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Article

Bioherbicidal Assessment of Aqueous Extracts of Mesquite (*Prosopis juliflora*) on Weeds Control and Growth, Yield and Quality of Wheat

*Avaliação do Efeito Bio-Herbicida de Extratos Aquosos da Algaroba (**Prosopis juliflora**) no Controle de Plantas Daninhas e no Crescimento, Rendimento e Qualidade do Trigo*

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ABSTRACT - Two-year field experiments were conducted to investigate the phytotoxicity of mesquite (*Prosopis juliflora*) on weed control and yield of wheat in 2013-14 and 2014-15. Mesquite aqueous extracts were prepared with 10, 20, 30 and 40% concentration of leaves, stems, and roots and were compared with tap water (control). These experiments were laid out in a completely randomized block design with four replications. All parameters (weed density, fresh weed biomass, dry weed biomass, chlorophyll content, leaf area index, leaf area duration, crop growth rate, net assimilation rate, plant height and number of tillers) were significantly reduced by applying the mesquite extracts. Among different concentrations, the maximum level (40%) of all three plant parts of mesquite subsequently reduced the study parameters including weed density, fresh and dry weed biomass, leaf area index, leaf area duration, crop growth rate, net assimilation rate, chlorophyll contents, plant height, number of tillers, spike length, number of grains, 1000-grain weight, grain yield, biological yield, harvest index and grain protein content. On the basis of the results, it is concluded that aqueous extracts of mesquite may contain many phytotoxic substances which can negatively affect the growth and yield of agricultural crops; therefore, wheat should not be planted close to mesquite.

Keywords: allelopathy, extract, weeds, wheat yield.

*RESUMO - Experimentos de campo foram conduzidos durante dois anos para investigar a fitotoxicidade da algaroba (**Prosopis juliflora**) no controle de plantas daninhas e no rendimento do trigo nos períodos de 2013-14 e 2014-15. Foram preparados extratos aquosos de folhas, caules e raízes de algaroba com concentração de 10, 20, 30 e 40%, os quais foram comparados com água corrente (controle). Utilizou-se o delineamento em blocos completamente casualizados com quatro repetições. Todos os parâmetros (densidade de plantas daninhas, biomassa fresca das plantas daninhas, biomassa seca das plantas daninhas, teor de clorofila, índice de área foliar, duração de área foliar, taxa de crescimento da cultura, taxa de assimilação líquida, altura da planta e número de perfilhos) sofreram redução significativa pela aplicação dos extratos de algaroba. Entre as diferentes concentrações, o nível máximo (40%) das três partes das plantas da algaroba reduziu os parâmetros do estudo, incluindo densidade das plantas daninhas, biomassa fresca e seca das plantas daninhas, índice de área foliar, duração da área foliar, taxa de crescimento da cultura, taxa de assimilação líquida, teores de clorofila, altura das plantas, número de perfilhos, comprimento da espiga, número de grãos, peso de mil grãos, rendimento de grãos, rendimento biológico, índice de*

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colheita e teor de proteína do grão. Com base nos resultados, conclui-se que os extratos aquosos da algaroba são capazes de conter muitas substâncias fitotóxicas que podem exercer efeito negativo no crescimento e no rendimento das culturas agrícolas. Por essa razão, o trigo não deve ser plantado perto da algaroba.

Palavras-chave: alelopatia, extrato, plantas daninhas, rendimento do trigo.

INTRODUCTION

Wheat (*Triticum aestivum*) is an important staple food crop of Pakistan, which is annually cultivated in an area of 9.04 million hectares with a total production of 25.3 million tons in Pakistan (Pakistan, 2014). Wheat demand is increasing every year as a result of increasing population and stagnant yield per unit area in the country. Wheat yield in Pakistan is two and half times lower as compared to advanced wheat-producing countries worldwide (Ullah et al., 2013). Weeds are the most serious yield-deteriorating factor that causes wheat yield loss of 28 billion rupees at the national level and 2 billion rupees at the provincial level in Khyber Pakhtunkhwa (Hassan et al., 2003). The most critical period of weed competition in wheat is 30 to 60 days after sowing. After 60 days, there is a lower economic benefit to eradicate weeds from the wheat crop (Ahmad and Shaikh, 2003). Shah (2006) reported that weeds cause 17-25% losses in wheat annually because of their competitive and allelopathic nature.

The term "allelopathy" means the interactions between plants which might lead to either stimulation or inhibition of crop growth (Ahmad et al., 2004). Different groups of plants, such as algae, lichens, crops and annuals and perennial weeds, have widely known allelopathic interactions (Uddin et al., 2007). Several phytotoxic substances causing germination and growth inhibition have been isolated from plant tissues and soils. These substances are known as allelochemicals. They are secondary waste products of main metabolic pathways of plants (Ashrafi et al., 2007). Allelochemicals belong to different categories of secondary compounds such as phenols, benzoic and cinamic acids derivates, flavonoids, tannins, coumarines, terpenoids, alkaloids and polyaccetylenes (Duke et al., 2000). These substances are released into the environment through leaching, decomposition of residues, root exudation, and volatilization. Allelochemicals such as coumarines and many alkaloids can inhibit cell division, cell wall formation, and water uptake. Flavonoids, tannins, quinines and many phenolic compounds inhibit germination, photosynthesis, respiration and protein synthesis (Einhellig, 2002). Therefore, it seems essential that the allelopathic compatibility of crops with trees should be checked before being introduced to an agroforestry system. One such plant which is reported to be both invasive and allelopathic (mostly in the detrimental sense) is mesquite, which can inhibit germination or growth of many plant species growing in the vicinity through the release of phytotoxic substances into the environment (Mehar, 2011).

