RESPONSE OF SESAME (*SESAMUM INDICUM* L.), ASSOCIATED WEEDS AND SUBSEQUENT CROPS TO PRE- AND POST-EMERGENCE HERBICIDES

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(Received 20th Jan 2024; accepted 21st Jun 2024)

Abstract. Sesame (*Sesamum indicum* L.) is employed in many countries in the food, pharmaceutical, and other industries due to its high oil, antioxidant, and protein content for human consumption and cattle feed, as well as straw fodder. The current study aimed to investigate the herbicidal effects of pre-emergence and post-emergence herbicides on the morphological and physiological traits of sesame and associated weeds under field conditions. The current study employed two commercial pre-emergence herbicides pendimethalin (Fist super 45.5% CS) and metribuzin (Marine El-Nasr 70% WG), and three post-emergence herbicides namely haloxyfop-methyl (Galint super 10.8% EC), clethodim (Secrit 12% EC) and mix of clethodim 7.5% + haloxyfop-methyl 15% (Fine 22.5% EC). The treatments were applied at 21 and 35 days after sowing (DAS) and hand hoeing was applied as well. Biomass (fresh weight gm^{-2}) of broad-leaved, grass, and total weeds in sesame field were determined during the summer seasons 2020 and 2021. The results showed in both seasons that all weed control treatments reduced weed biomass while increasing yield components. Higher weed control efficiency was observed with post emergence application of clethodim, cethodim + haloxyfop-methyl followed by hand hoeing. Pre emergence application of pendimethalin 0.75 kg ha^{-1} followed by post emergence application of quizalofop ethyl 0.0050 kg ha^{-1} was found to be the better treatment to control the weeds in broadcasted sesame. Also, application of pre- and post-emergence herbicides recorded significantly lower fresh weight of all weeds. A significant increase in all agronomic traits of sesame yield such as No. of branches/Plant, No. of capsules/Plant, No. of grains/capsules, 1000 grains weight (g), grain yield (kg/4200 m^2), stalk yield (kg/4200 m^2) and straw yield) were recorded with all treatments when compared to untreated control during the two seasons 2020 and 2021. Moreover, there was no significant ($p \leq 0.05$) difference in chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids levels between all herbicides or between the two-hand hoeing and unwedded control. Interestingly, no phytotoxic symptoms appeared on sesame leaf pigments in response to herbicide application. Also, the side effect of herbicides on subsequent crops was investigated and the results revealed no harmful effect due to residual effect from any of the tested herbicides to seed germination percentage of barley and green beans.
Keywords: *broad leaved, narrow-leaved, herbicide, post-emergence, sesame, weeds, yield*

Introduction

Sesame (*Sesamum indicum* L.) is widely used in the food, pharmaceutical and other industries in many countries due to its high oil, antioxidant and protein contents for

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

human consumption and livestock feed, as well as a significant source of straw fodder for animal feed. Sesame (*Sesamum indicum* L.) is the most common oilseed crop, regarded as the 'Queen of oil seeds' due to its high oil content (50% - 60%). One of the key issues restricting sesame productivity is high weed infestation, which is one of several restrictions in sesame cultivation (Aruna et al., 2020). Furthermore, one of the most significant agricultural practices is weed management. Weeds compete for space, nutrients, water, and sunlight with agricultural plants. Weeds serve as hosts and give refuge for a variety of pests (Kleiman, and Koptur, 2023; Kaur, et al., 2018). In their study, Babiker et al. (2014) observed that uncontrolled weed development had a detrimental effect on sesame seed output, resulting in a 30% reduction. Conversely, implementing weed management strategies to maintain a weed-free environment for varying durations after planting demonstrated positive impacts on seed yield. Specifically, keeping the sesame crop free from weeds for 2-, 4-, 6-, and 8-weeks post-planting resulted in seed yield increases of 8%, 37%, 40%, and 43% respectively. The observed critical period for weed management in sesame was found to occur within the timeframe of 2 to 6 weeks following the initial planting.

Weeds have always been an important nuisance for all types of agricultural production. The heat and abundances of the rains during the rainy season favor the development of these weeds. They are the direct competitors of the cultivated plants. Indeed, weeds are responsible for 10 - 90% of crop losses in temperate areas (Chauchan, 2012). The management of weeds poses a significant concern for sesame farmers. The interference caused by weeds is the primary component that significantly impacts the per unit output of sesamum. The growth of sesamum is adversely affected by several types of weeds, including monocotyledons, dicotyledons, and perennials, during the seedling period. Consequently, this leads to a reduction in production per unit area (Adewale et al., 2019). The presence of weeds significantly hampers sesame crop productivity due to its slow seedling growth within the initial four weeks, rendering it a weak competitor during the early phases of crop development (Lukurugu et al., 2023; Eid et al., 2015)**.** In their study, Chowdhury et al. (2021) documented the primary weed species present during the trial phases as *Echinochloa colona*, *Digitaria sanguinalis*, *Ludwigia parviflora*, *Chenopodium album*, and *Trianthema portulacastrum* in sesame cultivation. Although weeds can be controlled using cultural, biological, and chemical means, labour problem shortage is getting more acute by the day, and it will no longer be practicable or economical either to continue with traditional weed management practises (Tataridas et al., 2022; Singh et al., 2022; Kumar et al., 2023). Herbicides alone, however, are incapable of providing total weed control due to their selective killing. Their usage can be improved by combining it with hand weeding or hoeing (Nainwal et al., 2010)**.** Several annul grasses and broad leaf weeds invade this crop causing heavy losses. In oilseed crops, yield loss due to weed competition varied from 50% to 75% (Bhadauria et al., 2012). The method of hand weeding is frequently employed by farmers; however, the paucity of farm labor and the high expense associated with weeding operations make it impractical to carry out weeding activities. Chemical weed management offers advantages in terms of ease, time efficiency, and cost-effectiveness as compared to manual weeding (Mane et al., 2018).

