied with half of the amount used during the sowing seeds of BR and GC, and the other half during the planting of tomato seedlings. BR and GC were planted on March 1, 2019, and February 1, 2020. Whole plant samples of both BR and GC were taken from 1 m^2 during the flowering stage, the fresh weights (3.17 and 2.51 kg m^{-2}) and the dry weights (0.78 and 0.57 kg m^{-2}) of samples were determined, then ground and kept in the refrigerator at -4°C to use in greenhouse experiments and chemical analysis. In this stage whole plants were incorporated into the soil using a hoeing machine (30 cm depth), at the same time, mulch was applied. Tomato seedlings were planted on 10 June in the first year of the study and on 7 May in the second year. All weeds were removed from Cnt 1 periodically, while only johnsongrass was left in Cnt 2.

Effect of treatments on biomarkers of johnsongrass growth

At the ripening stage of johnsongrass seeds, the density was calculated by determining the number of johnsongrass stems in 1 m² for each treatment separately. In the same way, the length of 30 stems was measured by a ruler of 2m in both 2019 and 2020.

In the last harvest phase of tomatoes, weed stems were cut from 1 m² area from each treatment, and fresh weight was calculated. The cut stems were dried at 25 ± 2°C in room conditions for 4 weeks then the dry weight was determined.

The rhizomes formed in the soil were collected by digging 1m² at a depth of 0.5 m per treatment, then they were cleaned from the soil and the fresh weight was determined (Figure 2). Rhizomes were dried under room conditions for a month and their dry weight was calculated.

Figure 2. Collecting johnsongrass plant rhizomes from the soil

Şekil 2. Geliç bitkisi rizomlarının topraktan toplanması

Control efficiency of Johnsongrass

Control efficiency refers to the rate of dry biomass reduction of johnsongrass both above-ground (stems) and in-soil parts (rhizomes) due to applied treatments. Control efficiency was calculated as a percentage of treatment reduction of biomass over Cnt 2 according to formula (1).

$$\text{Control efficiency} = [1 - (Wt / W0)] \times 100 \qquad (1)$$

Where, Wt: dry weight of stems and rhizomes of johnsongrass in treatment; W0: dry weight of stems and rhizomes of johnsongrass in Cnt 2

Determine the effect of the treatments on the yield of tomato

To determine the average weight of tomato fruit grown under different treatments, the average weight of 10 fruits was calculated for each treatment separately for each harvest, and then the general average of all harvests was calculated.

The tomato yield was calculated from 1 m² for all harvesting operations for each treatment, and then the yield per hectare was calculated. Then the rate of increase in tomato yield over Cnt 2 (5016 kg ha^{-1} in 2019 and 5975 kg ha^{-1} in 2020) was calculated using formula (2).

$$\text{Tomato yield increase rate} = [(Yx / Y0) - 1] \times 100 \qquad (2)$$

Where, Yx: yield of tomato in treatment, Y0: yield of tomato in Cnt 2.

The tomato yield loss rate caused by johnsongrass was also calculated under the effect of the treatments over Cnt 1 (47771 kg ha^{-1} in 2019 and 64943 kg ha^{-1} in 2020) using formula (3).

$$\text{Tomato yield loss rate} = [1 - (Yt / Yc)] \times 100 \qquad (3)$$

Where, Yt: yield of tomato in treatment, Yc: yield of tomato in Cnt 1

To determine the difference in the quality of tomato fruits under the influence of the treatments, the fruits were analyzed in terms of nutritional content (glucose, fructose, protein, and potassium) and color characteristics (color depth). Tomato samples (2 kg) from the treatments were analyzed at Kahramanmaraş Sütçü Imam University Research and Application Development Center (USKIM).

Greenhouse Experiments

Experiment site and design

Greenhouse experiments were carried out in the greenhouse of Kahramanmaraş Sütçü Imam University Faculty of Agriculture in the years 2020-2021. The greenhouse was glass, with concrete floors, and a gable roof with dimensions of 16 × 8 m and a height of 5 m. The pots were placed on single-layer iron beds with 0.5 × 6.5 m dimensions, and 25 cm high from the floor, inside the greenhouse (Figure 3). Greenhouse climate conditions were recorded using a thermometer and hygrometer. The average maximum temperature was from 32°C to 34°C, the average minimum temperature was from 17°C to 18°C, and the average relative humidity was from 68% to 72%.

The greenhouse experiments were set up according to the completely randomized plot design with four replications twice in 2020 and 2021. BR and GC extracts were applied at 2, 5, and 10% concentrations against johnsongrass seeds and rhizomes.

Figure 3. Greenhouse experiment setting
Şekil 3. Sera deneme ortamı

Johnsongrass seeds and rhizomes used in the greenhouse experiments were collected from the field experiments after the last harvest of tomatoes. Johnsongrass seeds dormancy was broken by sandpaper, while rhizomes were cut 1 cm long and each part contained one bud (AL Sakran et al., 2020; Elsekran et al., 2023). Then 100 g of dried BR powder was weighed, and 1 liter of distilled water was added to prepare an extract with a concentration of 10%. Distilled water was added to obtain concentrations of 5 and 2%, and GC extracts were also prepared in the same way. The extracts were left at 25°C for 1 day and were manually agitated frequently, then filtered with filter papers of dimensions 50 × 50 cm twice. After preparing the extracts, 300 ml of each was added to pots containing 1:1:1 ratio of sand, soil, and peat in which one tomato seedling was planted, in addition to 20 seeds or 10 pieces of rhizome of johnsongrass. The experiment continued for forty days in greenhouse conditions.