Some exotic plants, when introduced to a new part of the world, have a greater impact than when in their native range (Callaway et al., 2012); mesquite, generally known as Kabuli Kikar, appears to be one of these species. It is one of the major invasive species in India and has also invaded other regions throughout the world including Saharan, Southern Africa, Middle East, Pakistan and Hawaii (Callaway et al., 2006). This large shrub has been naturalized in Pakistan since the 1950s. Mesquite can be tall compared to other leguminous shrubs and trees, but its canopies can have much stronger facilitative effects on neighbors than other leguminous tree species (Larrea-Alcazar et al., 2008).

The inhibitory effect of aqueous extracts of mesquite on the growth of some plants was reported by many workers (Al-Humaid and Warrag, 1999; Nakano et al., 2001). Indeed, the major phytotoxic substances in mesquite are the phenolics, which are not easily degraded by the microbes. Nakano et al. (2001, 2003) isolated L-Tryptophan from the freeze-dried leaves of mesquite, which inhibited the radicle growth of plants and they (Nakano et al., 2002) also isolated syringing and (-)- lariciresinol, which inhibited the growth and development of weeds. The aqueous extract of mesquite has a stimulatory effect at low concentrations (El-Keblawy and Al-Rawai, 2007). Such effect of mesquite on the associated flora depends on density and size of canopy, wherein larger individuals and greater densities have significantly greater negative impact on the associated plants. Inderjit et al. (2008) reported that the rhizosphere of mesquite had higher concentrations of total phenolics which inhibit the total biomass of weeds and crops. The amino acid Ltryptophan, isolated from foliage extracts of mesquite, has been shown to have allelopathic effect on weeds (Nakano et al., 2003).

Although all above-mentioned studies described the allopathic effect on morphological traits, hardly any study described the effect of the aqueous solution of mesquites on the physiological traits of wheat. Keeping all the facts, the present research was conducted to assess the extent of invasion caused by aqueous leaves, stem and root extracts of mesquite on weeds and growth parameters of wheat.

Experimental procedure

The experimental field was prepared by proper ploughings to ensure a fine seedbed. The wheat crop was sown in mid-November by a man driven single row hand drill. Standard plant to plant and row to row distance was maintained for optimum plant population per unit area. The net plot size was 1.5 m x 4.5 m. A recommended seed rate of 100 kg ha^{-1} of approved wheat variety "Gomal-8" was used. The experiment was laid out in a completely randomized block design with a factorial arrangement with four replications. A recommended fertilizer rate (150-120-90 NPK kg ha ^{1}) was applied in the form of Urea, Di-Ammonium Phosphate, and Potassium Sulphate, respectively, in all treatments. Half rate of nitrogen and all the P_2O_5 and K_2O rates were applied at the time of sowing while the remaining half of nitrogen was top dressed with the first irrigation. Fresh vegetative tissues of mesquite were collected from fields around the experimental site and were separated into leaf, stem and root parts, crushed and ground. Tap water was used as a control treatment. The ground plant material of mesquite was soaked in distilled water at different ratios given as under:

Preparation of extract

The different parts of leaves, stem and root of *P. juliflora* was soaked in distilled water at different ratios, given as:T_0 = Tap water, T_1 = 100 g leaves/liter of water for 72 h, T_2 = 200 g leaves/ liter of water for 72 h, T_3 = 300 g leaves/liter of water for 72 h, T_4 = 400 g leaves/liter of water for 72 h, T_5 = 100 g stem/liter of water for 72 h, T_6 = 200 g stem/liter of water for 72 h, T_7 = 300 g stem/liter of water for 72 h, T_8 = 400 g stem/liter of water for 72 h, T_9 = 100 g roots/liter of water for 72 h, T_{10} = 200 g roots/liter of water for 72 h, T_{11} = 300 g roots/liter of water for 72 h and T_{12} = 400 g roots/liter of water for 72 h of *P. juliflora*. The aqueous extracts were collected in bottles and labeled after filtering through 10 and 60 mesh sieves. Thirteen trays, replicated 4 times, filled with sand, silt and clay (1:1:1) were taken for sowing 100 wheat seeds in each tray viz. Tray-1: T0: Tap water (check) and Tray-2 to 13: Treatments T1-T12 *(P. juliflora).* All treatments were applied 5 and 10 days after sowing (DAS). Water was applied on a daily/alternate basis to keep soil moist/field capacity. During the course of experimentation, observations were recorded for germination percentage (%), germination energy (%), germination rate, mean germination time, speed of germination, root and shoot length (cm), fresh and dry root weight (g), fresh and dry shoot weight (g), root: shoot ratio and chlorophyll content (mg cm^{-2}). Aqueous extracts of leaf, stem and roots of *P. juliflora* was applied at 30 and 60 days after sowing (DAS).

Detail of treatments

T_0 = Tap water (check)

T_1 = 10% concentration of leaf aqueous extract of *P. juliflora*

T_2 = 20% concentration of leaf aqueous extract of *P. juliflora*

T_3 = 30% concentration of leaf aqueous extract of *P. juliflora*

T_4 = 40% concentration of leaf aqueous extract of *P. juliflora*

T_5 = 10% concentration of shoot aqueous extract of *P. juliflora*

T_6 = 20% concentration of shoot aqueous extract of *P. juliflora*

T_7 = 30% concentration of shoot aqueous extract of *P. juliflora*

T_8 = 40% concentration of shoot aqueous extract of *P. juliflora*

T_9 = 10% concentration of root aqueous extract of *P. juliflora*

T_{10} = 20% concentration of root aqueous extract of *P. juliflora*

T_{11} = 30% concentration of root aqueous extract of *P. juliflora*

T_{12} = 40% concentration of root aqueous extract of *P. juliflora*

Experimental procedure

The aqueous extracts of leaf, stem, and roots of *P. juliflora* were applied 30 and 60 days after sowing (DAS).

Growth parameters

Leaf area index (LAI)

Plant samples were taken from a randomly selected 0.25 m^2 area from each plot with 10 days interval starting from 35 days up to 95 days after sowing. Leaves were removed and weighed on an electric balance. The weight was recorded and a sub sample of 5 g was taken from each leaf lot. Leaf area was measured with a digital leaf area meter (JVC TK-5310) and leaf area index was calculated by taking into account the leaf area/ground surface area ratio.

