Journal of Pure and Applied Agriculture (2020) 5(2): 79-90
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

RESEARCH PAPER

Use of adjuvant and allelopathic plant extract to minimize the herbicide dose for controlling parthenium (*Parthenium hysterophorus* L.) in okra (*Abelmoschus esculentus*)

Muhammad Ehsan Safdar[1]*, Qaisar Mumtaz[1], Muhammad Asif[1], Muhammad Ather Nadeem[1], Amjed Ali[1], Sajad Hussain[2], Mubashar Nadeem[3] and Muhammad Sikander Hayyat[1]

[1]Department of Agronomy, College of Agriculture, University of Sargodha, PK-40100 Sargodha, Pakistan
[2]College of Agronomy, Sichuan Agricultural University, 211-Huimin Road, Wenjiang District, Chengdu 611130, PR China
[3]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

*****Corresponding author: Muhammad Ehsan Safdar (ehsan_safdar2002@yahoo.com)

Received: 14 February 2020; Accepted: 26 May 2020; Published online: 29 June 2020

Key Message: The findings of current study conclude that halosulfuron dose can be reduced up to 25% by alkyl ether sulfate adjuvant to obtain the same efficiency as with its full dose for controlling parthenium weed and getting higher yield of okra.

Abstract: Herbicide use in vegetables poses serious ecological and health hazards. To identify chemical strategy for minimizing herbicide doses with the use of adjuvant and allelopathic plant extract for controlling parthenium weed in okra, two-year field studies were undertaken at experimental area of College of Agriculture, University of Sargodha, Punjab-Pakistan during the summer seasons of years 2018 and 2019. The experimental treatments were a pre-emergence application of pendimethalin (495 g a.i. ha^{-1}), post-emergence applications of metribuzin and halosulfuron at their full (518 g a.i. ha^{-1} and 37 g a.i. ha^{-1}, respectively) and 75% doses alone and tank-mixed application with alkyl ether sulfate (AES) adjuvant and aqueous extract of *A. aspera* (AAE). The results indicated that among two herbicides, the efficiency of halosulfuron was proved to be higher than metribuzin in terms of reducing parthenium dry weight and getting higher okra pod yield. Among two herbicides, halosulfuron showed greater enhancement in its efficacy by addition of adjuvant as compared to that shown by metribuzin. Halosulfuron full and 75% dose alone and in mixture with AES and AAE caused significantly the highest reduction in parthenium weed dry weight (up to 78%), while the highest increases in plant height (up to 76%), number of leaves (443%), number of pods (up to 256%), pod length (up to 66%) and pod yield (up to 82%) of okra in comparison to control. The reduced dose of halosulfuron in mixture with AES adjuvant showed the same performance as shown by its full dose alone in reducing weed density and dry weight and increasing pod yield of okra. It can be concluded that the halosulfuron dose can be reduced up to 25% if AES adjuvant was tank-mixed in it to obtain the same efficiency as with its full dose without compromising okra yield.

Keywords: Alkyl ether sulfate, Halosulfuron, Herbicides, Pod yield, Weed dry weight

To cite this article: Safdar, M. E., Mumtaz, Q., Asif, M., Nadeem, M. A., Ali, A., Hussain, S., Nadeem, M., & Hayyat, M. S. (2020). Use of adjuvant and allelopathic plant extract to minimize the herbicide dose for controlling parthenium (*Parthenium hysterophorus* L.) in okra (*Abelmoschus esculentus*). *Journal of Pure and Applied Agriculture*, *5*(2), 79-90.

Introduction

Pakistan is an agricultural country. Only agriculture contributes 18.5% to gross domestic product and 38.5% to employment for labour (Government of Pakistan [GoP], 2019). Vegetables are particularly significant for human nutrition and have several medical advantages as these are rich sources of minerals, vitamins and dietary fiber (Yahia et al., 2019). Okra (*Abelmoschus esculentus* L.) is an important vegetable and usually grown in hot and sub-tropical regions. Okra belongs to the Malvaceae family. It contains about 20% of oil and protein and its fruit contains 32 Kcal/100g of energy (Siemonsma & Hamon, 2002). Its pods contain rich amounts of calcium, magnesium, potassium, iron, manganese, zinc, nickel, vitamin C, vitamin A and folate (Gemede et al., 2015). Its seed is also rich in oil (20-40%) that contains 47% unsaturated fatty acids like linoleic acid that is imperious for human health (Gemede et al., 2015). For cultivation of okra, ideal pH ranges from 6.6 to 8 and temperature from 21 to 30 ^{o}C is suitable for growth of okra (Nonnecke, 1989), while its germination cannot occur if the temperature is below the 16 ^{o}C. In Pakistan, the actual yield of okra is less than its potential yield due to several reasons including imbalanced fertilizers, conventional sowing method, high input cost and most importantly the weed infestation and poor weed management. The pod yield losses due to weed infestation in okra range from 69-74% (Zareen et al., 2017; Santos et al., 2020). Weeds mainly reduce the yield through competition with crops. In okra, there must be no weed within 9 weeks after planting to avoid substantial yield losses (Adejonwo et al., 1989).

Parthenium (*Parthenium hysterophorus* L.) is a new broadleaf weed of Pakistan belonging to the family Asteraceae, locally known as *gajjar booti.* Parthenium is most abundantly present around the fields, roadsides and in wasteland as well in different crops also. It leads to significant yield reduction in several crops including vegetables (Shabbir & Bajwa, 2007; Shi, 2016). In Pakistan, its role as host for disease transmission in vegetables has also been reported (Akhtar et al., 2018). It is exceptionally allelopathic in nature and discharges phytotoxic substances in the rhizosphere (Belz et al., 2007). Main phenolics which are present in parthenium are vanillic, caffeic, chlorogenic, ferulic and anisic,gallic, 4-hydroxy-3-methoxy benzoic, p-coumaric, m-coumaric and syringic acids (Safdar et al., 2014). Okra is quite susceptible to crop weed competition, and it requires a very quick and effective method to control weeds. Chemical control is viewed as the swiftest approach to control weeds. Halosulfuron and metribuzin are commonly used herbicides in vegetables. Halosulfuron is a sulfonylurea herbicide that stops branched chain amino acid biosynthesis through inhibition of acetolactate synthase (ALS) and acetohydroxy acid synthase (AHAS) enzymes whereas metribuzin is a triazinone that inhibit photosynthesis at photosystem-II (Copping & Hewitt, 1998). Abundant use of synthetic herbicides has brought about issues like environmental contamination, soil and water pollution (Kniss, 2017) and dangers to human wellbeing (Snelders et al., 2008). So there is an utmost requirement for using methodologies, which can in any way diminish the utilization of herbicides. One of the conceivable approaches to lessen herbicide use is to reduce their doses through enhancing their efficacy by mixing with adjuvants or other reasonable bio-enhancers (Devendra et al., 2004).