Effect of extracts on the growth of johnsongrass and tomato seedlings

The germination rate of johnsongrass seeds and rhizomes was calculated at the end of the experiment according to formula (4).

Germination rate = (number of germinated seeds or rhizomes/total number of seeds or rhizomes) × 100 (4)

At the end of the experiment, johnsongrass stems were cut from the soil surface and their length was measured using a ruler.

These stems were dried under room conditions for 4 weeks and their dry weight was calculated.

Tomato plant height was measured with a plastic ruler (100 cm) 40 days after planting seedlings.

Determination of ITCs

To determine the ITCs content of BR and GC by GC-MS analysis, samples were prepared according to the method described by Vaughn and Berhow (2005); and Elsekran et al. (2023). First, the samples were defatted using hexane, then dichloromethane and potassium phosphate were added, and placed in a shaker for 8 hours at 25 °C and 200 rpm. Then, NaCl and Na_2SO_4 were added and mixed. The mixtures were filtered by filter paper. Dichloromethane solutions were placed in ampoules and numbers were given according to the plant. Samples were analyzed in Ataturk University, Department of Chemistry by GC-MS.

Data Analysis

Data from field studies in 2019, and 2020 were subjected to multivariate analysis of variance (MANOVA) by IBM SPSS 26.0 program. Differences between values were grouped using the LSD test ($P \leq 0.05$). Greenhouse data in 2020, and 2021 were subjected to one-way analysis of variance (ANOVA). Differences between values were grouped using Duncan's test ($P \leq 0.05$). Data from field experiments in 2019 and 2020 and greenhouse in 2020 and 2021 were compared by t-test. There were no significant differences between the two years of study for greenhouse experiments, so the average results of the two years were analyzed.

RESULTS

Field Experiments

Effect of treatments on biomarkers of johnsongrass growth

There was no significant difference between the years of study for all treatments (Table 2). Johnsongrass density was very high in Cnt 2 parcels (426.7 and 448.8 number m^{-2} in 2019 and 2020). The lowest johnsongrass density was recorded in GC+M and BR+M treatment (97.2, 106.7, and 101.7, 115.3 number m^{-2} in 2019 and 2020 respectively). While the highest density was observed in mulch treatment in both years.

The shortest stem length of johnsongrass was observed in the GC+M treatment with 90.2 cm in 2019 and 92.9 cm in 2020. While the length of the stem was higher in the treatment of mulch. It was also found that there were no significant differences in terms of stem length in GC and BR treatments with and without mulch, as well as between the years of study. The average stem length of johnsongrass in the Cnt 2 was 142.7 and 144.5 cm in the two years of the study (Table 2).

The lowest fresh and dry stem weight was recorded in GC+M and BR+M treatments, followed by GC and BR. While the fresh weight in the GC+M treatment was 431.7 and 466.7 g m^{-2}, it was 3152.8 and 3239.2 g m^{-2} in the Cnt 2. As for the dry weight, it was 92.2 and 96.8 g m^{-2} in the GC+M treatment and 625.1 and 661.1 g m^{-2} in the Cnt 2 in the two years of the study (Table 3).

Table 2. The density (number m-2) and stem length (cm) of johnsongrass
Çizelge 2. Geliç bitkisi yoğunluğu (adet m-2) ve sap uzunluğu (cm)

Treat.	Density (number m-2)			Stem length (cm)		
	2019	2020	t Test	2019	2020	t Test
*BR	227.3bc**	233.6b	Sig.=0.638	93.87a	94.3a	Sig.=0.927
GC	209.1b	228.2b	Sig.=0.126	91.2a	93.6a	Sig.=0.679
BR+M	106.7a	115.3a	Sig.=0.482	93.7a	93.9a	Sig.=0.972
GC+M	97.2a	101.7a	Sig.=0.750	90.2a	92.9a	Sig.=0.548
Mulch	248.1c	251.7b	Sig.=0.314	105.9b	107.8b	Sig.=0.651
Cnt 2	426.7d	448.8c	Sig.=0.184	142.7c	144.5c	Sig.=0.672
LSD	25.6	27.0		8.1	10.9	

*BR: Black radish, GC: Garden cress, BR+M: Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch, Cnt 2: Johnsongrass control.
**Values followed by the same letter(s) in the same column do not differ significantly from each other ($p \leq 0.05$).

Table 3. The wet and dry weight of johnsongrass stems (g m-2)
Çizelge 3. Geliç bitkisi saplarının yaş ve kuru ağırlığı (g m-2)

Treat.	Stems wet weight (g m-2)			Stems dry weight (g m-2)		
	2019	2020	t Test	2019	2020	t Test
*BR	1027.8b**	1078.9b	Sig.=0.273	224.5b	229.9b	Sig.=0.773
GC	929.2b	1017.8b	Sig.=0.117	201.6b	218.7b	Sig.=0.349
BR+M	486.7a	549.2a	Sig.=0.154	102.8a	111.6a	Sig.=0.349
GC+M	431.7a	466.7a	Sig.=0.244	92.2a	96.8a	Sig.=0.440
Mulch	1312.4c	1355.2c	Sig.=0.454	263.0c	281.6c	Sig.=0.256
Cnt 2	3152.8d	3239.2d	Sig.=0.460	625.1d	661.1d	Sig.=0.070
LSD	124.7	123.1		29.4	29.0	

*BR: Black radish, GC: Garden cress, BR+M: Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch, Cnt 2: Johnsongrass control.
**Values followed by the same letter(s) in the same column do not differ significantly from each other ($p \leq 0.05$).

