Research Article

Effect of Allelopathic Water Extract of Sorghum and Sunflower on Weed Mortality and Cotton Yield

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Abstract | Sorghum and sunflower have been reported to contain several allelochemicals. Utilization of these allelochemicals is considered low-cost and natural sources for weed suppression. Field trials were undertaken at Cotton Section, Agriculture Research Institute, Tandojam Pakistan during summer 2010 and repeated during summer 2011 for validating the previous results. The experiments were laid out in three replicated randomized complete block design. The seed of cotton variety "Sindh-1" was sown through drilling in the 1st week of May each year. The treatments consisted of: weedy check (no weeding), interculturing twice (30+60 DAS), Dual Gold 960-EC (S-metolachlor) @ 2.50 L ha^{-1}, sorghum water extracts @ 15 L ha^{-1} (twice) and 25 L ha^{-1} (once and twice) and sunflower water extracts @ 15 L ha^{-1} (twice) and 25 L ha^{-1} (once and twice), sorghum water extract @ 15 L ha^{-1}+1.25 L ha^{-1} Dual Gold and sunflower water extract @ 15 L ha^{-1}+1.25 L ha^{-1} Dual Gold. In interculturing the land space in between two rows of crop plants was pulverized with the help of local tool spade. The statistical analysis of data showed that interculturing, Dual Gold, and sorghum and sunflower water extracts caused significant reduction of weeds and increased seedcotton yield as compared to weedy check. The combined application of sorghum @ 15 L ha^{-1}+ Dual Gold @ 1.25 L ha^{-1} resulted in weeds mortality upto 66.6%, produced seedcotton yield of 3961.4 kg ha^{-1} and gave net benefit of Rs. 2,20,029. Sunflower applied @ 15 L ha^{-1} in integration with Dual Gold @ 1.25 L ha^{-1} showed weeds mortality of 65.5 %, resulted in seedcotton yield of 3949.7 kg ha^{-1} and net monetary benefit of Rs. 2,19,821. Sole application of Dual Gold @ 2.5 L ha^{-1} reduced weeds by 55.9%, produced seedcotton yield of 3212.7 kg ha^{-1} and net resulted in net benefit of Rs. 1,77,414. It is noteworthy that interculturing twice (30+60 DAS) caused maximum (67.7%) suppression of weeds, produced maximum plant height (117.0 cm) and seedcotton yield (3977.8 kg ha^{-1}) but conferred less (Rs. 2,14,151) net monetary benefits as compared to obtained in sorghum + Dual Gold and sunflower + Dual Gold. Overall results suggested that maximum net income was recorded when sorghum water extract was applied in integration with Dual Gold. The combined application of sunflower with Dual Gold ranked second in monetary benefits. Interculturing twice was found less economical due to higher costs of labour. Hence, it can be inferred from the above results that Dual Gold dose can be reduced up to 50% in combination with sorghum or sunflower water extracts for effective and environment friendly weed management and enhancing cotton yield.

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Introduction

Cotton (*Gossypium hirsutum* L.) is an important cash crop of Pakistan and is grown in many parts of the world. The contribution of this crop in Pakistan during 2013-14 to value-added by agriculture was 6.7.0% and to GDP was 1.4%. The main purpose of growing cotton is fiber which is used for manufacturing of cloth. This crop provides not only foreign exchange earning but also raw material to local textile industry. In Pakistan, cottonseed contributes 75% domestic edible oil production (GOP, 2013). The oil content in the cottonseed ranges from 15-25% (Aladakatti et al., 2011). The current cotton yield in Pakistan is considerably lower than the yield obtained in other cotton growing countries of the world. There are several reasons that are responsible for lower yield of cotton but weed infestation is an important and major one. Weeds are major biotic factors reducting crop productivity (Bhoi et al., 2010). The wider row spacings arrangement and initially slow growth of cotton crop provide ideal conditions for the rapid germination and growth of weeds. The most common summer weeds have been identified infesting cotton (Iqbal et al., 2003). Weeds like Waho/Itsit (*Trianthema portulacastrum* L.), Lulur/Tandla (*Digera arvensis* Forsk.), Dungni/Mohbat booti (*Xanthum strumarium* L.), Naro/Lehli (*Convolvulus arvensis* L), Bhurt/ Bakhra (*Tribulus terrestris* L.), Mundheri/ Bhauphali (*Corchorus acutangulus* L.), Kabah/Deela (*Cyperus rotundus* L.), Chhabar/ Khabbal ghass (*Cynodon dactylon* L.), Gamm/Baru (*Sorghum halepense* L.), Sawari/ Swanki ghass (*Echinochloa colonum* L.), Dabh (*Desmostachya bipinnata* L.) have been found infesting the cotton crop (Memon et al., 2014; Rajput et al., 2008). The main goal of weed management is to increase the crop yield per unit area with minimum expenditure (Tauseef et al., 2012). Manual weed management practices are laborious and expensive. Herbicide application is the most effective and efficient approach for control of weeds. The indiscriminate and continuous application of herbicides has deteriorated the environment and increased resistant of weeds to herbicides. This situation has drawn the researcher's attention for taking efforts to plan alternative strategies of managing weeds (Jabran et al., 2010).