One of the easy and reliable methods of minimizing ecological risks and reducing herbicide cost is the use of adjuvants. These are important for easy herbicide mixing and application (Hess & Foy, 2000). Use of proper adjuvant has a potential to enhance herbicide ability to control weeds without damaging the yield of the crop. Kammler et al. (2008) demonstrated an increase in the efficacy of halosulfuron for controlling *Digitaria sanguinalis* and *D. ischaemum* in pumpkin (*Cucurbita pepo* L.) by adding different types of adjuvants. Alkyl ether sulfate has been evidenced to be a reasonable adjuvant as it can help in diminishing herbicide dose up to 75% of prescribed dose without impairing its effectiveness and brought about higher grain yield (Tanveer et al., 2017). The utilization of allopathic plant extracts in mixture with herbicide is another choice of improving its efficacy thus useful in reducing herbicide dose. *Achyranthes aspera* L. commonly known as prickly-chaff flower is highly allelopathic in nature which belongs to the family Amaranthaceae. This plant is enriched with various allelopathic compounds including dihydroxy ketones, alkaloids, saponins, phenolics (chromatotropic, gallic, caffeic, 4-hydroxy-3-methoxy benzoic, m-coumaric and syringic acids) and oleonolic acid (Srivastav et al., 2011; Safdar et al., 2016). The herbicidal potential of *A. aspera* against parthenium weed has been recorded due to its higher total phenolic contents (5779 mg L^{-1}) in its whole plant extract (Safdar et al., 2016). In the light of previously mentioned actualities, a field experiment was proposed to test various herbicides at reduced rates in tank mixed application with alkyl ether sulfate adjuvant and aqueous extract of *A. aspera* for controlling parthenium weed in okra.

Materials and Methods

The experiment was carried out at Agronomic research farm, College of Agriculture; University of Sargodha, Pakistan during summer seasons of year 2018 and 2019. Soil analysis before planting of okra crop was made. The soil of the experimental site was found to be sandy loam having pH 7.80-7.85, organic matter 1.07-1.12, N 0.42-0.43%, P 7.8 and K 137-143 ppm in years 2018 and 2019, respectively. Data related to temperature and rainfall for the okra growing season for year 2018 and 2019 of the experimental site are shown in Fig. 1.

The field was ploughed with disk harrow to break clods, followed by running cultivator twice. After that, ridges were made at 60 cm distance. The seed of okra variety "*Green Paree"* was sown on ridges manually keeping row to row and plant to plant distances of 60 and 45 cm, respectively. The crop was sown on 31^{st} and 28^{th} of March, 2018 and 2019, respectively. The treatments consisted of control (weedy check), pendimethalin (pre-emergence) at 495 g a.i. ha^{-1}, metribuzin (post-emergence) at 518 g a.i. ha^{-1} (full dose), halosulfuron (post-emergence) at 37 g a.i. ha^{-1} (full dose), metribuzin 75% dose alone, halosulfuron 75% dose alone, metribuzin full dose + alkyl ether sulfate (AES) as adjuvant, metribuzin 75% dose + AES, halosulfuron full dose + AES, halosulfuron 75% dose + AES, metribuzin full dose + aqueous extract of *A. aspera* (AAE), metribuzin 75% dose + AAE, halosulfuron full dose + AAE, halosulfuron 75% dose + AAE, halosulfuron 75% dose + AES + AAE, and metribuzin 75% dose + AES + AAE.

The net plot size was 4 m × 2 m, each treatment comprised of three replications and the experiment was laid out as a randomized complete block design. In both year of study, at the time of sowing, seed of parthenium was broadcasted at 15 kg ha^{-1} rate evenly over the entire field to get a uniform weed population. Knapsack sprayer was adjusted before spraying herbicides to estimate the actual amount of water (296 L ha^{-1}) required to apply herbicides. Pre-emergence herbicide was sprayed just after crop sowing while post-emergence herbicides were applied 30 days after crop emergence. Manual weeding was done to remove all other weeds except parthenium. Nitrogen, potassium and phosphorus were supplied in the form of urea, sulfate of potash and diammonium phosphate at sowing of the crop. All other management practices were kept uniform for the crop during its entire growing season.

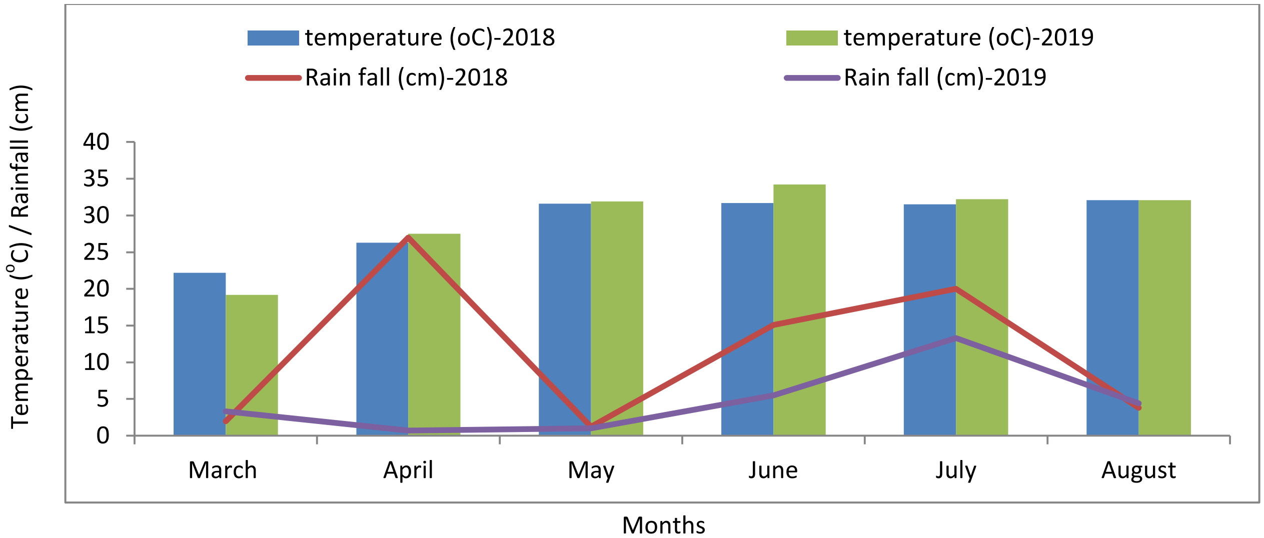

Fig. 1 Metrological data (temperature & rainfall) for the growing season of okra

Data collection

Crop was harvested on 24th and 20th of August, 2018 and 2019, respectively. Data associated with parthenium weed and okra crop were noted by following methods:

Weed density (plants m^{-2})

Density of parthenium was taken by calculating the number of parthenium plants in an area of 1 m^2 in every plot after 21 days of treatment application.

Weed dry weight (g m^{-2})

At maturity, parthenium plants per plot were uprooted and kept in shade for drying. After shade drying the weed sample was oven dried for 48 hours at 70 ºC and the weed dry weight was noted through electric balance.

Weed control efficiency (%)

It was computed according to the equation described by Gupta (1998):

$$\text{WCE} = \frac{\text{W1} - \text{W2}}{\text{W1}} \times 100$$

Where

W_1 = weed dry biomass in control treatment, and W_2 = weed dry biomass in herbicide treatment

Okra plant height (cm)

At maturity, height of 10 okra plants randomly selected in every plot was measured from the base to the tip of the plant with a meter rod and their average was worked out.

Number of leaves per plant

The number of leaves from 10 randomly selected plants from each plot was counted manually and then their mean was taken.

Days taken to flowering

It was calculated by counting the days after crop emergence to flower initiation in each plot.

Number of pods per plant

Data related to the number of pods per plant was noted by counting the pods of 10 haphazardly selected plants from every plot and then taking out their average.