Seasonal leaf area duration (LAD) (days)

Leaf area duration was calculated at fortnight interval by the following formula (Reddy, 2004):

$$LAD = \frac{(LA_2 + LAI_1) \times (t_2 - t_1)}{2}$$

where LAI_2 and LAI_1 stand for the leaf area indices at times t_2 and t_1, respectively.

Crop growth rate (CGR) (g m^{-2} d^{-1})

For estimation of crop growth rate, plants were harvested in a unit area of 0.25 m^2 and oven dried to constant dry weight. Crop growth rate was calculated fortnightly by using the formula given below (Reddy, 2004).

$$CGR = (W_2 - W_1) / (T_2 - T_1)$$

were W_1 = oven dried weight at first sampling; W_2 = oven dried weight at second sampling; T_1 = time of first sampling; T_2 = time of second sampling.

Net assimilation rate (NAR) (g m^{-2} d^{-1})

The following formula was used to determine NAR.

$$NAR = TDM/LAD$$

where TDM = Total dry matter accumulation (W_2 - W_1); LAD = (LAI_1 + LAI_2) x (T_2 – T_1)/2.

Number of tillers (m^{-2})

Number of fertile tillers in each plot was determined by counting them from an area of one square meter (1 m^2) at maturity.

Plant height at maturity (cm)

Ten plants were selected at random from each plot and individual plant height was measured from the soil surface to the tip of the ear, with the help of a meter rod; then, the average was calculated.

Spike length (cm)

Ten spikes were selected at random from each plot and their length was measured with the help of a meter rod and then average spike length was calculated.

Number of grains per spike

Grains from the ten randomly selected spikes were threshed and counted separately. Then, average number of grains per spike was calculated.

1,000 grain weight (g)

Thousand grains were counted from the grain sample of each plot and weighed on an electric balance.

Biological yield (ton ha^{-1})

In each plot, the crop was harvested and tied into bundles. Then, it was weighed using an electric balance.

Grain yield (ton ha^{-1})

Grain yield from each plot was recorded after threshing the crop.

Harvest index (%)

It was calculated by the following formula, as given by Hunt (1978).

$$H.I.=\frac{Economic\ yield}{Biological\ yield}\times 100$$

Chlorophyll contents (mg g^{-1})

The chlorophylls *a* and *b* were determined according to the method of Arnon (1949). Fresh leaves (0.5 g) were extracted overnight with 5 mL 80% acetone at 0-4 °C. The extracts were centrifuged at 10,000 x *g* for 5 min. Absorbance of the supernatant was read at 645 and 663 nm using a spectrophotometer (Hitachi-U2001, Tokyo, Japan). The chlorophylls *a* and *b* were calculated by the following formulae:

Chl a = [12.7 (OD 663) -2.69 (OD 645)] x V/1000 x W

Chl b = [22.9 (OD 645) -4.68 (OD 663)] x V/1000 x W

were V = volume of the extract (mL); W = weight of the fresh leaf tissue (g).

Statistical Analysis

Data collected for all the traits were statistically analyzed for analysis of variance (Steel et al., 1997) by Statistix 8.1 (Analytical Software, 2003) considering a completely randomized block design. Means were compared by Tukey's HSD test.

RESULTS AND DISCUSSION

Weed density

Data shown in Table 1 indicated that weed density recorded at 30 DAS was non-significantly affected by different aqueous extract concentrations of three plant parts of mesquite in 2013-14 and 2014-15. However, these aqueous extracts (leaves, stems, and roots) significantly reduced weed density at 60 DAS during both cropping seasons. Minimum weed density (39.00 and 35.25 m^{-2}) was recorded by applying maximum concentration (40%) of the aqueous leaf extract as compared to the untreated control, whose maximum weed density (57.25 and 42.25 m^{-2}) was recorded at 60 DAS in the two experimental years. Likewise, the highest concentration (40%) of aqueous stem and root extract showed minimum weed density (42.75 and 36.00 m^{-2} and 44 and 37 m^{-2}, respectively) in the two cropping years.

Fresh weed biomass

The data in Table 1 showed that there were non-significant differences in fresh weed biomass at 30 DAS in both sowing seasons. However, these were significantly reduced by applying different concentrations of aqueous extracts of leaves, stems and roots of mesquite at 60 DAS. T3 (40%) of aqueous extracts of leaves, stems and roots correspondingly reduced fresh and dry weed biomass (18.25 and 14.00 g m^{-2}; 20.74 and 14.93 g m^{-2} and 21.15 and 16.49 g m^{-2}) at 60 days after sowing, respectively, as compared to the untreated control, which had maximum fresh weed biomass (24.05 and 19.85 g m^{-2}) at 60 days after sowing and where no extract was used in 2013-14 and 2014-15.

Dry weed biomass

Information about dry weed biomass is given in Table 1, which showed that the application of different aqueous extracts of three plant parts significantly reduced relative weed density at

Table 1 - Phytotoxic effect of mesquite (*Prosopis juliflora*) on weed density, fresh weed biomass and dry weed biomass of wheat in 2013-14 and 2014-15