Application of herbicide as pre-emergence, early post emergence and post emergence approach is advantageous because, long and effective control of all weeds during crop season. A suitable, economically viable and ecologically safe combination of chemical with manual weeding would help to achieve control the weeds and reduced the yield

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

loss. Keeping, these points in view the present study was undertaken to find out the effect of different weed management practices in rainfed sesame (Sujithra et al., 2018). It is recommended to apply pendimethalin at a rate of 1000 g ha^{-1} before to emergence in line-sown sesame in order to manage weed growth. However, the effectiveness of pendimethalin in selectively controlling weeds is mostly influenced by the characteristics of the soil type and the depth at which the crop is sown (Aruna et al., 2020). The purpose of their study was to discover appropriate pre- and post-emergence herbicides for achieving comprehensive and long-lasting weed control in broadcasted sesame crops. The use of herbicides was documented, starting with the implementation of a weedy check. This was followed by the pre-emergence application of pendimethalin alone, and subsequently, the post-emergence application of quizalofop ethyl alone at 20 days after sowing (DAS).

Additionally, Soliman et al. (2015), elucidated that the use of weed control treatments resulted in a reduction in the dry weight of broadleaf, grassy, and total weeds in comparison to the unweeded treatments. In addition, El-Metwally et al. (2017) shown that the treatments involving Butralin and metribuzin exhibited the highest efficacy in the suppression of broad-leaved weeds and grasses. The chemical control strategy is deemed to be more expeditious, efficacious, and efficient in terms of time and labor conservation when compared to alternative methods (Ahmed et al., 2008). Therefore, this study aimed to investigate the effect of some pre- and post-emergence herbicides as well as hand weeding applied twice, on broad-leaved and grassy weeds in sesame fields and its effects on agronomical and physiological traits as well as yield and constituents.

Materials and methods

Experimental site and layout

The field experiments were carried out at the Itay El-Baroud Agricultural Research Station in El-Behera, Egypt, throughout the seasons of 2020 and 2021. The investigation was carried out with ten treatments under randomized block design (RBD) with three replications. The tested variety was Sesame Giza 32. The weed management treatments implemented were as follows: two pre-emergence herbicides namely pendimethalin (Fist super 45.5% CS) and metribuzin (Marine El-Nasr70% WG) and three post-emergence herbicides namely haloxyfop-methyl (Galint super 10.8% EC), clethodim (Secrit 12% EC) and mix of clethodim 7.5% + haloxyfop-methyl 15% (Fine 22.5% EC) as well as hand hoeing (twice at 21 and 35 days after sowing (DAS)) compared with the unweeded. The plot size was 21 m^2 (7.0 × 3.0 m). The physical and chemical parameters of the experimental soil are shown in *Table 1*. A knapsack sprayer (Gloria Hoppy No. 299 TS. (CP$_3$) at 200 L water fed^{-1} was used to apply the herbicide treatments. While hand hoeing was used twice (21 and 35 DAS before the 1st and 2nd irrigations, respectively). *Table 2* shows the herbicidal treatments. The herbicides were sprayed after sowing but before irrigation.

Plant materials and sowing

Sesame grains (*Sesamum indicum* L.) (c.v. Giza 32) were obtained from Administration of Seeds, ARC, Ministry of Agriculture and Land Reclamation. In both seasons, sesame seeds were hand planted in hills 25 cm apart and ridges 70 cm, 7 and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

12 May, respectively, at the recommended rate of 4 kg. fed^{-1}. The physical and chemical properties of soil of the experimental field was analyzed at the department of Soils and Water at the Faculty of Agriculture in Alexandria, Egypt.

Table 1. *Physical and chemical properties of the experimental soil*

Site	EC (dS/m)	pH	Cations (meq/L)				Anions (meq/L)			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
Mean	2.26	7.73	5.4	4.15	12.2	15	0.0	3.15	11.5	7.2

Site	SAR (%)	$CaCO_3$ (%)	Particle distribution (%)			Texture
			Clay	Silt	Sand	
Mean	5.44	4.81	51.5	15.5	33.5	Clay

Table 2. *List of the tested commercial herbicides in this study*

Common name	Trade name	Recommended rate fed^{-1}/200 L water	Time of application	Source
Pendimethalin	Fist super 45.5% CS	1.5 L	Pre-emergence (after sowing and before irrigation)	My trade Co.
Metribuzin	Marine El Nasr70% WG	300 gm		EL-Nasr Chemicals Co.
Haloxyfop-methyl	Galint super 10.8% EC	300 ml	Post-emergence (2 weeks after sowing)	Dow Chemicals Co.
Clethodim	Secrit 12% EC	500 ml		Bredig trade Co.
Clethodim 7.5% + Haloxyfop-methyl 15%	Fine 22.5% EC	800 ml	Post-emergence (4 weeks after sowing)	Starcime Chemicals Co.
Hand-hoeing twice	-	Twice	21 and 35 days after sowing	