Johnsongrass produced large amounts of rhizomes that were 2502.2 and 2513.0 g m-2 in the Cnt 2 in the two years of the study. The wet weight of rhizomes decreased significantly in GC+M and BR+M treatments and was 396.5, 490.8, and 438.5, 564.2 g m-2 in the two years of study, respectively (Table 4).

Although the growth of johnsongrass was prevented in Cnt 1, this procedure did not exhaust all rhizomes in the soil, as 125.0 g m-2 fresh weight of the rhizomes were collected in 2019 and 136.7 g m-2 in 2020. The effect of mulch treatment on the dry weight of rhizomes was weak (576.2 and 576.6 g m-2) and did not differ significantly from Cnt 2.

The effects of GC and BR treatments with and without mulch on the dry weight of rhizomes were similar to their effects on the fresh weight, and no significant difference was observed between the two years of study (Table 4).

Control efficiency of Johnsongrass

The highest control efficiency of johnsongrass was achieved by GC+M treatment which was 84.8% in 2019 and 84.0% in 2020. The lowest control efficiency was calculated in the mulch treatment, and it was 33.4 and 32.8% in the two years of the study. Figure (4) shows the efficiency of the applied treatments in johnsongrass control in the two years of the study and the significant differences between them.

The effect of the treatments on the yield of tomato

The highest weight of tomato fruits was obtained from Cnt 1 (164.6 and 166.2 g), and there was no significant difference between this treatment and GC+M and BR+M treatments in both years of the study. The fruit weight was statistically similar in all applied control methods. The weight of the fruit in Cnt 2 decreased significantly from the other treatments and the lowest weight of the fruits was recorded in it (76.5 and 80.8 g) in the two years of the study (Figure 5).

Johnsongrass caused losses at different rates to the tomato yield according to the applied treatments. The lowest rate of losses was achieved in the GC+M treatment (10.4 and 16.7%) in the two years of study.

The rate of loss in Cnt 2 was very high (89.3 and 90.1%), and the highest rate of loss was in the BR and mulch treatments. There were also significant differences between the two years of the study, and the rate of loss in production in 2020 was greater than in 2019 in all treatments (Table 5). The reason is that the tomato season in 2020 was longer than in 2019. That means the increase in the length of the season was in the interest of the weed, not the cultivated plant.

Table 4. The wet and dry weight of johnsongrass rhizomes (g m^{-2})
Çizelge 4. Geliç bitkisi rizomlarının yaş ve kuru ağırlığı (g m^{-2})

Treat.	Rhizomes wet weight (g m^{-2})			Rhizomes dry weight (g m^{-2})		
	2019	2020	t Test	2019	2020	t Test
*Cnt 1	125.0a**	136.7a	Sig.=0.421	30.7a	33.5a	Sig.=0.700
BR	1159.5c	1348.3c	Sig.=0.068	283.6c	321.1c	Sig.=0.326
GC	1049.5c	1286c	Sig.=0.053	257.6c	314.4c	Sig.=0.052
BR+M	490.8b	564.2b	Sig.=0.187	121.5b	140.6b	Sig.=0.391
GC+M	396.5b	438.5b	Sig.=0.196	96.1b	107.1b	Sig.=0.426
Mulch	2292.1d	2310d	Sig.=0.866	562.2d	576.6d	Sig.=0.802
Cnt 2	2502.2f	2513.0f	Sig.=0.923	613.7d	615.3d	Sig.=0.965
LSD	165.8	144.9		63.4	64.3	

*Cnt 1: weed-free control, BR: Black radish, GC: Garden cress, BR+M: Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch, Cnt 2: Johnsongrass control.
**Values followed by the same letter(s) in the same column do not differ significantly from each other ($p \leq 0.05$).

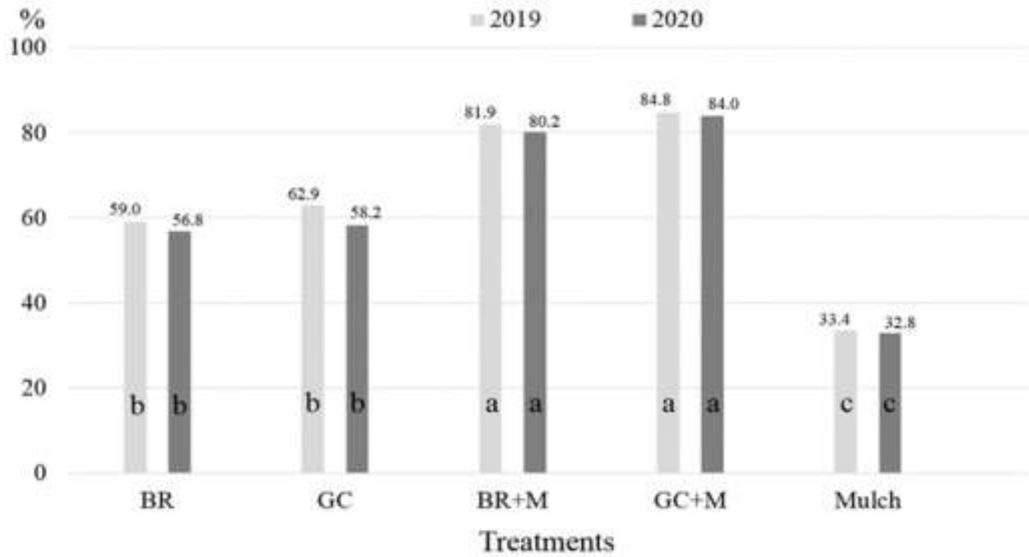

Figure 4. Control efficiency of johnsongrass (%)
Şekil 4. Geliç bitkisi mücadele etkinliği (%)
BR: Black radish, GC: Garden cress, BR+M: Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch.
LSD ($p \leq 0.05$) = 6.8 (2019) and 6.4 (2020). The same letter(s) do not differ significantly ($p \leq 0.05$).