Pod length (cm)

From each plot, lengths of 10 pods from randomly selected plants were measured with the help of measuring tape. After this their average was taken.

Pod yield (kg ha^{-1})

Picking of okra fruit (pods) was done within a 5 day interval. After last picking, the total fruit yield of all the pickings from each plot was cumulated and then converted into kg ha^{-1}.

Herbicide efficiency index

It was worked out by the equation described by Walia (2003):

$$HEI = \frac{YT - YC}{YC} \times 100 \Bigg/ \frac{DMT}{DMC} \times 100$$

Where
YT = Pod yield of herbicide treated plot; YC = Pod yield of control plot; DMT = Weed dry biomass in herbicide treated plot; DMC = Weed dry biomass in control plot.

Statistical analysis

The collected data were exposed to statistical analysis by using Fischer's analysis of variance technique. Treatments' means were compared by honestly significant different test (HSD) at 5% probability using Statistix 8.1 (McGraw-Hill, 2008) computer software. Planned meaningful contrast comparisons for various herbicide treatments were prepared using a single degree of freedom (df) contrast method (Little & Hills, 1978).

Results

Growth characteristics of parthenium

Parthenium density and dry weight per m^2

Data related to parthenium density at 21 days after herbicide application and dry weight at harvest are presented in Table 1. It indicated that all herbicides significantly reduced both the weed density as well as the parthenium dry weight compared to the weedy check except pre-emergence application of pendimethalin at 495 g a.i. ha^{-1}. The lowest parthenium density (10.3 and 11.6 plants m^{-2} in years 2018 and 2019, respectively) was noted with halosulfuron full dose along with AES which was not significantly different from all herbicides treatments except pre-emergence application of pendimethalin at 495 g a.i. ha^{-1} during year 2018 while from metribuzin full dose + AES and halosulfuron full dose + AAE and 75% doses along with AES + AAE during year 2019. Halosulfuron full dose + AES produced the lowest parthenium dry weights (107.1 g m^{-2} and 98.4 g m^{-2} during 2018 and 2019, respectively) which were statistically at par with halosulfuron full and 75% dose alone and in mixture with AES and AAE during both the years of study. Contrast analysis about parthenium weed density per m^2 and weed dry weight by the application of different herbicide treatments suggested that all herbicides caused significant reduction in parthenium weed density and dry weight in contrast to treatment where no herbicide was sprayed in both years. In comparison to metribuzin, halosulfuron showed significantly higher phytotoxic effect against parthenium. The efficacy of both herbicides was significantly improved by their tank-mixed application with AES as well as AAE. However among two herbicides, halosulfuron showed greater improvement in its efficacy by the addition of adjuvant and plant extract.

Weed control efficiency

Maximum weed control efficiency (78-82%) was shown by halosulfuron 75% dose + AES + AAE, that was statistically at par with halosulfuron full and 75% doses alone and in mixture with AES and AAE, and least weed control efficiency (19%) was observed in plots where pendimethalin at 495 g a.i. ha^{-1} was sprayed during both years 2018 and 2019 (Fig. 2).

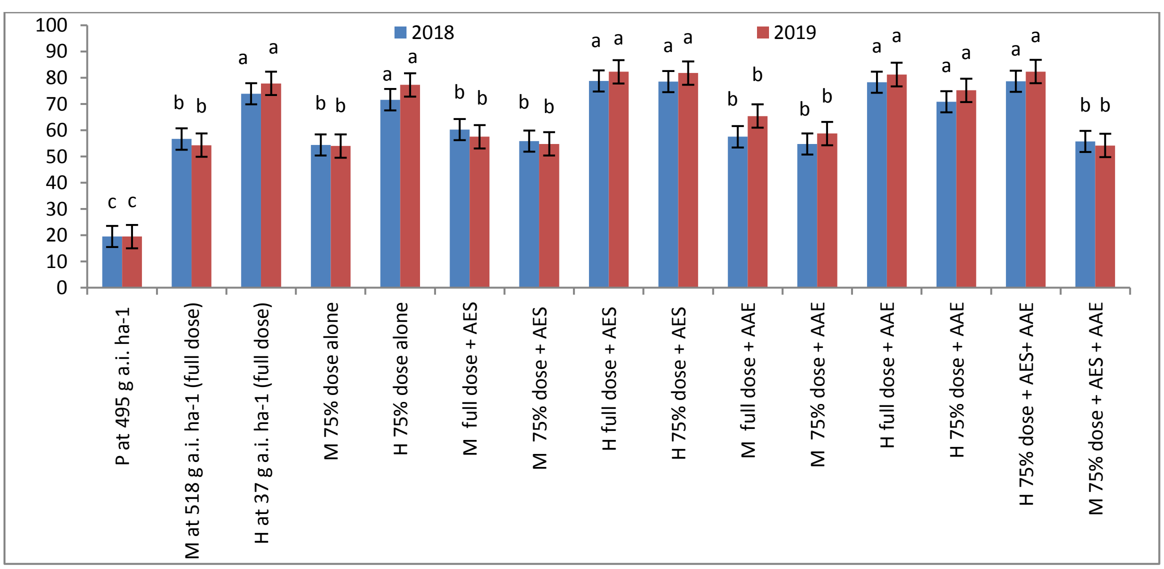

Fig. 2 Weed control efficiencies of different herbicide treatments in okra

Growth traits of okra

Plant height

Data related to plant height (Table 2) indicated significant improvement in plant height by all herbicide treatments except pre-emergence application of pendimethalin. The maximum plant heights (143.7 and 202.4 cm) of okra were recorded with halosulfuron full dose + AES in both the years 2018 and 2019, respectively. However, this treatment did not differ significantly from halosulfuron full and 75% dose alone and in mixture with AES and AAE during both years of study. Contrast comparison regarding this parameter showed that compared to metribuzin, halosulfuron both alone and with adjuvant or plant extract caused significantly the higher plant height of okra. Moreover, plant height of okra showed significant enhancement by tank-mixed application of halosulfuron with adjuvant in both the years of study (Table 2).

Number of leaves plant^{-1}

Data related to number of leaves (Table 2) showed that all herbicides markedly improved the number of branches of okra except pre-emergence application of pendimethalin and post-emergence application of metribuzin 75% dose alone and along with AES and AAE. Maximum number of leaves (5.66) and (5.43) was recorded in treatment where halosulfuron full dose was applied with AES and AAE was used in 2018 and 2019 respectively. This treatment was statistically similar to halosulfuron full dose alone, and 75% doses along with AES and AAE in both the experimental years. Contrast analysis indicated that in comparison to metribuzin, halosulfuron application resulted in significantly the higher number of leaves per plant of okra alone as well as in mixture with adjuvant or plant extract. Similarly, the performance of halosulfuron was noted to be improved significantly by its tank-mixed application with adjuvant in both the years (Table 2).

Days to flowering

Data relevant to number of days taken to flowering of okra as are presented in Table 3. The non-significant differences exist among means of days to flowering under the influence of different herbicide treatments in both the years of study.