Determination of total chlorophyll (a and b) and carotenoids in sesame leaves

Total chlorophyll (a and b)

Fresh leaves of ten random plants were picked and representative leaves from each replicate were cut into small pieces and homogenized, then 250 mg sample was taken and homogenized by hand glass homogenizer with 5 ml acetone 80%. The resulting homogenate was filtered using a Buchner funnel through Whatman filter paper, No. 1. The filtrate was finished with 80% acetone to get a final volume of 50 mL, and the absorbance (optical density) of the clear solution was measured spectrophotometrically at 645 and 663 nm wavelengths using Jenway 6305 UV/Visible spectrophotometer, according to Arnon (1949) as modified by Lorenzen (1967). Chlorophyll a, b, and total (a + b) concentrations in mg chlorophyll/g and sample fresh weight were estimated using the following equations:

$$\text{Ch. a} = (((12.7 \times \text{O.D}_{663}) - (2.69 \times \text{O.D}_{645})) \times 0.2)$$

$$\text{Ch. b} = (((22.9 \times \text{O.D}_{645}) - (4.68 \times \text{O.D}_{663})) \times 0.2)$$

$$\text{Total} = \text{Ch. a (mg/g fresh wt.)} + \text{Ch. b (mg/g fresh wt.)}$$

These equations were used for optical density measurements of chlorophyll extracts (acetone and water) in a 1 cm glass vial.

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Carotenoids

Samples, each of 0.25 g of representative fresh leaves of ten random plants were extracted using acetone 80% by grinding in glass homogenizer until the plant material was completely decolorized. The extract was filtered by using Buchner funnel. The marc was successively washed with acetone until it became colorless. The combined extracts were applied on alumina column for purification and eluted by diethyl ether. The absorbance (A) of diethyl ether elute was measured at 450 nm using Jenway 6305 UV/Vis spectrophotometer, according to Giannopolitis et al. (1989). The µg carotenes per gram fresh weight leaf were calculated from the following equation:

$$\mu g/g.\ F.\ Wt. = ((A/K) \times (1/0.25))$$

The extension coefficient (K) was obtained from 1-10 µg β-carotene and it was equal 0.0754583.

Evaluation of pre- and post-emergence herbicides

Nine weeks after sowing in both growing seasons 2020 and 2021, weeds of the middle row in each plot of all treatments were collected and sorted, counted and identified following the method of Hassanein et al. (2000) and their fresh weights were recorded as g m^{-2}.

The following criteria were calculated:

(1) $$\text{Weed density} = \text{average number of each weed } m^{-2}$$

(2) $$\text{Percent of density as} = \frac{\text{Average number of one weed}}{\text{Average total number of weeds}} \times 100$$

(3) $$\text{Weed biomass} = \text{average (fresh) weight of each weed } (gm^{-2})$$

(4) $$\text{Percent of weed biomass} = \frac{\text{Average(fresh) weight of one weed}}{\text{Average (fresh) weight of total weeds}} \times 100$$

(5) $$\text{Percentage of weed control efficiency (WCE)\%} = \frac{\text{Average fresh weight of weeds the unweeded} - \text{Average fresh weight of weeds treatment}}{\text{Average fresh weight of weeds the unweeded}} \times 100$$

Measurement of morphological traits and yield of sesame

At harvest, in 6 and 10 October in both seasons, respectively, ten plants were chosen at random from each plot, then air dried for 4 days and the following agronomic traits were measured:

At harvesting, the following data were recorded:

1. Plant height (cm)
2. No. of branches/plant
3. No. of capsules/plant
4. No. of grains/capsules
5. 1000 grains weight (g)
6. Grain yield (kg/fed)
7. Stalk yield (kg/fed) (straw yield)
8. Harvest index (%)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

Potential effect of herbicide residues on subsequent green beans and barley

At harvest in the second season, soil samples were gathered from each experimental plot at depths ranging from 0 to 30 cm to investigate the pesticides' residual effect on the following successive winter crops 45 days after sowing:

1. Green beans
2. Barley

Twenty seeds of barley and ten seeds of green beans were sown in pots (30 cm diameter, 25 cm depth). Three replicates were used and the following parameters were measured:

1. Germination percentage of barley and green beans
2. Dry weight of seedling shoot (g)
3. Dry weight of seedling root (g)

Statistical analysis

The obtained data were subjected to statistical analyses using one way ANOVA according to Gomez and Gomez (1984). The least difference significant (LSD) test was used to compare means at 5% significance levels (Statistics SPSS) Statistical Package for the Social Sciences.

Results

Weed survey and determination of incidence and biomass

The surveyed experimental site showed the presence of nine dominant broad-leaved and narrow weeds from five different families (*Table 3*) and (*Fig. 1*). The weeds *Solanum nigrum* L. and *Amaranthus viridis* L. had the highest density compared to other weeds, with an incidence value of 33.33% during the 2020 growing season (*Fig. 1a*). Furthermore, *S. nigrum* and *A. viridis* had the greatest fresh weight values among the other weeds, with 432.03 and 493.43 gm^{-2}, respectively, during the 2020 season (*Fig. 1c*). *Portulaca oleracea*, L. and *Amaranthus viridis* L. exhibited the highest incidence percentages during the 2021 season, with values of 40% and 30%, respectively (*Fig. 1a*). However, *Cynodon dactylon* L. had a 100% occurrence rate in both the 2020 and 2021 seasons (*Fig. 1b*). Nevertheless, the biomass of *C. dactylon* exhibited the lowest measurement compared to other narrow weeds, with recorded values of 167.17 gm^{-2} in 2020 and 254.54 gm^{-2} in 2021 (*Fig. 1c*). The other narrow-leaved weeds exhibited fluctuations in their occurrence and relative biomass across the two seasons of 2020 and 2021 (*Fig. 1d*).