The highest rate of increase in tomato yield was obtained in GC+M (737.2 and 741.7%) in the two years of study. The lowest rate of increase in yield was in the treatments of mulch, BR, and GC. With the exception of Cnt 1 and mulch, there was no significant difference between the two years of study in the rate of increase in yield (Table 5).

According to the analysis of the nutritional content and color of tomato fruits, the GC+M treatment was superior to the other treatments in characteristics of tomato fruits, followed by the BR+M treatment and Cnt 1, while the quality of fruits in Cnt 2 was very low (Table 6).

Greenhouse Experiments

Germination of johnsongrass

GC extract at a concentration of 10% was more effective in reducing the germination rate of seeds (7.50%) than BR extract (17.50) while it was statistically similar against rhizomes (12.50 and 20.00%). With the exception of GC extract, which stimulated seed germination (87.50%), the low concentration (2%) had no effect on the germination of seeds and rhizomes. There was an increase in the negative effect on johnsongrass germination with increasing concentration of extracts (Figure 6).

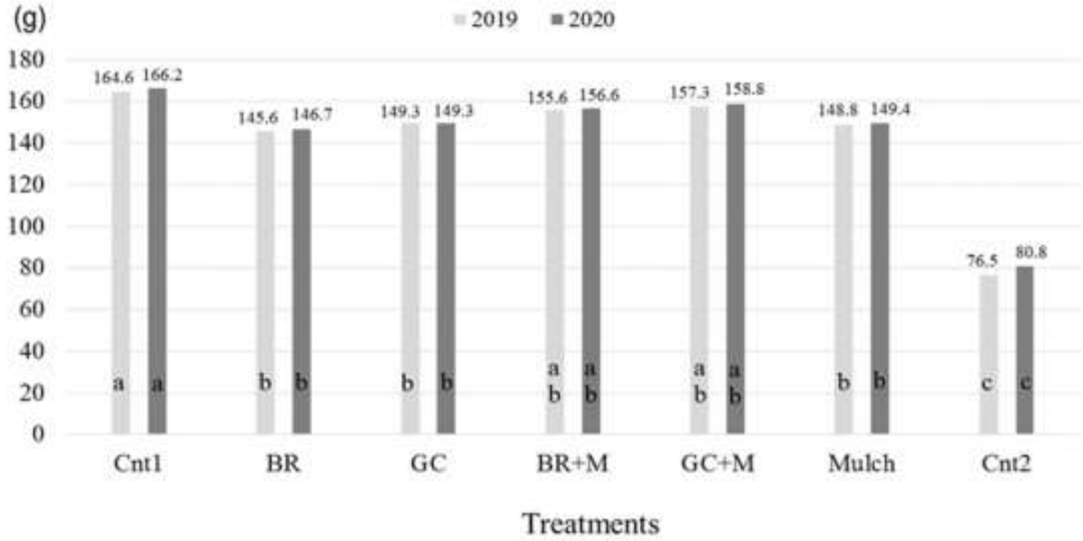

Figure 5. The average weight of tomato fruit (%)
Şekil 5. Domates meyvesinin ortalama ağırlığı (%)
Cnt 1: weed-free control, BR: Black radish, GC: Garden cress, BR+M: Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch, Cnt 2: Johnsongrass control.
LSD ($p \leq 0.05$) = 13.2 (2019) and 14.5 (2020). The same letter(s) do not differ significantly ($p \leq 0.05$).

Table 5. Tomato yield loss and yield increase (%)
Çizelge 5. Domateste verim kaybı ve verim artışı (%)

Treat.	Tomato yield loss (%)			Tomato yield increase (%)		
	2019	2020	t Test	2019	2020	t Test
*Cnt 1	-	-		834.5a	910.2a	Sig.=0.028
BR	40.3d	45.5d	Sig.=0.038	457.9d	450.5d	Sig.=0.667
GC	36.3c	43.7c	Sig.=0.005	495.3d	468.7d	Sig.=0.160
BR+M	19.2b	23.5b	Sig.=0.005	655.1c	672.8c	Sig.=0.081
GC+M	10.4a	16.7a	Sig.=0.001	737.2b	741.7b	Sig.=0.554
Mulch	36.7cd	44.6cd	Sig.=0.001	491.6d	459.6d	Sig.=0.017
Cnt 2	89.3f	90.1f	Sig.=0.196	-	-	
LSD	3.8	1.6		38.4	19.1	

*Cnt 1: weed-free control, BR: Black radish, GC: Garden cress, BR+M: BR+M Black radish + mulch, GC+M: garden cress + mulch, Mulch: Black polyethylene mulch, Cnt 2: Johnsongrass control.
Values followed by the same letter(s) in the same column do not differ significantly from each other ($p \leq 0.05$).