Pod length

In comparison to weedy check, significant improvement in pod length of okra during both years was observed in response to all herbicide treatments except pre-emergence application of pendimethalin (Table 3). The highest pod lengths (13.86 cm in year 2018 and 13.17 cm in year 2019) of okra were measured from plots that were treated with halosulfuron full dose + AES. However, full dose of halosulfuron alone and its 75% doses alone and in mixture with AES and AAE produced statistically similar results regarding this parameter during both experimental years. The meaningful contrasts' analysis revealed that in terms of achieving higher pod length of okra, halosulfuron performed better than metribuzin. Moreover, the efficacy of halosulfuron was significantly enhanced by mixing adjuvant with it. Similarly, the performance of halosulfuron in mixture with adjuvant and plant extract was found to be better compared to that of metribuzin in both the years of study (Table 3).

Number of pods plant^{-1}

Data related to the number of pods per plant of okra (Table 4) indicated significant improvement in this parameter by all herbicide treatments except pre-emergence application of pendimethalin. The highest number of pods per plant (10.53 and 12.6 in year 2018b and 2019, respectively) was recorded with halosulfuron full dose + AES. However, non-significant differences from this treatment existed of full dose of halosulfuron alone and its 75% dose alone and in mixture with AES and AAE during both experimental years. The contrasts' comparison regarding this parameter revealed that halosulfuron performed better than metribuzin. Further, the performance of halosulfuron was significantly increased by mixing adjuvant with it. Likewise, among two herbicides, halosulfuron performed better in mixture with adjuvant and plant extract in both the years of study (Table 4).

Pod yield

It is evident from the data (Table 4) that pod yield of okra was prone to a significant increase in response to all herbicide applications except pre-emergence application of pendimethalin. The highest pod yields (417.7 kg ha^{-1} and 425.7 kg ha^{-1} during years 2018 and 2019, respectively) of okra were obtained from plots that were treated with halosulfuron full dose + AES. Nevertheless, halosulfuron full dose alone and 75% doses and in mixture with AES and AAE also gave statistically similar pod yields in both the years of study. The contrast analysis has shown that among two herbicides, halosulfuron showed the better efficiency in increasing pod yield of okra. Furthermore, in comparison to metribuzin, this herbicide also showed better results in its tank-mixed application with adjuvant as well as plant extract in both experimental years (Table 4). The comparison of herbicide efficiency indices (HEIs) of different herbicide treatments has been presented in Fig. 3. The data highlighted that among all herbicide treatments, the highest HEIs (3.88 and 4.48 in year 2018 and 2019, respectively) were shown by the halosulfuron full dose along with AES. This herbicide treatment was followed by halosulfuron 75% dose + AES + AAE as it gave the second highest values (3.48 and 4.06 in year 2018 and 2019, respectively) of HEIs. Likewise, Halosulfuron 75% dose + AES followed these. While, the lowest HEI (0.14 in both the years) was given by the pre-emergence application of pendimethalin.

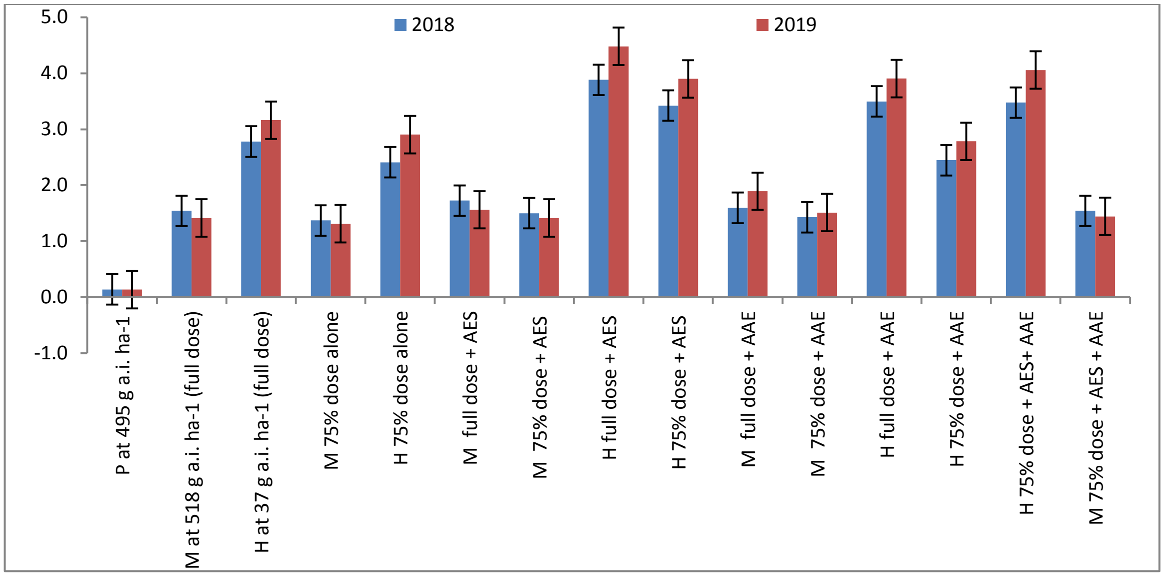

Fig. 3 Herbicide efficiency indices of different herbicide treatments in okra

Table 1 Effect of different herbicide treatments on density and dry biomass of parthenium weed in okra

Treatments	Weed density (plants m^{-2}) 21 days after herbicide application		Weed dry weight (g m^{-2})	
	2018	2019	2018	2019
Control (Weedy check)	26.0^{a}	28.3^{a}	505.0^{a}	554.3^{a}
Pendimethalin at 495 g a.i. ha^{-1}	23.0^{ab}	25.3^{a}	436.4^{a}	446.0^{a}
Metribuzin (M) at 518 g a.i. ha^{-1} (full dose)	14.6^{cd}	19.0^{b}	218.8^{bcd}	253.2^{b}
Halosulfuron (H) 37 g a.i. ha^{-1} (full dose)	12.3^{cd}	16.0^{c-g}	131.7^{ef}	122.8^{cd}
M 75% dose alone	18.6^{abc}	21.0^{b}	230.2^{b}	255.1^{b}
H 75% dose alone	15.3^{cd}	17.3^{cde}	143.3^{def}	126.1^{cd}
M full dose + AES	13.0^{d}	14.0^{fgh}	200.9^{b-e}	235.5^{bc}
M 75% dose + AES	16.6^{bcd}	17.0^{cdef}	222.8^{bcd}	250.6^{b}
H full dose + AES	10.3^{d}	11.6^{h}	107.1^{f}	98.4^{d}
H 75% dose + AES	13.3^{cd}	16.3^{c-g}	108.6^{f}	101.1^{d}
M full dose + AAE	13.0^{cd}	17.0^{c-f}	214.5^{bcd}	191.8^{bcd}
M 75% dose + AAE	16.6^{bcd}	18.0^{bcd}	228.3^{b}	228.8^{bc}
H full dose + AAE	10.3^{d}	13.3^{gh}	109.7^{f}	104.2^{d}
H 75% dose + AAE	13.6^{cd}	15.6^{d-g}	147.4^{c-f}	137.4^{d}
H 75% dose + AES+ AAE	13.6^{cd}	14.3^{e-h}	107.8^{f}	98.0^{d}
M 75% dose + AES + AAE	16.6^{bcd}	18.0^{bcd}	223.7^{bc}	253.8^{b}
HSD (at $P < 0.05$)	7.511	3.131	79.651	117.93
Contrasts				
Control Vs All	26.0 Vs 14.7**	28.3 Vs 16.91**	505 Vs 170.8**	554.3 Vs 187.9**
M Vs H	15.5 Vs 12.6*	16.2 Vs 14.3*	166.5 Vs 141.6*	235.5 Vs 103.4**
M with AES Vs M without AES	15.4 Vs 15.7**	15.1 Vs 17.2*	189.3 Vs 146.4**	246.6 Vs 227.2*
H with AES Vs H without AES	12.4 Vs 12.9*	15.9 Vs 16.7*	156.4 Vs 140.4*	99.2 Vs 106.6*
M with AAE Vs M without AAE	15.4 Vs 15.7*	14.3 Vs 17.8*	183.2 Vs 143.8**	245.9 Vs 227.8**
H with AAE Vs H without AAE	12.5 Vs 12.8^{NS}	17.2 Vs 15.7*	143.3 Vs 126.4*	91.9 Vs 112.1*
M with adjuvant Vs H with adjuvant	15.4 Vs 12.4*	15.1 Vs 12.8*	167.7 Vs 108.6**	246.6 Vs 99.2**
M with plant extract Vs H with plant extract	15.4 Vs 12.5*	14.3 Vs 17.2*	151.6 Vs 110.5**	245.9 Vs 91.9**