Effect of treatments on the individual broad-leaved weeds (BLW)

The results shown in *Table 4* demonstrate that all examined herbicide treatments statistically significant ($p \leq 0.05$) decreased the biomass (fresh weight) of broad-leaved weeds, including *Xanthium brasilicum* Vellozo, *Solanum nigrum* L., *Portulaca oleracea* L., and *Amaranthus viridis* L. The effectiveness of each experimental treatment, namely hand hoeing, pendimethalin, metrbuzine, haloxyfop-methyl, clethodim, and clethodim + haloxyfop-methyl, in controlling broadleaved weeds throughout the growing seasons of 2020 and 2021, was readily apparent. When comparing the efficacy

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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of the other herbicides, it was observed that pendimethalin and metrbuzine exhibited the highest values, ranging from 83.23 to 100%. On the contrary, the least effective agents in controlling this species were clethodim, clethoxyfop-methyl, and their combination, with respective efficacy values ranging from 57.85% to 69.64%. It is noteworthy that hand hoeing weeding demonstrated the highest efficacy in controlling this particular species, with recorded rates of 93.26% and 93.79% for the seasons of 2020 and 2021, respectively. During both seasons, the substances clethodim, haloxyfop-methyl, and clethodim + haloxyfop-methyl exhibited the lowest efficiency, with recorded values varying from 44.03% to 69.64%.

Effect of treatments on the individual narrow-leaved weeds (NLW)

All weed control treatments and manual hoeing twice significantly ($p \leq 0.05$), reduced the fresh weight of narrow-leaved weeds in both growing seasons compared to untreated control (*Table 5*). In 2020 and 2021, clethodim, clethodim + haloxyfop-methyl, and haloxyfop-methyl reduced total narrow-leaved weed biomass by 70% to 96.66%. Both seasons, clethodim and clethodim + haloxyfop-methyl had the maximum weed control efficacy of 81.45%–100%. Using pendimethalin and metrbuzine, overall narrow-leaved weeds were lowest (64.94% to 76.16%). Double-hand hoeing yielded the highest efficiency of 73.85% to 87.62% in both seasons. *Table 5* shows that pre-emergence and post-emergence herbicides and hand hoeing twice in both seasons had significant herbicidal effects on narrow-leaved weeds. After hand hoeing, post-emergence clethodim + haloxyfop-methyl controlled weeds. Weeds included *Echinochloa colonum*, *Brachiaria reptans*, *Cenchrus ciliairis*, and *Dactyloctenium aegyptium*. All pesticides reduced fresh weed weight compared to control. At 60 DAS, two-hand hoeing at 15 and 30 DAS greatly reduced weed fresh weight. Pre-emergence pendimethalin 0.5 kg/ha at 40 DAS reduced weed fresh weight and improved weed control, The untreated weeds had the highest fresh weed biomass (414.08 and 82.81 gm^{-2}) and the pendimethalin treatment was the lowest (169.50 and 33.90). The biomass (fresh weight) of all weeds in the experimental sesame field was affected differently by metrbiuzine and pendimethalin.

Influence of weed control interventions on sesame yield component

The application of herbicidal treatments affected the productivity and yield characteristics of sesame during both the 2020 and 2021 seasons (*Tables 6* and *7*). There were no notable differences observed in the height of sesame plants between those that were hoed manually and those that were treated with herbicides. A substantial improvement was observed in all agronomic characteristics of sesame, including the number of grains per capsule, the number of branches per plant, the weight of 1000 grains per capsule, the grain yield per kilogram of feed, the stalk yield per kilogram of feed, and the straw yield, in comparison to the untreated control group. A greater quantity of branches per plant was observed in plants treated with pendimethalin and metrbuzine prior to emergence, as well as clethodim and clethodim + haloxyfop-methyl after emergence (*Table 6*). An increase in the quantity of capsules per plant was observed when pre-emergence and post-emergence herbicides were applied, followed by manual hoeing. In 2020 and 2021, the seed yield of sesame was significantly ($p \leq 0.05$) higher when treated with clethodim + haloxyfop-methyl and haloxyfop-methyl (724.8 and 713.7 kg/4200 m^2) respectively, compared to the weedy control (338.4 and 318.4 kg/4200 m^2).