Table 6. Tomato fruits content of some nutrients and color depth
Çizelge 6. Domates meyvelerinin bazı besin içerikleri ve renk derinliği

Treat.	Glucose (%)	Fructose (%)	Protein (%)	Potassium (mg kg^{-1})	Color depth (%)		
					L*	a*	b*
Cnt 1	3.28	2.12	5.32	29.76	37.21	33.80	27.92
BR	2.61	1.90	4.71	28.81	38.71	33.03	27.40
GC	2.80	1.71	4.90	28.90	36.30	32.72	26.73
BR+M	3.35	2.11	5.21	29.15	36.90	33.20	27.51
GC+M	3.44	2.29	5.43	29.69	36.61	34.40	27.53
Mulch	2.68	1.90	5.10	28.51	37.11	33.23	28.10
Cnt 2	1.10	0.91	4.03	28.22	39.26	30.18	25.47

*=D65 was made with daylight and 10 degrees' perspective. The fruits' color was L (brightness; 100 white, 0 black), a (+ red; – green) and b (+ yellow; – blue) was measured on the cheek area (Kaymak et al., 2010).

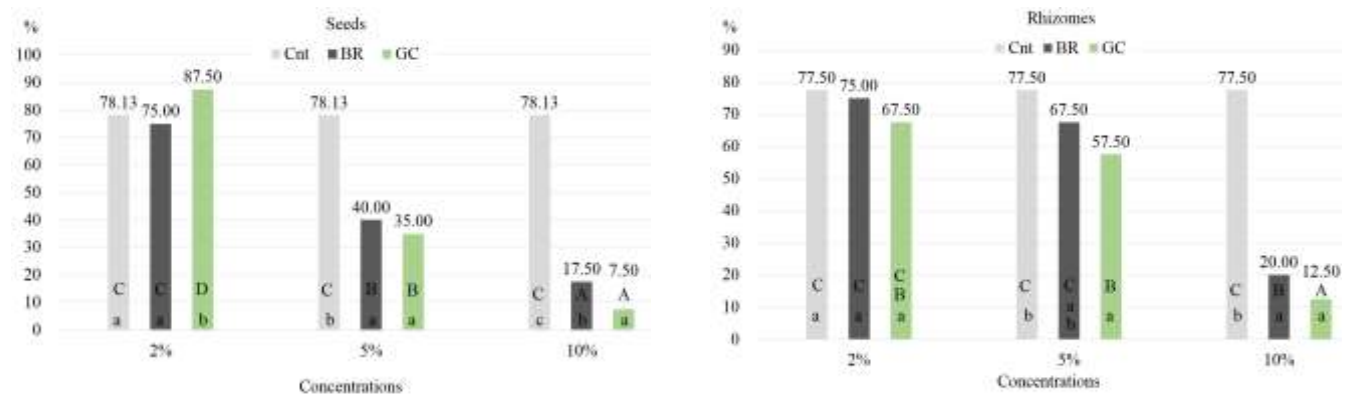

Figure 6. Effects of extracts on germination of johnsongrass seeds and rhizomes (%)
Şekil 6. Özütlerin geliç bitkisi tohum ve rizomlarının çimlenme üzerine etkileri (%)
Cnt: Control, BR: Black radish, GC: Garden cress.
The same small letter(s) in the same concentration group and the same capital letter(s) at different concentrations of the same plant extract do not differ significantly according to Duncan's test ($p \leq 0.05$).

Stem length of Johnsongrass

Concentrations of 5 and 10% of the extracts of both plants significantly reduced the length of stems growing from seeds and rhizomes. While the concentration of 2% was effective on the stem length of the rhizomes only. It was also found that GC was more effective in reducing the stem length of johnsongrass than BR (Figure 7).

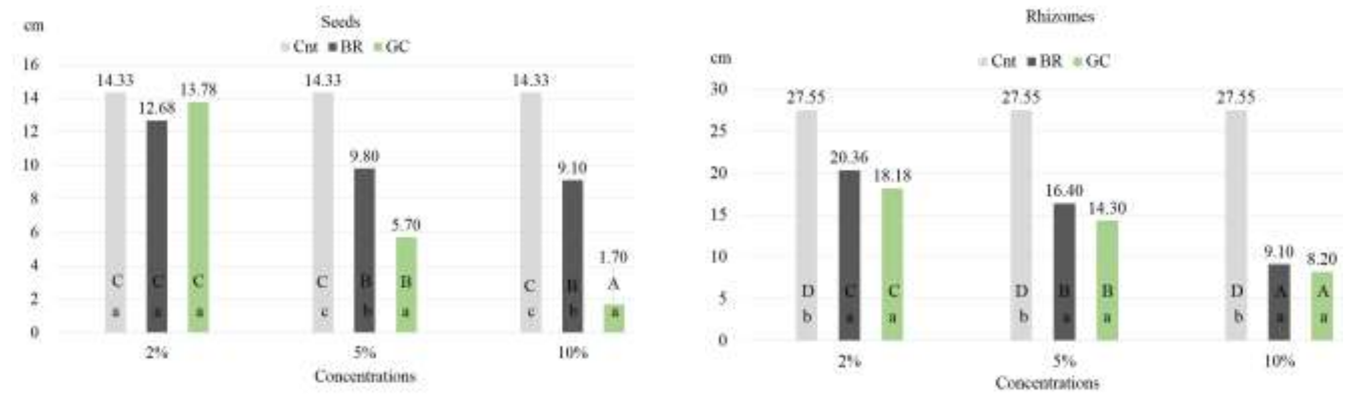

Figure 7. Effects of extracts on stem length of johnsongrass seeds and rhizomes (cm).
Şekil 7. Özütlerin geliç tohum ve rizom sürgünleri uzunluğuna etkileri (cm)
Cnt: Control, BR: Black radish, GC: Garden cress.
The same small letter(s) in the same concentration group and the same capital letter(s) at different concentrations of the same plant extract do not differ significantly according to Duncan's test ($p \leq 0.05$).