Means laying in a column with dis-similar lettering significantly differ from one another at 5% probability level, AES = alkyl ether sulfate, AAE = *Achyranthes aspera* plant extract, * = Significant at 5% probability, ** = Significant at 1% probability, NS = Non-significant

Table 2 Effect of different herbicide treatments on plant height and number of branches per plant of okra

Treatments	Plant height (cm)		Number of leaves plant^{-1}	
	2018	2019	2018	2019
Control (Weedy check)	81.4^{e}	92.6^{f}	1.00^{e}	1.00^{e}
Pendimethalin at 495 g a.i. ha^{-1}	83.4^{e}	111.1^{ef}	1.33^{de}	1.66^{de}
Metribuzin (M) at 518 g a.i. ha^{-1} (full dose)	128.6^{cd}	148.49^{cd}	3.33^{bcd}	2.80^{bcd}
Halosulfuron (H) 37 g a.i. ha^{-1} (full dose)	140.5^{ab}	190.7^{a}	4.00^{abc}	4.83^{ab}
M 75% dose alone	125.6^{d}	139.4^{de}	2.33^{cde}	2.10^{cde}
H 75% dose alone	138.6^{abc}	178.4^{abc}	3.33^{bcd}	2.80^{bcd}
M full dose + AES	130.5^{bcd}	153.5^{bcd}	3.33^{bcd}	3.40^{b}
M 75% dose + AES	129.9^{cd}	145.1^{d}	3.00^{bcde}	1.90^{cde}
H full dose + AES	143.7^{a}	202.4^{a}	5.66^{a}	5.43^{a}
H 75% dose + AES	142.4^{a}	195.7^{a}	4.00^{abc}	5.20^{a}
M full dose + AAE	129.2^{cd}	145.8^{d}	3.33^{bcd}	3.00^{bc}
M 75% dose + AAE	126.6^{d}	140.0^{de}	3.00^{bcde}	1.83^{cde}
H full dose + AAE	138.7^{abc}	194.5^{a}	3.66^{abc}	5.06^{a}
H 75% dose + AAE	138.9^{abc}	191.9^{a}	3.66^{abc}	5.20^{a}
H 75% dose + AES+ AAE	143.2^{a}	184.6^{ab}	5.00^{ab}	5.36^{a}
M 75% dose + AES + AAE	130.1^{bcd}	141.9^{de}	3.00^{bcde}	2.13^{cde}
HSD (at P <0.05)	10.529	31.773	2.2010	1.1693
Contrasts				
Control Vs All	81.4 Vs 131.3**	92.6 Vs 164.2**	1.3 Vs 3.4**	1.6 Vs 3.4**
M Vs H	128.6 Vs 140.8*	144.8 Vs 191.1*	3.0 Vs 4.0*	2.4 Vs 4.6*
M with AES Vs M without AES	130.2 Vs 127.5^{NS}	146.8 Vs 143.4^{NS}	3.3 Vs 2.9^{NS}	2.5 Vs 2.4^{NS}
H with AES Vs H without AES	143.1 Vs 129.2*	194.2 Vs 180.9*	4.9 Vs 3.5*	5.3 Vs 4.2*
M with AAE Vs M without AAE	128.6 Vs 128.7^{NS}	142.6 Vs 146.6^{NS}	3.2 Vs 3.0^{NS}	2.3 Vs 2.6^{NS}
H with AAE Vs H without AAE	140.4 Vs 141.2^{NS}	190.3 Vs 191.8^{NS}	4.2 Vs 4.0^{NS}	5.2 Vs 4.9^{NS}
M with adjuvant Vs H with adjuvant	130.2 Vs 143.1**	146.8 Vs 194.2**	3.2 Vs 4.2*	2.5 Vs 5.3**
M with plant extract Vs H with plant extract	128.8 Vs 140.4**	142.6 Vs 190.3**	3.3 Vs 4.9^{NS}	2.3 Vs 5.2**

Means laying in a column with dis-similar lettering significantly differ from one another at 5% probability level, AES = alkyl ether sulfate, AAE = *Achyranthes aspera* plant extract, * = Significant at 5% probability, ** = Significant at 1% probability, NS = Non-significant

Discussion

All herbicide treatments except pre-emergence application of pendimethalin at 495 g a.i. ha^{-1} resulted in significant decline in parthenium weed density and dry weight in okra. Among two herbicides, halosulfuron was proved to be more effective for controlling parthenium as its 75% dose alone gave significantly the lowest parthenium density as noted at 21 days after herbicide application. Moreover, the efficacy of this herbicide was further enhanced by making its tank-mixed application with adjuvant as well as plant extract consistently over both the years. Although the efficacy of metribuzin was also enhanced in both the years by addition of adjuvant as well as plant extract as indicated by the parthenium dry biomass at harvest, yet the enhancement in efficacy of halosulfuron by mixing it with those was still higher than that observed with metribuzin. The results of present study have a nearby similarity with those of Javaid et al. (2012) who suggested that AES adjuvant had potential to reduce herbicide doses and to enhance the efficacy of herbicides. They further suggested that even the less doses of carfentrazone ethyl and fluroxypyr + MCPA when used in combination with AES as adjuvant resulted in less biomass and 100% death of *Emex spinosus*, respectively.