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DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

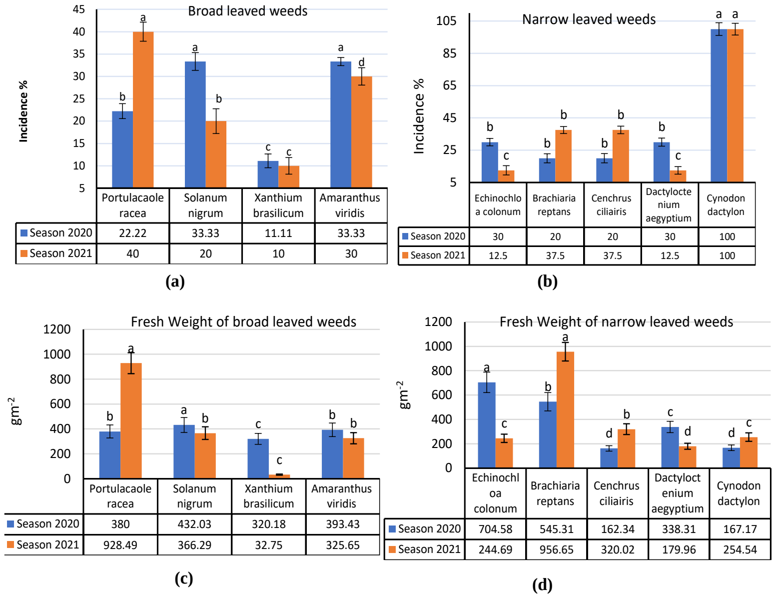

Figure 1. *Incidence (%) (a and b) and biomass weight (g) (c and d) of the annual broad and narrow leaved weeds in the experimental sesame field during seasons 2020 and 2021. The values expressed within columns represent the mean of three repetitions ± standard deviation. Bars marked by different letters differ significantly (p ≤ 0.05), as revealed by the LSD test*

Table 3. *Weed species prevailed in the experimental sesame field during the growing seasons 2020 and 2021*

English name	Scientific name	Family name	Type of weeds
Common purslane	*Portulacaoleracea*, L.	Portulacaceae	Annual broad-leaved weeds
Black nightshada	*Solanum nigrum* L.	Solanaceae	
Cocklebur	*Xanthium brasilicum*, Vellozo	Compositae	
Pigweed	*Amaranthus viridis* L.*	Chenopodiaceae	
Bermuda grass	*Cynodon dactylon* L.	Gramineae	Perennial narrow-leaved weeds
Jungle rice	*Echinochloa colonum*, L.	Gramineae	Annual narrow-leaved weeds
Signal grass	*Brachiaria reptans* L.	Gramineae	
Sandbur	*Cenchrus ciliairis* L	Gramineae	
Crow footgrass	*Dactyloctenium aegyptium* L	Gramineae	

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

Table 4. *Efficacy of herbicides on broad leaved weeds after 60 days from sowing (DAS) of sesame during the seasons 2020 and 2021*

Treatments and formulations	***Portulaca oleracea***				***Solanum nigrum***				***Amaranthus viridis***				***Xanthium brasilicum***				**Total annual broad-leaved weeds**			
	Fresh weight (g)		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**	
	2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Metrbuzine	38.28	76.29	89.93	91.78	0	61.43	100	83.23	0	51.43	100	84.21	17.42	0	95.57	100	55.7	189.15	96.35	88.56
Pendimethalin	42.92	64.86	88.71	93.01	17.53	48.13	95.94	86.86	25.66	38.97	91.99	88.03	0	0	100	100	86.11	151.96	94.36	90.81
Haloxyfop-methyl	132.29	297.14	65.19	68	142.4	149.71	67.03	59.13	179.2	138.3	44.03	57.52	235.6	19.83	40.12	39.45	689.53	605.03	54.8	63.4
Clethodim	115.37	345.29	69.64	62.81	198.5	183.71	54.04	49.85	149.4	167.1	53.33	48.68	198.54	22.67	49.54	30.78	661.88	718.78	56.62	56.52
Clethodim + Haloxy fop-methyl	137.5	391.36	63.82	57.85	212.3	164.5	50.86	55.09	153.5	153.2	52.05	52.93	211.3	21.41	46.29	34.63	714.65	730.56	53.16	55.81
Hand-hoeing	25.6	57.69	93.26	93.79	54.21	73.71	87.45	79.88	29.08	57.52	90.92	82.34	19.95	9.54	94.93	70.87	128.84	198.46	91.56	88
Control	380	928.49			432.0	366.29			320.1	325.6			393.43	32.75			1525.4	1653.2		
L.S.D at 5%	64.40	136.27			81. 81	92.88			92.28	83.78			76.82	9.76			117.12	210.539		

Table 5. *Efficacy of certain herbicides on annual narrow leaved weeds at 60 days after sowing (DAS) of sesame crop during the seasons 2020 and 2021*

Treatments and formulations	***Echinochloa colonum***				***Brachiaria reptans***				***Cenchrus ciliairis***				***Dactyloctenium aegyptium* L**				**Total annual narrow leaved-weed**			
	Fresh weight (g)		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**		**Fresh weight (g)**		**Efficiency (%)**	
	2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Metrbuzine	236.55	86.67	66.43	64.58	182.3	351.6	66.55	63.24	70.71	112.5	56.44	64.85	55.76	45.76	83.52	74.57	545.4	596.55	68.84	64.94
Pendimethalin	212.47	99.81	69.84	59.21	128.2	244.8	76.47	74.41	33.1	129	79.61	59.69	43.42	26.5	87.17	85.27	417.28	500.1	76.16	70.6
Haloxyfop-methyl	154.74	35.2	78.04	85.61	55.74	35	89.78	96.34	37.26	59.33	77.05	81.46	0	0	100	100	247.74	129.5	85.85	92.39
Clethodim	130.71b	24.29	81.45	90.07	16.48b	29b	96.98	96.97	22.14	35.8	86.36	88.81	0	0	100	100	169.33	89.09	90.33	94.76
Clethodim+ Haloxyfop-methyl	115.09a	10.01	83.67	95.91	12.15	25.02	97.77	97.38	12.38	21.75	92.37	93.2	0	0	100	100	139.62	56.78	92.02	96.66
Hand- hoeing twice	196.85	50.11	72.06	79.52	155.7	97.24	71.45	89.84	40	45.48	75.36	85.79	65.21	12.65	80.72	92.97	457.77	205.4	73.85	87.92
Control	704.58	244.6			545.3	956.6			162.3	320.0			338.3	179.9			1750.54	1701.32		
L.S.D at 5 %	117.91	95.70			95.18	175.21			27.15	98.54			78.78	65.21			341.696	130.12		