Treatment	Weed density m^{-2}				Fresh weed biomass g m^{-2}				Dry weed biomass g m^{-2}			
	2013-14		2014-15		2013-14		2014-15		2013-14		2014-15	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_0 = Tap water	19.58 ^{NS}	57.25 a	16	42.25 a	8.72 ^{NS}	24.05 a	6.21	19.85 a	3.68 ^{NS}	9.62 a	2.36	7.96 a
T_1 = 100 g leaves	20.75	50.00 bc	17	41.00 abc	9.00	22.84 bcd	6.25	18.59 bcd	3.94	9.13 bcd	2.55	7.46 bcd
T_2 = 200 g leaves	18.75	48.25 bcd	15	39.25 cde	8.66	20.97 e	5.91	16.72 e	3.80	8.39 e	2.41	6.78 e
T_3 = 300 g leaves	20.00	46.50 de	16.25	37.5 def	8.90	19.18 f	6.15	16.90 e	3.58	7.67 f	2.19	6.71 e
T_4 = 400 g leaves	20.75	39.00 g	17.2	35.25 f	8.56	18.25 g	5.81	14.00 g	3.99	7.30 g	2.6	5.62 g
T_5 = 100 g stem	18.50	49.00 bcd	14.75	40.0 bcd	7.91	22.98 bc	5.16	18.73 bc	3.80	9.19 bc	2.45	7.52 bc
T_6 = 200 g stem	19.25	47.50 cd	15.5	38.5 def	7.46	22.11 d	4.71	17.86 d	3.72	8.84 d	2.33	7.17 d
T_7 = 300 g stem	17.25	47.00 d	16.25	38.0 def	8.10	20.39 e	5.35	14.93 f	3.98	8.15 e	2.59	6.62 e
T_8 = 400 g stem	17.50	42.75 f	13.75	36.00 ef	7.25	20.74 e	4.5	16.14 e	3.82	8.29 e	2.43	5.99 f
T_9 = 100 g roots	19.00	50.75 b	15.25	41.75 ab	7.87	23.43 ab	5.12	19.18 ab	3.97	9.37 ab	2.58	7.69 ab
T_{10} = 200 g roots	17.75	49.75 bc	14	40.75 abc	7.38	22.94 bcd	4.63	18.69 bc	3.81	9.17 bcd	2.42	7.50 bc
T_{11} = 300 g roots	19.50	47.50 cd	15.75	38.55 def	8.73	22.22 cd	5.98	17.97 cd	3.82	8.89 cd	2.43	7.21 cd
T_{12} = 400 g roots	18.00	44.00 ef	14.25	37.0 def	8.06	21.15 e	5.31	16.49 e	3.92	8.46 e	2.53	6.48 e
$LSD_{0.05}$	9.803	2.701	6.945	3.61	2.341	0.842	2.277	0.815	0.771	0.336	0.743	0.3263

Means followed by a different letter(s) in a column are statistically significant at 5% level of probability.

60 DAS in both cropping years. Dry weed biomass at 60 DAS in 2013-14 and 2014-15 was significantly reduced with increased concentrations of aqueous extract of leaves, stem and root of mesquite when compared with the control. There was significantly lower dry weed biomass (7.30 and 5.62 g m^{-2}) with the application of the highest concentration (40%) of the aqueous leaf extract over the control (Tap water), which showed higher dry weed biomass (9.62 and 7.96 g m^{-2}) in the two years. Similarly, the highest concentration (40%) of the aqueous extracts of stems and root resulted in the lowest dry weed biomass (8.29 and 8.46 g m^{2}) in the first year while the lowest grain yield (5.99 and 6.48 g m^{-2}) was found in the second year, respectively.

Chlorophyll content

Data shown in Table 2 revealed that chlorophyll content was significantly reduced with increased concentrations of aqueous extracts of leaves, stems and root of mesquite when compared with tap water in the two experimental years. In 2013-14, there was maximum chlorophyll content (36.32, 42.30, 50.95, 56.37 and 51.25 µg cm^{-2}) at 7, 9, 11, 13 and 15 weeks after sowing (WAS), respectively, in the control. There was a corresponding decrease in chlorophyll content with increased aqueous extracts of all three plant parts of mesquite. Treatment T3 (40%) of aqueous leaves had minimum chlorophyll content (32.12, 37.65, 45.65, 50.22 and 46.75 µg cm^{-2}) at all time intervals. Chlorophyll content was significantly reduced (32.42, 39.45, 46.35, 54.45 and 49.52 µg cm^{-2}) with treatment T8 (40%) of the aqueous stem extract over the control. Similar results (34.02, 39.65, 48.50, 50.50 and 47.20 µg cm^{-2}) were found at all time intervals by applying treatment T12 (40%) of the aqueous root extract when compared with the control. Similarly, in 2014-15, there was also a decreasing trend was also recorded over the control treatment. Likewise, chlorophyll content was later reduced due to increase in the aqueous stem and root extract concentrations. The highest concentration (400 g) of the aqueous stem and root extracts produced the lowest chlorophyll content as compared to the untreated plot.

Leaf area index (m^{-2}) at 49 and 98 DAS

Table 2 shows the data on leaf area index at 49 days after sowing. The results showed that different concentrations of the aqueous extract of all three plant parts had a significant effect on leaf area index at 49 DAS in 2013-14 and 2014-15. In the control, the highest leaf area index (0.380 and 0386) was recorded at 49 days after sowing in both cropping years while the lowest LAI (0.261 and 0.264 m^{-2}) was found with maximum concentration (40%) of the aqueous leaf extract of mesquite in 2013-14 and 2014-15.

Table 2 **-** Phytotoxic effect of mesquite (*Prosopis juliflora*) on chlorophyll content and LAI of wheat in 2013-14 and 2014-15