Table 3 Effect of different herbicide treatments on days to flowering and pod length of okra

Treatments	No. of days taken to flowering		Pod length (cm)	
	2018	2019	2018	2019
Control (Weedy check)	44.0	43.6	8.30[e]	8.86[f]
Pendimethalin at 495 g a.i. ha^{-1}	43.3	44.0	10.34[de]	9.61[ef]
Metribuzin (M) at 518 g a.i. ha^{-1} (full dose)	41.6	43.6	10.40[d]	11.29[b-e]
Halosulfuron (H) 37 g a.i. ha^{-1} (full dose)	43.0	42.3	13.21[abc]	11.46[a-d]
M 75% dose alone	43.0	40.3	11.19[cd]	10.54[de]
H 75% dose alone	42.6	42.6	12.94[abc]	11.60[a-d]
M full dose + AES	42.3	44.3	9.94[de]	11.28[b-e]
M 75% dose + AES	43.0	42.6	10.47[d]	10.40[de]
H full dose + AES	41.0	40.6	13.86[a]	13.17[a]
H 75% dose + AES	43.6	40.6	13.08[abc]	12.34[ab]
M full dose + AAE	41.6	44.3	11.42[bcd]	10.59[cde]
M 75% dose + AAE	42.6	40.6	9.84[de]	10.20[de]
H full dose + AAE	41.3	42.3	13.28[ab]	13.08[a]
H 75% dose + AAE	41.6	43.6	12.66[abc]	12.30[abc]
H 75% dose + AES+ AAE	42.6	43.0	13.01[abc]	11.46[a-d]
M 75% dose + AES + AAE	41.6	41.0	10.45[d]	10.47[de]
HSD (at P <0.05)	NS	NS	2.085	1.730
Contrasts				
Control Vs All	44.0 Vs 42.3[NS]	43.6 Vs 42.5[NS]	8.30 Vs 11.72[**]	8.86 Vs 11.32[**]
M Vs H	42.2 Vs 42.2[NS]	42.4 Vs 42.3[NS]	10.49 Vs 13.15[*]	10.68 Vs 12.20[*]
M with AES Vs M without AES	42.3 Vs 42.2[NS]	42.6 Vs 8.8[NS]	10.18 Vs 10.71[NS]	10.72 Vs 10.66[NS]
H with AES Vs H without AES	42.4 Vs 42.1[NS]	41.4 Vs 8.8[NS]	13.32 Vs 13.02[*]	12.32 Vs 12.11[*]
M with AAE Vs M without AAE	42.0 Vs 42.5[NS]	42.0 Vs 42.7[NS]	10.47 Vs 10.50[NS]	10.42 Vs 10.88[NS]
H with AAE Vs H without AAE	41.8 Vs 42.5[NS]	40.6 Vs 41.9[NS]	12.98 Vs 13.27[NS]	12.28 Vs 12.14[NS]
M with adjuvant Vs H with adjuvant	42.3 Vs 42.4[NS]	42.6 Vs 41.4[NS]	10.18 Vs 13.32[*]	10.72 Vs 12.32[*]
M with plant extract Vs H with plant extract	42.0 Vs 91.3[NS]	42.0 Vs 43.0[NS]	10.47 Vs 12.98[*]	10.42 Vs 12.28[*]

Means laying in a column with dis-similar lettering significantly differ from one another at 5% probability level, AES = alkyl ether sulfate, AAE = *Achyranthes aspera* plant extract, * = Significant at 5% probability, ** = Significant at 1% probability, NS = Non-significant

A similar finding was reported by Cheema et al. (2003) who predicted that use of 1/3rd of the recommended rates of S-metolachlor and pendimethalin when applied along with *sorgaab* @ 10 L ha^{-1} resulted in significant reduction in dry matter of weeds by 58-71% and 50-74%, correspondingly and ultimately improved the yield of cotton. Weed control efficiency (WCE) of herbicide is an indicator of its suppressive action regarding percent weed biomass reduction compared to the weedy check. When we make a comparison of WCEs of different herbicides, it was clear that the reduced doses of halosulfuron in mixture with adjuvant and plant extract gave the higher efficiencies as compared to reduced doses of metribuzin in mixture with adjuvant as well as plant extract. The highest WCE of halosulfuron 75% dose + AES (78-82%) was possibly due to its greatest herbicidal activity against *P. hysterophorus*. Similar results were observed by Richardson et al. (2007) and Everman et al. (2007) who recorded reduction in *T. portulacastrum* dry weight as a result of several herbicide treatments in cotton. An experiment performed by Ali et al. (2013) also revealed marked reduction in dry weight of weed in herbicide treated plot in contrast with control treatment. Although plant height is a varietal character and is related to plant genetic make-up, yet genetic interaction with environmental conditions determines it. Number of leaves is an important trait reflecting vegetative growth pattern of the plant. Higher the number of leaves, greater will be the surface area available for production of photosynthates and ultimately final yield. Plant height and number of leaves per plant of okra were significantly improved by the application of all herbicides except pre-emergence application of pendimethalin.

Table 4 Effect of different herbicide treatments on number of pods per plant and pod yield of okra

Treatments	Number of pods plant^{-1}		Pod yield (kg ha^{-1})	
	2018	2019	2018	2019
Control (Weedy check)	3.13^{e}	3.53^{e}	229.1^{d}	237.1^{d}
Pendimethalin at 495 g a.i. ha^{-1}	5.46^{de}	5.13^{de}	255.2^{d}	263.2_{d}
Metribuzin (M) at 518 g a.i. ha^{-1} (full dose)	6.76^{bcd}	8.43^{bcd}	382.4^{bc}	390.4^{bc}
Halosulfuron (H) 37 g a.i. ha^{-1} (full dose)	8.20^{abcd}	11.06^{abc}	395.2^{abc}	403.2^{abc}
M 75% dose alone	6.73^{bcd}	7.50^{cd}	372.3^{c}	380.3^{c}
H 75% dose alone	7.83^{a-d}	10.36^{abc}	385.8^{bc}	393.8^{bc}
M full dose + AES	7.00^{bcd}	8.96^{bc}	386.5^{bc}	394.5^{bc}
M 75% dose + AES	6.63^{bcd}	8.36^{bcd}	380.8^{bc}	388.8^{bc}
H full dose + AES	10.53^{a}	12.60^{a}	417.7^{a}	425.7^{a}
H 75% dose + AES	9.60^{abc}	10.96^{abc}	399.7^{abc}	409.7^{abc}
M full dose + AAE	6.70^{bcd}	8.66^{bcd}	384.5^{bc}	392.5^{bc}
M 75% dose + AAE	6.68^{bcd}	8.23^{bcd}	377.1^{bc}	385.1^{bc}
H full dose + AAE	10.0^{ab}	10.40^{abc}	403.1^{ab}	411.1^{ab}
H 75% dose + AAE	7.20^{a-d}	11.13^{ab}	392.8^{abc}	400.8^{abc}
H 75% dose + AES+ AAE	10.36^{a}	10.83^{abc}	399.1^{abc}	407.1^{abc}
M 75% dose + AES + AAE	6.70^{bcd}	8.26^{bcd}	385.8^{bc}	393.8^{bc}
HSD (at P <0.05)	3.4240	3.5781	27.343	27.343
Contrasts				
Control Vs All	4.1 Vs 8.0**	3.5 Vs 9.3**	229.1 Vs 381.0**	237.1 Vs 389.0**
M Vs H	7.4 Vs 9.1*	8.3 Vs 11.0*	381.3 Vs 398.7*	389.3 Vs 406.7*
M with AES Vs M without AES	7.4 Vs 7.4NS	8.5 Vs 8.2NS	384.4 Vs 379.1NS	392.4 Vs 387.1NS
H with AES Vs H without AES	10.2 Vs 8.3*	11.5 Vs 8.7*	407.8 Vs 392.2*	417.8 Vs 395.2*
M with AAE Vs M without AAE	7.7 Vs 7.2NS	8.4 Vs 8.3NS	382.5 Vs 380.5NS	390.5 Vs 388.5NS
H with AAE Vs H without AAE	9.2 Vs 9.0NS	10.8 Vs 11.2NS	398.3 Vs 399.1NS	406.3 Vs 407.1NS
M with adjuvant Vs H with adjuvant	7.4 Vs 10.2*	8.5 Vs 11.5*	384.4 Vs 404.8*	392.4 Vs 412.8**
M with plant extract Vs H with plant extract	3.2 Vs 9.2**	2.3 Vs 10.8**	382.5 Vs 398.3**	390.5 Vs 406.3**