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DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

Table 6. *Effect of weed control treatments on yield component of sesame at harvest during 2020 season*

Treatments	Plant height (cm)	No. of branches/plant	No. of capsules/plant	No. of grains/capsules	Weight of 1000 grains (g)	Seed yield (kg/4200 m^2)	Stalk yield (kg/4200 m^2 straw yield	Harvest index (%)
Metrbuzine	131.5	5.9	43.4	50.5	39.5	586.6	1952	30.05
Pendimethalin	138.6	5.8	39.6	52.6	42.2	643.4	1960	32.82
Haloxyfop-methyl	141.3	5.4	43.6	46.8	45.8	713.7	2260	31.57
Clethodim	139	5.7	44.5	54.7	41.4	590.9	1760	33.57
Clethodim + Haloxyfop-methyl	143.8	6.3	48.6	56.8	42.4	724.8	2640	27.45
Hand- hoeing twice	123.6	5.8	40.4	47.7	38.6	540.4	1740	31.05
Control	110.2	4.2	22.3	32.6	31.1	338.4	1100	26.03
L.S.D at 5%	N.S	0.60	6.21	4.53	5.63	89.98	279.09	

Table 7. *Effect of weed control treatments on yield component of sesame at harvest during 2021 season*

Treatments	Plant height (cm)	No. of branches/plant	No. of capsules/plant	No. of grains/capsules	Weight of 1000 grains (g)	Seed yield (kg/4200 m^2)	Stalk yield (kg/4200 m^2) straw yield	Harvest index (%)
Metrbuzine	123.5	6.2	33.6	45.5	37.4	576.7	2121	27.19
Pendimethalin	118.4	4.6	30.3	43.6	38.4	623.8	2165	28.81
Haloxyfop-methyl	121.8	5.5	38.5	49.2	41.8a	693.3	1987	34.89
Clethodim	129	6.4	42.4	52.4	39.2	665.8	2043	32.58
Clethodim + haloxyfop-methyl	133.8a	6.8a	49.5a	57.2a	37.1	743.3a	2054a	36.18a
Hand-hoeing twice	120.3	5.3	35.1	43.3	36.7	654.9	2142	30.57
Control	102.4	3.1	20.3	35.8	30.2	318.4	1450	21.58
L.S.D at 5%	N.S	0.54	5.87	7.98	4.43	88.75	431.21	

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DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

The effect of all treatments on chlorophyll and carotenoids content in sesame plants

The levels of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids did not statistically significant ($p \leq 0.05$) differ between all herbicides, hand hoeing, and the unweeded control, as shown in *Figure 2*. The chlorophylls exhibited the greatest non-significant increase in 2020 in the case of pendimethalin and double hand hoeing, yielding 4.20 and 4.55 mg/g FW, respectively, for total chlorophyll. Clethodim + haloxyfop-methyl and double hand hoeing, on the other hand, had the least detrimental effect on total chlorophyll concentrations. For the 2021 season, statistical analysis revealed that none of the interventions had a statistically significant ($p \leq 0.05$) adverse impact on chlorophyll a, b total chlorophyll, or carotenoids (*Fig. 2*). In contrast, the minimum detrimental impact on total chlorophyll was observed with the implementation of hand hoeing twice, yielding 4.55 mg/g FW (*Fig. 2c*).

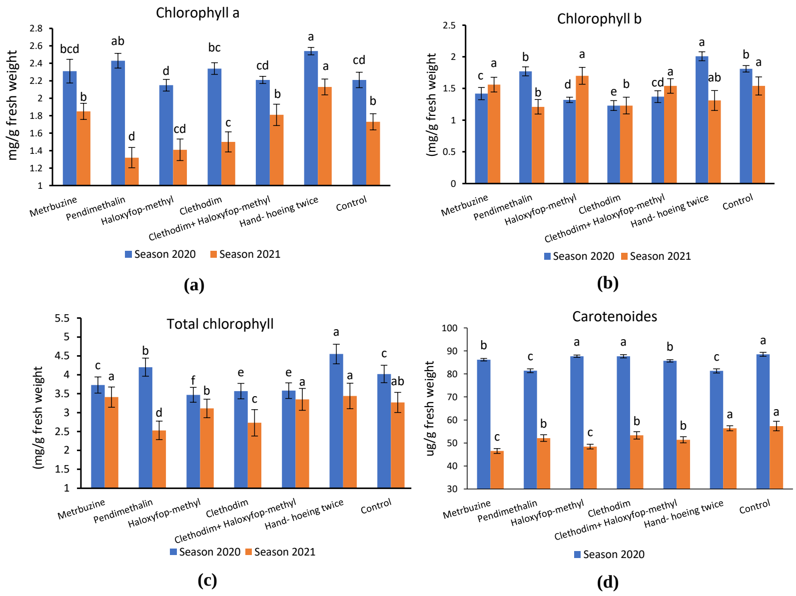

Figure 2. *Levels of chlorophyll a (a), chlorophyll b (b), total chlorophyll (c), and carotenoids (d) in sesame plants during the two seasons 2020 and 2021 in response to treatments with herbicides and hand hoeing in relative to untreated control. The values expressed within columns represent the mean of three repetitions ± standard deviation. Bars marked by different letters differ significantly ($p \leq 0.05$), as revealed by the LSD test*