Treatment	Chlorophyll Content (µ g cm^2)								Leaf area index (49 DAS)		Leaf area index (98 DAS)	
	2013-14				2014-15				2013-14	2014-15	2013-14	2014-15
	7 WAS	9 WAS	11 WAS	13 WAS	7 WAS	9 WAS	11 WAS	13 WAS				
T_0 = Tap water	36.32 a	42.30 a	50.95 a	56.37 a	38.49 a	43.89 a	52.35 a	57.74 a	0.380 a	0.386 a	3.892 a	3.897 a
T_1 = 100 g leaves	33.62 de	39.65 e	47.70 ef	53.52 d	36.19 cd	41.32 e	49.90 cd	55.82 bc	0.341 b	0.346 b	3.511 c	3.516 c
T_2 = 200 g leaves	33.55 de	39.42 ef	47.37 f	53.30 de	35.79 de	41.24 e	49.10 ef	54.89 d	0.31c	0.320 c	3.30 d	3.313 d
T_3 = 300 g leaves	32.72 fg	38.75 f	46.42 g	52.77 e	35.71 de	41.04 ef	48.78 f	53.39 f	0.282 d	0.287 d	3.120 f	3.125 f
T_4 = 400 g leaves	32.12 h	37.65 g	45.65 h	50.22 h	34.29 h	39.24 g	47.05 h	51.59 h	0.261 e	0.264 e	2.94 g	2.952 g
T_5 = 100 g stem	34.55 c	40.70 c	48.62 cd	54.32 c	36.71 c	42.29 c	50.03 cd	56.29 b	0.373 a	0.376 a	3.723 b	3.730 b
T_6 = 200 g stem	34.22 c	40.42 cd	48.35 de	54.92 b	36.39 c	42.02 cd	49.75 de	55.69 c	0.340 b	0.345 b	3.521 c	3.532 c
T_7 = 300 g stem	33.17 ef	39.90 de	47.52 f	54.52 bc	35.34 ef	41.49 de	48.93 f	53.37 f	0.31 c	0.320 c	3.332 d	3.341 d
T_8 = 400 g stem	32.42 gh	39.45 ef	46.35 gh	54.45 bc	34.59 gh	40.34 f	47.75 gh	51.87 h	0.28 d	0.291 d	3.194 e	3.200 e
T_9 = 100 g roots	35.95 ab	41.67 ab	49.62 b	52.02 f	38.11 ab	43.27 ab	51.03 b	55.89 bc	0.37 a	0.380 a	3.721 b	3.726 b
T_{10} = 200 g roots	35.40 b	40.97 bc	49.35 b	52.00 f	37.56 b	42.57 bc	50.75 b	54.67 de	0.341 b	0.344 b	3.525 c	3.530 c
T_{11} = 300 g roots	34.35 c	40.57 cd	49.07 bc	51.37 g	36.51 c	42.17 cd	50.48 bc	54.14 e	0.314 c	0.315 c	3.340 d	3.345 d
T_{12} = 400 g roots	34.02 cd	39.65 e	48.50 cd	50.50 h	34.89 fg	41.02 ef	47.83 g	52.74 g	0.283 d	0.287 d	3.123 f	3.128 f
$LSD_{0.05}$	0.550	0.729	0.717	0.542	0.55	0.729	0.717	0.542	0.017	0.0172	0.055	0.0559

Means followed by a different letter(s) in a column are statistically significant at 5% level of probability.

The data shown in Table 2 revealed that the application of different concentrations of the aqueous extracts of leaves, stem and the root of mesquite significantly reduced leaf area index at 98 days after sowing of wheat as compared to the control in 2013-14 and 2014-15. There was a linear increase in leaf area index from one growth phase to another. Maximum leaf area index (3.89 m^{-2} in 2013-14 and 3.897 m^{-2} in 2014-15) was recorded in the control at 98 days after sowing. Among different concentrations, maximum level (40%) of aqueous extracts of leaves, stems and roots produced minimum leaf area index at 98 DAS in both cropping years.

Leaf area duration (m^{-2}) at 49 and 98 DAS

Leaf area index and leaf area duration were directly proportional to each other: the higher the leaf area index, the higher the leaf area duration and vice-versa. Data shown in Table 3 revealed that leaf area duration was subsequently reduced with increasing extract concentration at 49 DAS in both sowing seasons. Maximum leaf area duration (2.68 and 2.70 m^{-2}) was noted in the control at 49 days after sowing in 2013-14 and 2014-15. Among different concentrations, the lowest leaf area duration (1.83 and 1.85 m^{-2}) was recorded at 49 DAS with the highest concentration (40%) of the aqueous leaf extract in both cropping years. Similarly, after application of the maximum concentration (40%) of the aqueous extracts of the stem and root of mesquite, there was minimum leaf area duration (2.02 and 2.03) and (1.99 and 2.00) at 49 DAS, respectively, in 2013-14 and 2014-15, as compared to the control.

The data shown in Table 3 revealed that leaf area duration at 98 DAS was significantly reduced in both years with a corresponding increase in the quantity of aqueous extracts obtained from the leaves, stem and roots of mesquite. Compared to the untreated plants, there was maximum reduction in LAD at 98 DAS (41.26 and 41.33 m^{-2}) where the highest concentration (40%) of leaf extract was applied in both cropping years. There was a similar trend among the plants which were treated with stem and root extracts. The maximum quantity of stem and root extracts (40%) caused a maximum reduction (44.73 and 43.72 m^{2}) in leaf area duration at 98 DAS in 2013-14 while in the following year it turned out to be 44.80, and 43.79 for stem and root extracts, respectively. By contrast, there was maximum LAD at 98 DAS (54.49 and 54.56 m^{-2}) in the control where no extract was used.

Crop growth rate ($g\ m^{-2}\ day^{-1}$)

Crop growth rate plays an important role in crop production and it is highly manipulated by crop variety, temperature, radiation and supply of nutrients. Information about crop growth rate

Table 3 - Phytotoxic effect of mesquite (*Prosopis juliflora*) on leaf area duration, CGR, NAR, PH, and number of tillers of wheat in 2013-14 and 2014-15