Means laying in a column with dis-similar lettering significantly differ from one another at 5% probability level, AES = alkyl ether sulfate, AAE = *Achyranthes aspera* plant extract, * = Significant at 5% probability, ** = Significant at 1% probability, NS = Non-significant

Significantly the higher values of these parameters were achieved by the application of halosulfuron at its full and 75% doses alone and in mixture with adjuvant as well as plant extract. The overall efficacy of halosulfuron in improving plant height and number of leaves per plant of okra was proved to be higher compared to that of metribuzin. Moreover, a significant improvement was observed in its efficacy when mixed with adjuvant while no improvement was observed by adding plant extract in it. The significant increase in plant height and number of leaves of okra by the use of different herbicide treatments were resulted due to its better vegetative growth on account of effective management of parthenium weed. Due to reduced weed infestation, competition between crop and weed was decreased and ultimately the better crop growth occurred that resulted in increased plant height and number of leaves of okra. These results corroborate the conclusions of Bellinder et al. (2003); Nadeem et al. (2008); Mohassel e al. (2011) who demonstrated that efficacies of herbicides were improved by adding adjuvants. An experiment conducted by Javaid et al. (2012) proved that AES as an adjuvant improved herbicides' efficacy. An experiment performed by Zareen et al. (2017) also proved the considerable improvement in the number of branches of okra by reducing weed infestation in the crop.

Numbers of pods per plant and pod length are the pivotal yield bearing traits of okra that contributed positively to pod yield. All herbicides significantly improved the pod number per plant and pod length except pre-emergence application of pendimethalin. However, significantly the highest pod length and number of pods per plant of okra was noted from plots that were sprayed with full and 75% doses of halosulfuron alone as well as in combination with adjuvant and plant extract. Among two herbicides, halosulfuron showed an overall better performance than metribuzin in increasing the pod number of okra. Moreover, its efficiency was further improved by the addition of adjuvant in it. However, this was not the case with metribuzin as it did not show enhancement in its efficiency by addition of either the adjuvant or plant extract in it. The increase in pod length and pod number of okra as a result of various herbicide treatments was due to decrease in growth and density of parthenium weed that provided a better environment for okra to produce more fruits. A study performed by Singh et al. (1996) concluded that almost 40% reductions in number of seeds per plant of mung bean crop occurred due to competitions of weeds with the crop. Borras et al. (2004) demonstrated that reduction in weeds resulted in increased assimilation of photosynthates and their translocation towards seed formation.

Pod yield is the ultimate resultant of different yield related traits of okra. All herbicide treatments considerably enhanced the pod yield of okra crop except pre-emergence use of pendimethalin. Halosulfuron full dose and its 75% doses along with adjuvant and plant extract out-performed all herbicide treatments in attaining the higher pod yield of okra. It is noticed that performance of 75% dose of halosulfuron could only reach to the level of full dose when mixed with adjuvant or plant extract. Halosulfuron showed an overall higher efficiency than metribuzin in terms of getting higher okra pod yield. Among two herbicides, halosulfuron showed greater enhancement in its efficacy by addition of adjuvant as compared to that shown by metribuzin. The enhancement in pod yield of okra because of herbicide use is the result of better establishment of okra due to decline in crop weed competition. Resultantly, the improvement in number of pods per plant and pod length resulted in improved fruit yield. The HEI that is the ratio of percent improvement in crop yield per unit decrease in weed dry weight is an indicator of herbicide performance in terms of efficient weed control with minimum crop injury. In present study, considerable enhancement in HEI of full and 75% doses of halosulfuron was observed by mixing adjuvant as well as plant extract in them.

These findings are similar to those of Cheema and Khaliq (2000); Cheema et al. (2003) who noted improvement in efficacy of herbicides for controlling weeds and getting higher yields in wheat and cotton crops by making their tank-mixed applications with sorghum plant extract. Rana and Pal (1997) reported that optimum weed management leads to increase in yields. An experiment conducted by Mitra and Bhattacharya (2005) suggested that use of butachlor in combination with manual removal of weed (35 days after sowing) resulted in higher mung bean yield, biomass and seed production of crop. Hassan (2003) also noted greater seed yield in contrast with control, with less weed infestation. The enhancement in efficacy of dicamba by mixing with 2% ammonium sulfate as adjuvant for controlling parthenium weed and achievement of same fodder yield of sorghum by its 25% reduced dose along with adjuvant as its full dose alone has been reported by Asif et al. (2019).

Conclusion

The results of the present study indicated that among two herbicides i.e. metribuzin and halosulfuron, the efficiency of halosulfuron was proved to be higher than metribuzin in terms of reducing parthenium dry weight and getting higher okra pod yield. Among two herbicides, halosulfuron showed greater enhancement in its efficacy by addition of adjuvant as compared to that shown by metribuzin. It can be concluded that halosulfuron dose can be reduced up to 25% if AES adjuvant was tank-mixed in it to obtain the same efficiency as with its full dose without compromising on okra yield.

Author Contribution Statement: All the authors mentioned in the manuscript have contributed for the study, statistical analysis and write-up of this manuscript.

Acknowledgments: The authors of this manuscript greatly acknowledged the University of Sargodha, Pakistan for providing the funding of this study under its ORIC funded research project number UOS/ORIC/2016/04.

References

Adejonwo, K. O., Ahmed, M. K., Lagoke, S. T. O. & Karikari, S. K. (1989). Effects of variety, nitrogen and period of weed interference on growth and yield of okra (*Abelmoshus esculentus*). *Nigeria Journal of Weed Science, 2,* 21-27.

Akhtar, K. P., Saleem, M. Y., Yousaf, S., Ullah, N., Rasool, G., & Sarwar, N. (2018). Occurrence, identification and transmission of the phytoplasma associated with tomato big bud disease and identification of its vector and weed host in Pakistan. *Archives of Phytopathology and Plant Protection*, *51*(7-8), 387-398.

Ali, H. H., Tanveer, A., Nadeem, M. A., Javaid, M. M., Kashif, M. S. & Chadhar, A. R. (2013). Allelopathic effects of *Rhynchosia capitata* on germination and seedling growth of mungbean. *Planta Daninha*, *31*, 501-509.

Asif, M., Tanveer, A., Safdar, M., Ali, A., & Ahmad, S. (2019). Effect of dicamba and adjuvant combination on parthenium control, fodder yield and yield components of forage sorghum (*Sorghum bicolor*). *Planta Daninha*, *37*, e019189215

Bellinder, R. R., Arsenovic, M., Shah, D. A. & Rauch, B. J. (2003). Effect of weed growth stage and adjuvant on the efficacy of fomesafen and bentazon. *Weed Science*, *51*, 1016-1021.

Belz, R. G., Reinhardt, C. F., Foxcroft, L. C. & Hurle, K. (2007). Residue allelopathy in *Parthenium hysterophorus* L. - Does parthenium play a leading role? *Crop Protection*, *26*, 237-245.