The potential effect of the herbicidal treatments on two subsequent barley and green beans crops

The previous application of herbicides did not affect the germination percentage of barley and green bean seeds (*Fig. 3a*). The germination percentages of barley and green bean seedlings reached their highest levels at 88.72% and 84.77% respectively when the soil was pre-treated with clethodim + haloxyfop-methyl, as shown in *Figure 3a*. In addition, when sown in soil that was previously treated solely with clethodim, barley and green beans exhibited remarkably high germination rates of 80.83% and 87.32%, respectively. Nevertheless, performing hoeing twice led to the highest germination rate of 89.14% specifically for green beans (*Fig. 3a*). The results depicted in *Figure 3* demonstrate that the presence of herbicide residues had a substantial impact on the dry

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

mass of both the shoots and roots of barley and green bean seedlings. In contrast, green bean seedlings grown in soil that had been pre-treated with a combination of clethodim and haloxyfop-methyl had the greatest dry weight of 31.98 g DW (*Fig. 3b*). In contrast, the investigated treatments had a noticeable inhibitory effect on green beans, as indicated by the substantial decrease in the dried weight of roots, in comparison to a minimal influence (*Fig. 3c*).

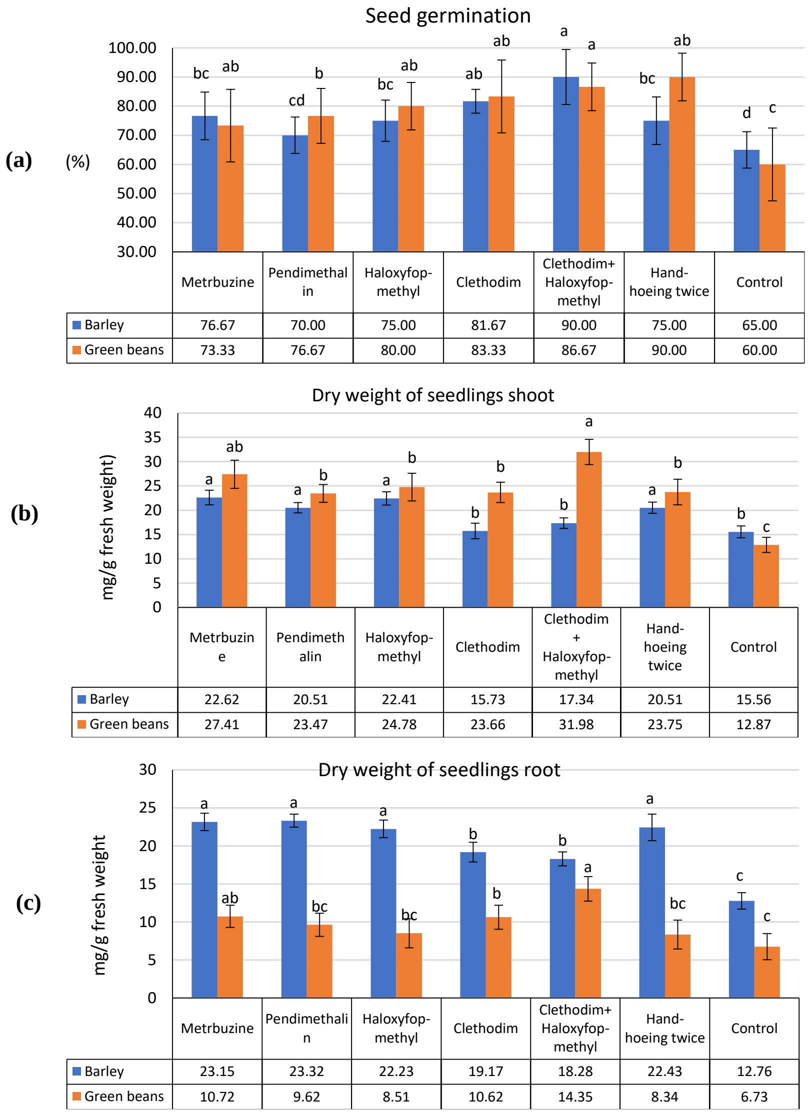

Figure 3. *Herbicides residual effect on seed germination (%) (a), dry weight (mg/FW) of shoots (b) and roots (c) of Barley and green beans seedlings in relative to untreated control. The values expressed within columns represent the mean of three repetitions ± standard deviation. Bars marked by different letters differ significantly (p ≤ 0.05), as revealed by the LSD test*

Discussion

The results of the current study revealed that narrow-leaved weeds exhibited fluctuations in their occurrence and relative biomass across the two seasons of 2020 and 2021. This fluctuation may be attributed to the variation in environmental conditions during the season. These findings are congruent with Nichols et al. (2015), who