Treatment	Leaf area duration (49 DAS)		Leaf area duration (98 DAS)		Crop growth rate ($g\ m^{-2}\ day^{-1}$)		Net assimilation rate ($g\ g^{-1} day^{-1}$)		Plant height (cm)		No. of Tillers (m^2)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
T_0 = Tap water	2.68 a	2.705 a	54.49 a	54.56 a	27.76 a	30.27 a	3.726 a	4.02 a	101.19 a	101.34 a	402.0 a	415.7 a
T_1 = 100 g leaves	2.40 b	2.426 b	49.16 c	49.23 c	23.99 fg	26.70 fg	2.879 de	3.15 ef	96.97 cd	97.39 bc	386.0 de	398.5 bc
T_2 = 200 g leaves	2.22 c	2.245 c	46.31 d	46.38 d	22.76 h	26.50 fg	2.586 gh	2.92 h	93.08 fg	96.18 de	380.2 fg	394.7 de
T_3 = 300 g leaves	1.99 d	2.011 d	43.69 f	43.76 f	21.94 i	24.44 i	2.425 h	2.67 i	91.62 gh	93.11 g	374.5 h	389.2 gh
T_4 = 400 g leaves	1.83 e	1.854 e	41.26 g	41.33 g	20.71 j	23.21 j	2.177 i	2.41 j	89.35 i	91.57 h	369.0 i	386.5 h
T_5 = 100 g stem	2.61 a	2.635 a	52.16 b	52.23 b	25.50 d	28.00 d	3.200 c	3.48 c	99.07 b	97.50 bc	394.0 b	397.7 cd
T_6 = 200 g stem	2.40 b	2.419 b	49.39 c	49.46 c	25.14 de	27.64 de	3.036 cd	3.31 de	96.92 cd	96.62 de	388.0 cd	396.7 de
T_7 = 300 g stem	2.22 c	2.243 c	46.70 d	46.77 d	24.50 ef	27.00 ef	2.839 ef	3.10 fg	94.57 ef	95.78 ef	383.7 ef	394.7 de
T_8 = 400 g stem	2.02 d	2.037 d	44.73 e	44.80 e	23.78 g	26.28 g	2.704 fg	2.96 gh	91.31 h	93.10 g	379.0 g	390.2 fg
T_9 = 100 g roots	2.64 a	2.662 a	52.10 b	52.17 b	27.03 b	29.54 b	3.381 b	3.66 b	98.60 b	97.73 b	391.5 bc	400.0 b
T_{10} = 200 g roots	2.39 b	2.413 b	49.35 c	49.42 c	26.28 c	28.79 c	3.188 c	3.46 cd	97.81 bc	97.12 cd	389.2 cd	396.0 de
T_{11} = 300 g roots	2.18 c	2.205 c	46.76 d	46.83 d	25.45 d	27.95 d	2.983 de	3.24 ef	95.98 de	96.04 ef	387.5 de	393.2 ef
T_{12} = 400 g roots	1.99 d	2.009 d	43.72 f	43.79 f	24.20 fg	25.26 h	2.673 fg	2.84 hi	94.52 ef	95.09 f	385.5 de	389.2 gh
$LSD_{0.05}$	0.120	0.1207	0.782	0.782	0.702	0.7029	0.166	0.174	1.544	1.0649	4.006	3.5618

Means followed by different letters in a column are statistically significant at 5% level of probability.

is shown in Table 3. Crop growth rate was significantly reduced with an increase in extract concentration of leaves, stems, and roots of mesquite as compared to the untreated control in 2013-14 and 2014-15. Maximum crop growth rate (27.76 and 30.27 g m^{-2} day^{-1}) was recorded in the control in both sowing seasons, while the highest concentration (40%) of the aqueous leaf extract considerably reduced crop growth rate (20.71 and 23.21 g m^{-2} day^{-1}) in both cropping seasons. A similar reduction in crop growth rate (23.78 and 26.28 g m^{-2} day^{-1}) and (24.20 and 25.26 g m^{-2} day^{-1}) was noted by the application of the highest concentration (40%) of the aqueous stem and root extracts, respectively, in 2013-14 and 2014-15.

Net assimilation rate (g $g^{-1}$$day^{-1}$)

Net assimilation rate corresponds to the efficiency of photosynthesis in an overall sense and in connection with relative growth rate (Reddy, 2004). It is affected by different factors such as temperature, CO_2, water, leaf age, minerals, chlorophyll, and genotype. Table 3 shows the data on net assimilation rate in 2013-14 and 2014-15. The data revealed that net assimilation rate was significantly influenced by phytotoxicity of mesquite. However, minimum NAR (2.17 and 2.41 g g^{1} day^{-1}) was noted with maximum concentration (40%) of the aqueous leaf extract as compared to the control, which had maximum net assimilation rate (3.72 and 4.02 g g^{-1} day^{-1}) in the two cropping seasons. A similar result was also found by applying the maximum amount of extracts from the stem and root of mesquite (Table 3). Minimum net assimilation rate (2.704 and 2.673 g g^{1} day^{-1}) was recorded with the highest level of the stem and root extract in 2013-14 while in 2014-15 it turned out to be 2.96 and 2.84 g g^{-1} day^{-1}, respectively.

Plant height at maturity (cm)

The data given in Table 3 revealed that the application of different concentrations of aqueous extracts of leaves, stem and the root of mesquite significantly reduced plant height of wheat as compared to the control in two cropping seasons. Maximum plant height (101.19 and 101.34 cm) was noted in the control where no extract was used in the two consecutive years. Among different concentrations, the leaf extract (40%) produced short-statured plants (89.35 and 91.57 cm). Similarly, maximum concentration (40%) of the aqueous stem and root extracts produced minimum plant height (91.31 and 93.10 cm, and 94.52 and 95.09 cm, respectively) as compared to the control in 2013-14 and 2014-15.

Number of tillers (m^{-2})

The data given in Table 3 indicated that number of tillers was significantly affected by the application of different concentrations of the aqueous leaf, stem and root extracts of mesquite. The use of increasing concentrations of all three plant parts of mesquite significantly reduced the number of tillers compared to the control. The maximum number of tillers (402 and 415.7 m^{-2}) was found in the control while the highest concentration (40%) of all three plant parts – leaves, stem and root of mesquite – resulted in the lowest number of tillers (369 and 386.5 m^{-2}), (379 and 390.2 m^{-2}) and (385.5 and 389.2 m^{-2}), respectively, than the untreated control in both experimental years.