The releasing of allelochemicals from various parts of plants negatively affects germination, density and growth of weeds (Hozayn et al., 2011). Allelochemicals interfere with internode elongation, leaf expansion, cell division, dry biomass accumulation and seed germination; alter the biomass partitioning into the leaves as well as inhibit stomatal movement and respiration (Asgharipour and Armin, 2010). In sorghum seven allelopathic compounds viz. p-hydroxybenzoic acid, protocateuic acid, syringic acid, p-coumaric acid, gallic acid, benzoic acid and vanillic acid have been identified (Iqbal and Cheema, 2008) whereas, in sunflower several phenolics and terpenoids have been reported (Anjum and Bajwa, 2008).

The use of herbicides could be reduced from 50-67% in cotton by using water extract of allelopathic crops (Cheema et al., 2003). Iqbal and Cheema (2008) observed that sorghum water extract in combination with reduced doses of s-metolachlor exhibited 75-88% reduction in dry biomass of *C. rotundus* (L.) in cotton. Sunflower water extracts @ 15 L ha^{-1} in integration with reduced label rate of glyphosate, decreased weed density by 59 to 99%, produced seedcotton yield comparable to herbicide applied at recommended rate (Iqbal et al., 2007). The water extract prepared from different parts of sunflower substantially suppressed germination and growth of weeds (Asgharipour, 2011). When Pendimethalin at reduced rates was applied in combination with crop water extracts, effective suppression of purple nutsedge was achieved (Jabran et al. 2010). Others (Afridi and Khan, 2014 and 2015) have also reported the success of using allelopathic plant water extracts for weed suppression. Therefore the present studies were conducted to investigate the efficacy of plant water extracts in combination with reduced dose of Dual Gold for weed suppression in cotton.

Materials and Methods

The trial was undertaken during summer 2010 at Cotton Section, ARI, Tandojam, Sindh province of Pakistan and repeated during summer 2011 for validating the previous results. The study was carried out at clay loam soil with three replications in randomized complete block design having net plot size of 6 m x 5 m. The treatments included: weedy check (no weeding), interculturing twice: 30+60 days after sowing (DAS), Dual Gold (s-metolachlor) 960-EC: 2.5 L ha^{-1}, sorghum water extract: 15 L ha^{-1} (two sprays:15+30 DAS), sorghum water extract: 25 L ha^{-1} (one spray-15 DAS), sorghum water extract: 25 L ha^{-1} (two sprays-15+30 DAS), sunflower water extract: 15 L ha^{-1} (two sprays-15+30 DAS), sunflower water extract: 25 L ha^{-1} (one spray-15 DAS), sunflower water

extract: 25 L ha^{-1} (two sprays-15+30 DAS), sorghum water extract: 15 L ha^{-1}+Dual Gold 960-EC: 1.25 L ha^{-1} and sunflower water extract: 15 L ha^{-1} +Dual Gold 960-EC: 1.25 L ha^{-1}. It is essential to mention for many readers that interculturing is a local practice performed by farmers to control weeds. In this practice the space between two rows of wider row crops is turned up and down through spade (local tool) by man power. Due to this practice soil is pulverized, made porous and aerated and the weeds present in between space of crop plants are uprooted and cut. The sowing of cotton variety "Sindh-1" was done in 1st week of May through single row hand drill keeping distance of 75 cm between rows. Thinning of extra plants was done at 25 DAS in order to maintain the distance of 22 cm between plants. Dry ploughing through disc plough was done to prepare land, followed by irrigation. The field was ploughed and levelled at proposed moisture condition; using cultivator and planked. In order to apply irrigation water properly bunds and feeding channels were prepared. The fertilizers NPK were applied in the form of Urea, DAP and SOP @ 115, 60 and 50 kg ha^{-1}. 1/3rd of nitrogen and total recommended quantity of potassium and phosphorus was applied at sowing time, whereas the left nitrogen was applied at 1st and 3rd irrigation. The 1st irrigation was applied at 35 DAS while succeeding irrigations were at the interval of 15 days. Total seven irrigations were applied keeping in view the soil moisture condition. However, the approximate depth of 7.5 cm was maintained for each irrigation. The data were collected on weed density (m^{-2}), fresh biomass and dry biomass (g m^{-2}) from each treatment at 90 DAS. The weeds were cut with the help of sharp sickle at soil surface level. The fresh biomass of weeds was measured immediately after cutting whereas, dry biomass was recorded after drying for 48 hours in oven at 70 ^{0}C. The weed mortality (WM) % was calculated by using the following formula:

$$WM\% = \frac{WD\ (m^{-2}) \text{of weedy check} - \text{WD}\ (m^{-2}) \text{of given treatment}}{WD\ (m^{-2}) \text{of weedy check}} X100$$