Borras, L., Slafer, G. A., & Otegui, M. E. (2004). Seed dry weight response to sourcesink manipulations in wheat, maize and soybean: A quantitative reappraisal. *Field Crop Research*. *86,* 131-146.

Cheema, Z. A., & Khaliq, A. (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agricultural Ecosystems & Environment, 79(2-3),* 105-112.

Cheema, Z. A., Khaliq, A., & Hussain, R. (2003). Reducing herbicide rate in combination with allelopathic sorgaab for weed control in cotton. *International Journal of Agriculture and Biology*, *5*(1), 1-6.

Copping, L. G., & Hewitt, H. G. (1998). *Chemistry and Mode of Action of Crop Protection Agents*. Royal Society of Chemistry.

Devendra, R., Umamahesh, V., Prasad, T. R., Prasad, T. G., Asha, S. T., & Ashok, A. (2004). Influence of surfactants on efficacy of different herbicides in control of *Cyperus rotundus* and *Oxalis latifolia*. *Current Science Bang, 86,* 1148-1151.

Everman, W. J., Burke, I. C., Allen, J. R., & Wilcut, J. W. (2007). Weed control and yield with glufosinate-resistant cotton weed management system. *Weed Technology, 21(3),* 695-701.

Government of Pakistan [GoP], (2019). Economic Survey of Pakistan 2018-19. Economic Adviser's Wing, Finance Division Government of Pakistan, Islamabad. P. 11.

Gemede, H. F., Ratta, N., Haki, G. D., Ashagrie, Z., & Beyene W. F. (2015). Nutritional quality and health benefits of okra (*Abelmochus esculentus*): A review. *International Journal of Nutrition and Food Sciences*, *4*, 208-215.

Hassan, G. (2003). Effect of zero tillage and herbicides on the weed density and yield of chickpea under rice-based conditions of D.I.Khan [Pakistan]. *Pakistan Journal of Weed Science Research*, *9*, 193-200.

Gupta, O. P. (1998). *Weed Management: Principles and Practices.* Agro Botanica, Bikaner, India.

Hess, F. D., & Foy, C. L. (2000). Interaction of surfactants with plant cuticles. *Weed Technology*, *14*, 807-813.

Javaid, M. M., Tanveer, A., Ahmad, R., Yaseen, M., & Khaliq, A. (2012). Optimizing activity of herbicides at reduced rate on *Emex spinosa* Campd. with adjuvants. *Planta Daninha*, *30(2),* 425-435.

Kammler, K. J., Walters, S. A., & Young, B. G. (2008). Halosulfuron tank mixtures and adjuvants for weed control in pumpkin production. *HortScience*, *43*(6), 1823-1825.

Kniss, A. R. (2017). Long-term trends in the intensity and relative toxicity of herbicide use. *Nature Communications, 8*(1), 1-7.

Little, T. M., & Hills, F. J. (1978). Agricultural experimentation: design and analysis (No. 630.72 L5)

McGraw-Hill, C. (2008). Statistix 8.1 (Analytical Software, Tallahassee, Florida). *Maurice/Thomas text*.

Mitra, S., & Bhattacharya, B. K. (2005). Water use and productivity of green gram (*Vigna radiate*) as influenced by spacing, mulching and weed control under rain-fed upland situation of Tripura. *Indian Journal of Agricultural Science*, *75(1),* 52–54.

Mohassel, M. H. R., Aliverdi, A., & Rahimi, S. (2011). Optimizing dosage of sethoxydim and fenoxaprop-p-ethyl with adjuvants to control wild oat. *Industrial Crops and Products*, *34*(3), 1583-1587.

Nadeem, M. A., Ahmad, R., Khalid, M., Naveed, M., Tanveer, A., & Ahmad, J. N. (2008). Growth and yield response of autumn planted maize (*Zea mays* L.) and its weeds to reduced doses of herbicide application in combination with urea. *Pakistan Journal of Botany*, *40*(2), 667-676.

Nonnecke, I. L. (1989). *Vegetable Production*. Springer Science & Business Media.

Rana, K. S., & Pal, M. (1997). Productivity and water use in pigeonpea (*Cajanus cajan*) based intercropping systems as affected by weed control in rain-fed conditions. *Indian Journal of Agronomy*, *42*(4), 576-80.

Richardson, R. J., Wilson, H. P., & Hines, T. E. (2007). Pre-emergence herbicide followed by trifloxysulfuron post-emergence in cotton. *Weed Technology, 21*(1), 1-6.

Safdar, M. E., Tanveer, A., Khaliq, A., & Naeem, M. S. (2014). Allelopathic action of parthenium and its rhizospheric soil on maize as influenced by growing conditions. *Planta Daninha*, *32*(2), 243-253.

Safdar, M. E., Tanveer, A., Khaliq, A., Ali, H. H., & Burgos, N. R. (2016). Exploring herbicidal potential of aqueous extracts of some herbaceous plants against parthenium weed. *Planta Daninha*, *34*(1), 109-116.

Santos, R., Pires, T. P., Mesquita, M. L. R., Correa, M. J. P., & Silva, M. R. M. (2020). Weed interference in okra crop in the organic system during the dry season. *Planta Daninha*, *38*, e020217201.

Shabbir, A., & Bajwa, R. (2007). Parthenium invasion in Pakistan - a threat still unrecognized. *Pakistan Journal of Botany*, *39*(7), 2519-2526.

Shi, B. (2016). *Invasive potential of the weed Parthenium hysterophorus: The role of allelopathy* (Doctoral dissertation). The University of Queensland, Brisbane, Australia.

Siemonsma, J. S., & Hamon, C. S. (2002). *Abelmoschus caillei* (A. Chev.) Stevels Record from Protabase. *PROTA* (Plant Resources of Tropical Africa/Resources Vegetables de l'Afrique tropicale), *Wageningen*, *4,* 8-14.

Singh, A., Singh, S., & Bhan, V. M. (1996). Crop weed competition in summer green gram. *Indian Journal of Agronomy*, *14*(4), 616-619.

Snelders, E., Van Der Lee, H. A., Kuijpers, J., Rijs, A. J. M., Varga, J., Samson, R. A., & Verweij, P. E. (2008). Emergence of azole resistance in Aspergillus fumigatus and spread of a single resistance mechanism. *PLoS Medicine*, *5*(11), 1629-1637.

Srivastav, S., Singh, P., Mishra, G., Jha, K. K., & Khosa, R. L. (2011). *Achyranthes aspera* - An important medicinal plant: A review. *Journal of Natural Products and Plant Resources*, *1*(1), 1-14.

Tanveer, A., Abbas, N., Safdar, M. E. & Ikram, R. M. (2017). Alkyl ether sulfate improves efficacy of herbicides against common goosefoot and field bindweed in wheat. *Planta Daninha*, *35*, e017164307.

Walia, U. S. (2003). *Weed Management*. Kalyani Publishers, New Delhi, India.

Yahia, E. M., Garcia-Solis, P., & Celis, M. E. M. (2019). Contribution of fruits and vegetables to human nutrition and health. In *Postharvest physiology and biochemistry of fruits and vegetables* (pp. 19-45). Woodhead Publishing.

Zareen, S., Khan, S., Ahmad, I., Haroon, M., Khan, I., & Ullah, I. (2017). Effect of various weed infested periods on okra under agro-climatic conditions of D.I. Khan, Pakistan. *Pakistan Journal of Weed Science Research*, *23*, 91-101.