Dry weight of Johnsongrass

GC and BR extracts at 10% concentration significantly reduced the dry weight of stems growing from seeds (0.01 and 0.11 g) compared to the control (0.97 g). Also, the dry weight of the stem of the rhizomes in these treatments was 0.13 and 0.18 g, compared to 2.07 g in the control. All concentrations of extracts of both plants (except for GC 2% on seeds) had a significant effect on reducing the dry weight of stems grown from both seeds and rhizomes (Figure 8).

Tomato seedling length

The growth of tomato seedlings in the greenhouse experiment was affected by different concentrations of GC extracts. The highest seedling length was obtained from GC extract at a concentration of 10% (33.8 cm) and the shortest from BR extract at a concentration of 2% (23.9 cm). No negative effect of extracts was observed for all concentrations on the length of tomato seedlings. Figure (9) shows the effect of BR and GC extracts on the length of tomato seedlings.

Determination of ITCs

According to GC-MS analysis, 5 different ITCs were determined as a result of GSL components hydrolysis in BR. These components were tert-butyl-ITC, 2-propenyl-ITC, benzyl-ITC, 4-methylthio-3-butenyl-ITC, and 2-phenylethyl-ITC, while their ratios were determined as 4.7, 5.6, 6.6, 19.3, and 4.2%, respectively, and their total percentages were 40.4% (Figure 10).

Only one ITC compound was recorded in GC, which is benzyl-ITC, and its percentage was 61%, as shown in Figure (11).

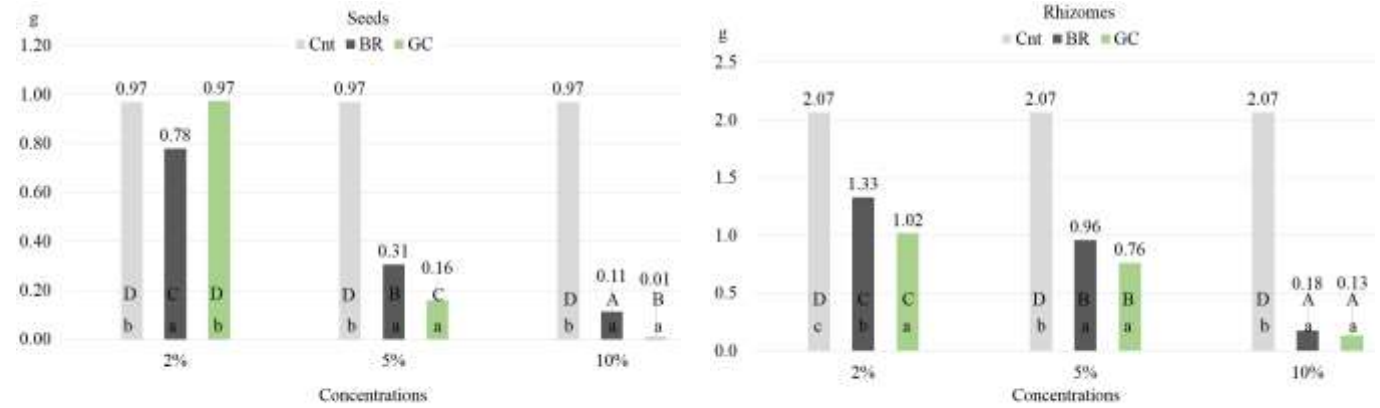

Figure 8. Effect of extracts on the dry weight of johnsongrass grown from seeds and rhizomes (g)
Şekil 8. Özütlerin tohum ve rizomlardan süren geliç kuru ağırlığına etkileri (g)
Cnt: Control, BR: Black radish, GC: Garden cress.
The same small letter(s) in the same concentration group and the same capital letter(s) at different concentrations of the same plant extract do not differ significantly according to Duncan's test (p ≤ 0.05).

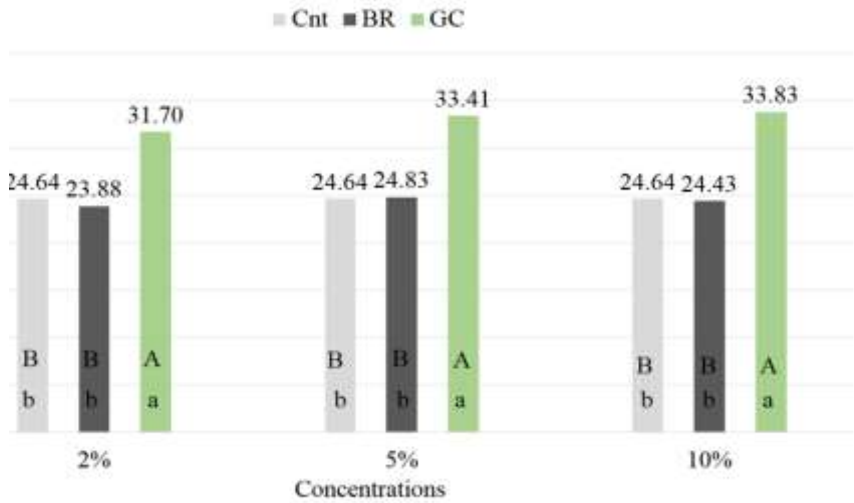

Figure 9. The effect of extracts on the length of tomato seedlings (cm)
Şekil 9. Özütlerin domates fide uzunluğuna etkileri (cm)
Cnt: Control, BR: Black radish, GC: Garden cress.
The same small letter(s) in the same concentration group and the same capital letter(s) at different concentrations of the same plant extract do not differ significantly according to Duncan's test (p ≤ 0.05).