Spike length (cm)

The data given in Table 4 showed significant variations in spike length when different concentrations of three plant parts of mesquite were applied. In both experimental years, the lowest spike length (11.04 and 11.12 cm) was recorded in the control where no extract was used. There was a substantial decrease in spike length as a result of the application of the aqueous leaf, stem, and root extracts. Maximum concentration (40%) of extracts obtained from the aforementioned plant parts reduced spike length. It was reduced to 9.74 cm in 2013-14 and 9.48 cm in 2014-15 with the highest quantity of leaf extract as compared to the control (tap water). There was a similar effect (10.10 and 10.08 cm, and 10.16 and 10.43 cm) with the application of higher stem and root extract concentrations, respectively, in both consecutive years.

Table 4 - Phytotoxic effect of mesquite (*Prosopis juliflora*) on spike length, number of grains, 1000 grain weight, grain yield, biological yield and harvest index of wheat in 2013-14 and 2014-15

Treatment	Spike length (cm)		Number of grains ($spike^{-1}$)		1,000-grain weight (g)		Grain yield (kg ha^{-1})		Biological yield (kg ha^{-1})		Harvest index (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
T_0 = Tap water	11.04 a	11.12 a	69.25 a	70.17 a	43.72 a	43.92	4120.0 a	4165.0 a	15075 a	15075 a	27.34 h	29.20 a
T_1 = 100 g leaves	10.36 de	10.48 cde	66.00 bcd	64.97 cd	42.67 de	42.24	4045.0 d	4042.5 c	14550 bc	14575 bc	27.81 g	27.73 fg
T_2 = 200 g leaves	10.27 e	9.70 fg	62.75 ef	63.53 fg	42.52 def	42.19	3965.0 fg	3992.5 d	14075 e	14250 d	28.18 efg	28.02 fg
T_3 = 300 g leaves	9.89 fg	9.66 g	62.00 fg	59.47 h	42.22 g	42.02	3930.0 h	3942.5 ef	13525 f	13775 f	29.08 b	28.64 bc
T_4 = 400 g leaves	9.74 g	9.48 g	57.75 h	56.91 i	41.85 h	41.12	3882.5 i	3915.0 g	12900 g	13425 g	30.13 a	27.63 g
T_5 = 100 g stem	10.59 cd	10.72 abc	67.50 ab	68.17 ab	42.72 cd	43.04	4107.5 abc	4082.5 b	14725 b	14450 c	27.99f g	28.26 de
T_6 = 200 g stem	10.33 de	10.51 bcd	65.50 cd	64.20 de	42.65 def	42.87	4082.5 bc	4040.0 c	14475 cd	14050 e	28.21 efg	28.76 b
T_7 = 300 g stem	10.19 e	10.22 de	63.25 ef	62.51 fg	42.40 efg	42.29	4005.0 e	3962.5 e	14000 e	13750 f	28.61 cd	28.83 ab
T_8 = 400 g stem	10.10 ef	10.08 ef	60.25 g	61.75 g	42.37 fg	41.79	3947.5 gh	3932.5 fg	13675 f	13475 g	28.87 bc	29.18 a
T_9 = 100 g roots	10.92 ab	10.85 ab	66.25 bc	66.71 bc	43.05 b	42.92	4115.0 ab	4097.5 b	14575 bc	14725 b	28.24 def	27.83 fg
T_{10} = 200 g roots	10.74 bc	10.84 abc	64.25 de	64.92 cd	42.97 bc	42.72	4080.0 c	4055.0 c	14300 d	14425 cd	28.54 cde	28.11 ef
T_{11} = 300 g roots	10.25 e	10.67 bc	62.75 ef	64.13 ef	42.55 def	42.14	4017.5 de	3945.0 ef	13975 e	13975 e	28.76 bc	28.23 de
T_{12} = 400 g roots	10.16 ef	10.43 cde	60.75 g	61.97 fg	42.47 efg	42.19	3992.5 ef	3940.0 fg	13725 f	13775 f	29.10 b	28.61 cd
$LSD_{0.05}$	0.2843	0.413	1.789	2.1907	0.289	6.4973	32.57	25.464	204.11	199.2	0.426	0.3951

Means followed by different letters in a column are statistically significant at 5% level of probability.

Number of grains ($spike^{-1}$)

The results in Table 4 showed that the aqueous extract of leaves, stems and root of mesquite negatively affected the number of grains per spike. All the treatments showed a significant reduction in the number of grains per spike in both years (2013-14 and 2014-15) as compared to the control (tap water). The maximum number of grains per spike (69.25 and 70.17) was noted in the control, where no extract was used in the two cropping seasons. Among the different concentrations applied, the aqueous leaf extract (40%) showed maximum reduction in number of grains per spike in both years (57.75 and 56.91). A similar trend was also noted with increasing concentration of the aqueous stem and root extracts, which significantly reduced (60.25 and 61.75; 60.75 and 61.97) the number of grains per spike in both experimental years.

1,000 grain weight (g)

Thousand seed weight is a genetic character of a particular genotype, which is seldom changed or affected by environmental factors. The data in Table 4 indicated that different concentrations of aqueous extracts of mesquite plant parts had significantly reduced grain weight when compared with control in the two cropping years. The lowest grain weight was recorded (41.85 and 41.12 g) with the highest concentration (40%) of the aqueous leaf extract over the control (tap water), which showed maximum grain weight (43.72 and 43.92 g) in the two years. Similarly, the highest concentration (40%) of the aqueous stem and root extracts led to significant minimum grain weight (42.72, and 42.47 g) in the first cropping year, while the weights of 41.79 and 42.19 g, respectively, were noted in the second year.