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

observed that climatic and cultural variables affected weed density in any crop over time. Species of broad-leaved weeds investigated in this study exhibited variation in their susceptibilities to herbicides The observed variations in the activity of the herbicides under investigation during the two seasons may have been attributable to climate conditions. These results may also be explained by the inhibitory effect of herbicidal interventions on weed growth, as well as by pesticide formulations and adjuvant components. Conforming to the findings of Aruna et al. (2020). Our results indicated that at 60 DAS, two-hand hoeing at 15 and 30 DAS greatly reduced weed fresh weight. This was consistent with the statement of Mahajan and Chauhan (2015), who stated that hand weeding is the most effective method for managing vegetation in any crop. According to Mane et al. (2018), hand hoeing reduced fresh weed weights in thier trials. Sesame dissemination complicates manual weeding to the extent that herbicides are required. Post-emergence quizalofop ethyl 0.0050 kg ha^{-1} and pre-emergence pendimethalin 0.75 kg ha^{-1} were more effective at controlling broadcast sesame weeds. El-Mahy (2005) found out that metribuzin when applied at 300 mg fed^{-1} was the most effective in controlling grassy and broad-leaved plants. Additionally, according to Senseman (2007) pendimethalin modulates acetolactate synthase and triazine-resistant biotypes, common lamb'squarters (*Chenopodium album* L.), and redroot pigweed. Weeds were suppressed at germination and late-germinating by pre-emergence and early post-emergence herbicides. Similarly, to our results, Sheoran et al. (2012) and Mruthul (2015) found consistent results. According to Aruna et al. (2020), pendimethalin @ 0.75 kg ha^{-1} as PE fb metribuzin 0.350 kg ha^{-1} + quizalofop ethyl 0.050 kg ha^{-1} at 20 DAS improved weed control at 45 DAS Metribuzin caused sesame phytotoxicity everywhere. Using preemergence pendimethalin and hand weeding at 25, 15, and 30 DAS increased weed control at 65 DAS. According to Yadav (2004). In IWM, quitalofop-ethyl reduced weeds when compared to other herbicides. Early-germinating weeds were controlled by pendimethalin and metrbuzine, while late-germinating weeds were controlled by clethodim, clethodim + haloxyfop-methyl, and Haloxyfop-methy. Our findings matched those published by Mruthul et al. (2015) and Sujithra (2018). Herbicide efficacy may vary due to sensitivity and mechanism of action against weed growth (Belfry et al., 2016). According to Hidayat et al. (2013) metribuzin 70 WP at 0.42 kg a.i. ha^{-1} maximized fresh and dried weed biomass in the weedy check. Furthermore, application of metribuzin 70 WP at 0.75 kg ha^{-1} and acetochlor revealed 95-94% and 92-88.8% suppression of weed number and biomass, respectively (Jovović et al., 2013; Nestorovic and Konstantinovic, 2014).

The increase in yield characteristics and seed production resulting from the implementation of different weed control regimens can be attributed to successful weed management and weed competition (El-Metwally et al., 2017). This increased seed production and yield attributes increased the likelihood of sesame development. This could potentially be attributed to the impact of pre-emergence and early post-emergence herbicides, which effectively suppress crop-weed competition and maintain weed control to an essential degree by decreasing weed density and dry weight. Consequently, the primary crop can benefit from enhanced access to nutrients, moisture, and light (Mruthul et al., 2015; Yadav, 2004). In contrast, Grichar et al. (2018) discovered that the application of dinitroaniline and trifloxysulfuron-sodium led to significant damage to sesame, with yield reductions of up to 97% compared to the untreated control. Furthermore, Schrodter and Rawson (1984) provided evidence that

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2204_35213537

the application of bentazone (e.g., Broadstar®) after sesame emergence resulted in toxicity, leading to a decrease in both vigor and yield.

Herbicide exposure can induce a range of physiological and biochemical responses in plants, such as antioxidant responses, chlorosis, and lipid peroxidation (Kaya and Yigit, 2014). After 45 days, sesame plants exhibited no discernible phytotoxic effects in response to the herbicide treatments and appeared to develop tolerance to the examined herbicides. In a similar vein, Choudhary (1983) found that there were no discernible differences in groundnut germination between untreated and treated sites 30 days, 50 days, and 80 days after pre-emergence metolachlor spraying at a rate of 2.52 kg/ha. The primary mechanism by which plants may sustain a low concentration of a particular herbicide is the ability to metabolize an adequate amount of the herbicide (through degradation or detoxification). To illustrate, clethodim can undergo metabolism into sulfoxide, sulfone, and S-methyl sulfoxide, according to Tomlin (2001). In addition, Ansolabehere and Kvasnicka (1988) discovered that groundnuts exhibited a notable degree of tolerance towards chlorothiodim.

Moreover, specific research has demonstrated that the presence of metribuzin and pendimethalin herbicide residues does not have a detrimental effect on the germination of barley seeds or the following growth of wheat crops (Karim, 2009; Patel et al., 1992). Subsequent research has shown that metribuzin and pendimethalin do not have any harmful impact on the process of seed germination or the growth of subsequent species of seedling roots in various crops (Chopra and Chopra, 2005; Pornprom et al., 2010; El-Metwally, 2016; Vouzounis, and Americanos, 1995). Furthermore, the use of pennedimethalin at a rate of 1.00 and 0.75 kg a.i./ha to manage weeds in rice did not have any harmful effects on the germination of subsequent crops. However, it did have a detrimental impact on the dry weight of maize, soybeans, and cucumber, although it did not affect their germination (Strandberg and Scott-Fordsmand, 2004).

Funding. This research was funded by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, grant number (GRANT2370).

Acknowledgments. This research was funded by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, grant number (GRANT2370).

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