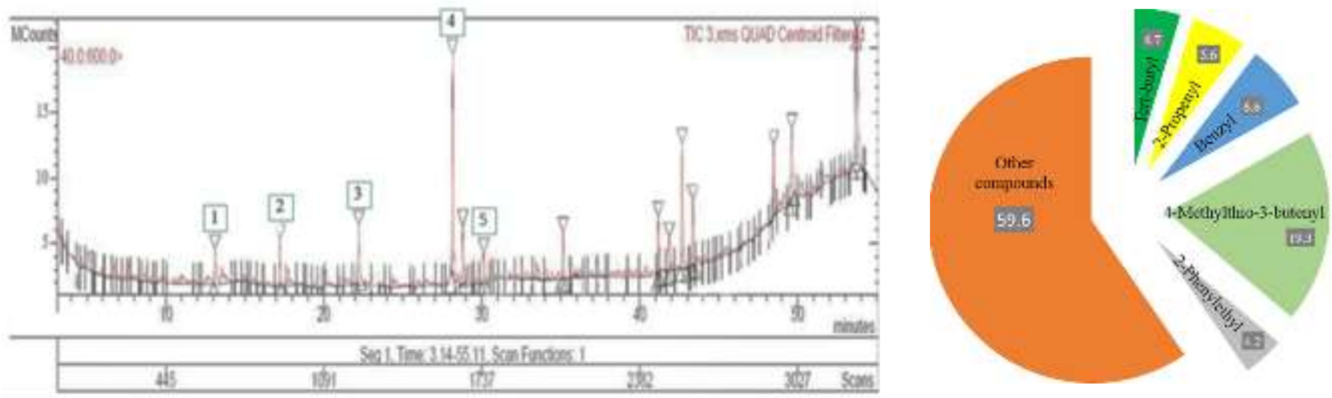

Figure 10. ITC components in black rasish (%)
Şekil 10. Siyah turpta ITC bileşenleri (%)

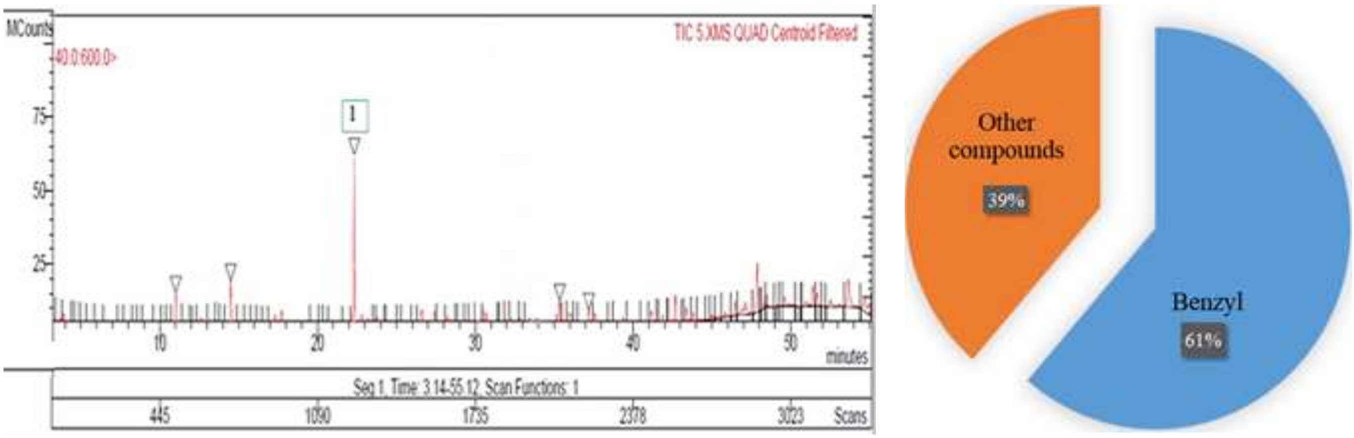

Figure 11. ITC components in garden cress (%)
Şekil 11. Terede ITC bileşenleri (%)

DISCUSSION

The treatments of BR+M and GC+M were the most effective in reducing the growth of johnsongrass stems, where the fresh biomass in these treatments was (466.7 and 549.2 g m^{-2}) while it was 3239.2 g m^{-2} in Cnt 2.

According to Bangarwa and Norsworthy (2014), cruciferous plants (*B. rapa*, *B. juncea*, and *S. alba*) + mulch decreased johnsongrass fresh weight by 34-46%. The reason for increasing the effectiveness of BR and GC compared to these plants may be due to the differences in their ITCs content. Many studies mentioned that the ITCs content of cruciferous plants varies according to variety, species, and growth conditions (Nakamura et al., 2008; Shah et al., 2016; Elsekran et al., 2023).

BR+M and GC+M treatments reduced fresh rhizome biomass with high efficiency (564.2 and 438.5 g m^{-2}) compared to Cnt 2 (2513.0 g m^{-2}). On the other hand, cruciferous plants contain GSLs, which are enzymatically hydrolyzed in a pH-neutral medium to ITCs (Uda et al., 1986). The results of the analysis showed that the soil in the study site is neutral in acidity (pH=7.04), which is an ideal medium for the decomposition of GSLs into ITCs.

Mulch treatment had no effect on rhizomes, although it reduced the biomass of stems. Johnsongrass was unable to penetrate the mulch used in this experiment. The growth space was limited to the holes designated for tomato seedlings, so the application of mulch reduced the biomass of johnsongrass above the soil surface. The rhizomes were observed in the form of a net on the surface of the soil under the mulch, growing densely, and this explains the lack of reduction in the biomass of the rhizomes compared to Cnt 2.