Grain yield (kg ha^{-1})

Organic matter accumulation by green plants depends on photosynthesis and conversion of light energy into chemical energy, which represents crop productivity (Reddy, 2004). The data shown in Table 4 revealed significant variation in grain yield by the application of different aqueous extract concentrations of mesquite plant parts. Grain yield in 2013-14 and 2014-15 was significantly reduced with the increasing absorption of the aqueous leaf, stem and root extracts of mesquite when compared with the control. Significantly lower grain yield (3882.5 and 3915.0 kg ha^{-1}) was recorded with the application of the highest concentration (40%) of the aqueous leaf extract over the control (tap water), which showed the highest grain yield (4120.0 and 4165.0 kg ha^{-1}) in the two years. Similarly, the highest concentration (40%) of the aqueous stem and root extracts resulted in the lowest grain yield (3947.5 and 3992.5 kg ha^{-1}) in the first year while minimum grain yield (3932.5 and 3940.0 kg ha^{-1}, respectively) was noted in the second year.

Biological yield (kg ha^{-1})

Biological yield is composed of plant height and number of tillers per unit area while the latter highly influences biomass production of a particular crop. The data in Table 4 indicated that biological yield was significantly affected by using aqueous leaf, stem and root extracts of mesquite. All the study treatments showed a corresponding reduction in biological yield over the control (tap water). However, among different concentrations of the aqueous leaf extract, there was a maximum and subsequent reduction in biological yield (12,900 and 13,425 kg ha^{-1}) when using the highest concentration (40%) as compared to the control in 2013-14 and 2014-15.

Harvest index (%)

To express the yield of a particular crop in absolute terms, harvest index is calculated. It represents both the economic and biological yield in percentage. Application of different concentrations of mesquite extracts showed a significant decrease in harvest index (Table 4). In 2013-14, for maximum leaf extract (40%), the maximum harvest index of wheat (30.13%) was recorded as compared to the control (13.50%), while the maximum harvest index (27.63%) was noted as compared to the untreated control, which was 29.20% in 2014-15. The results for the stem and root extracts followed the same trend as leaf extract; as the harvest index was increased with icreasing concentration of the aqueous extracts of stem and root. Maximum harvest index was (28.87 and 29.18 %), and (29.10 and 28.61 %) for stem and root extrcats at the maximum level of concentration (40%) in both experimental years, respectively.

The allelopathic potential of chemicals is present in mesquite tissues, including leaves, stems, flowers, roots, seeds and buds. Under appropriate conditions, these chemicals may be released into the environment (generally the rhizosphere) in sufficient quantities to affect neighboring plants (Khan et al., 2005). In this study, different concentrations of the aqueous leaf, stem and root extracts of mesquite were applied on weeds and wheat crop. Weeds parameters were significantly reduced by applying different concentrations of all three plant parts of mesquite as compared to the untreated control. Maximum weed density and relative density at 60 days after sowing were noted in the control because no extract was applied, whereas the use of the maximum concentration (40%) of the aqueous leaf, stem, and root extracts suppressed the growth of weeds considerably. Several reports revealed the phytotoxic effects of various plant extracts e.g. *E. camaldulensis*, *P. julifera,* and *A. nilotica*, which significantly affected germination and growth of weed species (Khan et al., 2004). Similarly, maximum fresh and dry weed biomass values were recorded in the untreated control because no aqueous extract was applied and all the germinated weeds remained unchecked. Fresh and dry weed biomass was significantly reduced by applying different concentrations of all three plant parts of mesquite, as mesquite produces allelochemicals which can be used to control weeds when applied as bioherbicides in the form of aqueous extracts (Akhtar et al., 2014).

Leaf area subsequently increases to its maximum value after crop emergence (Reddy, 2004). In this study, leaf area index was correspondingly reduced by increasing the concentration of aqueous extracts of mesquite. The application of the highest concentration (40%) of all three plant parts significantly reduced leaf area index at 49 and 98 DAS. Maximum leaf area index was noted in the control where no extract was applied. Leaf area duration is directly related to leaf area index, which was subsequently decreased due to increase in the concentration of aqueous extracts of leaves, stem and roots as compared to the untreated control. It might be due to the fact that mesquite contains water-soluble allelochemicals which could inhibit germination and reduce the rate of weed growth (Al-Humaid and Warrag, 1999). The inhibitory effect on wheat growth was likely due to the presence of allelochemicals in mesquite, including alkaloids, tannins, wax, flavonoids and phenolic acids (Pragnesh et al., 2013).

Net assimilation rate expresses the plant's capacity to increase dry weight in terms of area of its assimilatory surface. It represents the photosynthetic efficiency in the overall sense

(Reddy, 2004). By applying different concentrations, the maximum level (40%) of the aqueous leaf extract of mesquite produced the lowest net assimilation rate as compared to the control. Similarly, crop growth rate was also negatively affected by applying different concentrations of mesquite as compared to the control. There was maximum reduction in leaf area duration by applying the highest concentration of the aqueous leaf extract. Growth percentage is reported to decrease with increasing concentration of aqueous leaf extract of mesquite (Siddiqui et al., 2009). Singh (2012) reported that a phytochemical analysis of mesquite revealed the presence of alkaloids, terpenoids, steroids, flavonoids, phenolics and tannins in leaf extracts. Khan (2005) found that the germination and growth of *Asphodelus tenuifolius*, *Brassica campestris,* and *Triticum aestivum* were significantly affected by mesquite extracts as compared to the control. A particularly high degree of inhibition occurred with aqueous leaf extracts at the maximum concentrations in wheat.

In the present study, aqueous leaf, stem and root extracts of mesquite were also tested for growth, yield and quality parameters including plant height, number of tillers, spike length, number of grains per spike, 1,000 grain weight, grain yield, biological yield, harvest index and grain protein content of wheat. All these parameters were correspondingly reduced with increased concentration of the aqueous extract of all three plant parts of mesquite as compared to the control. The use of the highest concentration of aqueous leaves extract of mesquite negatively affected all yield parameters as compared to the control.

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