Covering BR and GC with mulch immediately after incorporating them into the soil increased the control efficiency of johnsongrass (80.2 and 84.0%) compared to them without mulch (56.8 and 58.2%), while the efficacy of mulch alone was less (32.8%). The reason may be due to the fact that ITCs are short-lived compounds in the soil, and they volatilize from it quickly (van Ommen Kloeke et al., 2012; Price and Norsworthy 2013). The use of mulch leads to an increase in the life of these compounds in the soil, and thus an increase in the period of exposure of roots and rhizomes to them, thus the effect on their growth. The control efficiency of BR+M and GC+M treatments was relatively high and may be sufficient to be an effective alternative to herbicides in controlling johnsongrass. Ustuner et al. (2023) showed that chemical control using fluazifop-P-butyl (1.5 L ha^{-1}) achieved johnsongrass control by 69.8%, while according to Karkanis et al. (2022), this percentage was 90%.

According to the results of this research, the control methods that had the greatest impact on the yield and quality of tomatoes were the pre-plant with mulch treatments. Pre-plant with mulch treatments achieved the highest tomato plant fruit quality, sugar, protein percentage, and color characteristics. The highest increase in tomato yield was GC+M treatment and ranged between 737.2 and 741.7% in two years of study. This is due to the low density of johnsongrass in this treatment, as the tomato plants may have benefited from the organic materials and ITCs contained in the GC. Also, it was shown in greenhouse experiments that GC extracts have an effect that stimulates the growth of tomato seedlings.

The results of the greenhouse experiments were consistent with those obtained from the field experiments. BR and GC extracts at 10% concentration were effective in reducing the germination of seeds (17.5 and 7.5%) and rhizomes (20.0 and 12.5%) of johnsongrass, compared to the controls (78.13 and 77.5%).

Elsekran et al. (2023) showed that cruciferous plants such as garden rockets at 10% concentration reduce the germination of johnsongrass seeds by 100.0% and rhizomes by 83.9%. The difference is due to the fact that Elsekran et al. (2023) carried out the experiment in closed petri dishes, which prevented the ITCs from volatilizing and thus increased the effect period on johnsongrass seeds and rhizomes. In addition, there is a difference between the species of cruciferous plants used in the two experiments.

Extracts of BR and GC at a concentration of 10% reduced the dry biomass of johnsongrass both grown from seeds and rhizomes in a greenhouse experiment. Also, the effect of the extracts at a concentration of 5% was significant in reducing the dry biomass. These results are similar to what Uremis et al. (2009) reached when using BR extracts at a concentration of 8% on johnsongrass rhizomes, where the rate of inhibition of rhizome germination was 45.5%.

Plant extracts at all concentrations did not have a negative effect on the growth of tomato seedlings, while the effect of GC extracts at all concentrations was stimulative. The reason is that the negative effect of allelopathic substances in cruciferous plants is greater on the seeds and this effect decreases on established plants. Bangarwa et al. (2012) showed that tomato seedlings were not negatively affected by the allelochemicals contained in cruciferous plants. Some research also indicated that allelochemicals can play as plant growth regulators that enhance the growth of cultivated plants (Bellostas et al., 2007; Jabran 2017).

According to the results of GC-MS analysis, five ITC compounds were detected in BR, and their total percentages were 40.4% of the GSLs hydrolysis products. It was also found that the dominant ITC was 4-methylthio-3-butenyl-ITC, which is an aliphatic compound with a percentage of 19.3%. Yi et al. (2015) reported that one of the most abundant GSL components in radish is glucoraphasatin, which hydrolyses into 4-methylthio-3-butenyl-ITC.

In GC, it was found that there is only one compound that belongs to the ITC-aromatic group, which is benzyl-ITC with a percentage of 61.0%. Radwan et al. (2007), and Sarikami and Yanmaz (2011) reported benzyl-GSL, the major GSL component of GC.

CONCLUSION

The results of these experiments showed that both black radish and garden cress have strong allelopathic potentials that inhibit the germination and growth of johnsongrass seeds and rhizomes very effectively, especially if they are used with black plastic mulch immediately after incorporating them into the soil. The density of johnsongrass in both black radish and garden cress with plastic black mulch treatments was 97.2, 106.7, and 101.7, 115.3 number m^{-2} in 2019 and 2020 respectively, while it was 426.7 and 448.8 number m^{-2} in 2019 and 2020 in the control plots respectively. Also, the control efficiency of johnsongrass was achieved by both black radish and garden cress with plastic black mulch treatments of 84.8% and 81.9%, respectively. This process will reduce the bank of seeds, and the rhizomes of johnsongrass in agricultural lands, hence the reduction of its population gradually in the following years. Thus, sustainable management of johnsongrass can be achieved by introducing black radish and garden cress into a crop rotation which may be an alternative to or reduce the use of herbicides.

ACKNOWLEDGMENT

This study was supported by Kahramanmaraş Sütçü Imam University Scientific Research Projects Coordination Unit. GC-MS analysis was conducted in the laboratories of the Atatürk University, College of Science, Department of Chemistry, under the supervision of Prof. Dr. Hamdullah KILIÇ. The color depth and nutrient content of tomato fruits were analyzed at the Center for University and Industry Collaboration (ÜSKİM) of Kahramanmaraş Sütçü Imam University.

Conflicts of Interest

Authors have declared no conflict of interest.

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