Where
WM = Weed mortality
WD = Weed density

Data were collected regarding important growth and yield attributes of cotton such as plant height (cm), sympodial branches $plant^{-1}$, opened bolls $plant^{-1}$ and seedcotton yield (kg ha^{-1}). The 1st picking was done during 3rd week of September when 50% bolls opened whereas, 2nd and 3rd pickings were done during 1st and 3rd week of October each year at the intervals of 15 days between each picking. The two year data with regard to maximum, minimum and average temperature as well as relative humidity and rainfall during experiment period is presented in Table 1.

Preparation and application of allelopathic crops water extracts

The herbage of sorghum and sunflower was collected from Students' Experimental Farm, Sindh Agriculture University, Tandojam. The allelopathic crops were sown in February for the purpose of herbage and cut at the peak of their vegetative stage in April each year. The harvested material was kept for drying, chopped into 2 cm pieces and in the ratio of 1:10 w/v was soaked for 24 hours in water. The herbage mixed water was boiled on gas burner, filtered through muslin cloth and concentrated to 20 times by boiling. The Dual Gold and water extracts of sunflower and sorghum were sprayed as per treatment by mixing with 300 L of water ha^{-1}.

Statistical analysis

The collected data was subjected to analysis of variance technique using Statistix 8.1 computer software (Statistix, 2006). The LSD test was applied for comparing the superiority of treatments.

Results and Discussion

Weeds density (m^{-2})

Water extract of sorghum and sunflower applied as sole or in combination with 50% reduced label dose of Dual Gold significantly ($P \leq 0.05$) suppressed the weeds (Table 2) as compared to weedy check. Minimum weed density (55.3 m^{-2}) was recorded in interculturing twice (30+60 DAS), followed by sorghum water extract (15 L ha^{-1})+Dual Gold (1.25 L ha^{-1}) with 57 m^{-2}. Sunflower water extract (15 L ha^{-1})+Dual Gold (1.25 L ha^{-1}) ranked third in weed suppression and resulted in 59.9 weeds m^{-2}. Weed density of 76.7 m^{-2} was observed in plots where Dual Gold was applied at its label dose (2.5 L ha^{-1}) dose. Among sole applications of allelopathic water extracts, sorghum water extract: 25 L ha^{-1} (two sprays: 15+30 DAS) resulted in less weed density (84.1 m^{-2}) as compared to 91.8 m^{-2} in sunflower water extract: 25 L ha^{-1} (two sprays: 15+ 30 DAS). The respective combined application of sorghum and sunflower water extracts with Dual Gold showed non-significant differences with interculturing twice. The water extracts of sorghum

Table 1: *Environmental conditions of Tandojam during experiment (2010 and 2011)*

Month	Week	2010				2011			
		Temperature (°C)		Relative Humidity (%)	Rainfall (mm)	Temperature (°C)		Relative Humidity (%)	Rainfall (mm)
		Minimum	Maximum			Minimum	Maximum		
May	i	26.1	40.3	55.0	0.0	27.0	42.5	64.0	0.0
	ii	24.3	43.2	54.0	0.0	26.8	41.9	65.0	0.0
	iii	25.0	42.4	56.0	0.0	27.3	42.0	63.0	0.0
	iv	26.0	42.1	53.0	0.0	26.7	42.6	66.0	0.0
June	i	27.4	38.8	60.0	0.0	27.1	38.0	68.0	0.0
	ii	27.0	39.0	61.0	0.0	27.4	39.0	67.0	0.0
	iii	27.4	38.6	63.0	0.0	26.5	38.4	66.0	0.0
	iv	27.0	37.0	64.0	0.2	26.0	38.5	68.0	0.0
July	i	27.3	36.6	66.0	0.7	26.8	36.7	73.0	0.0
	ii	26.9	36.8	68.0	0.4	26.0	36.1	74.0	0.0
	iii	26.4	35.9	69.0	0.2	26.4	35.9	76.0	0.0
	iv	26.0	35.2	70.0	1.3	26.7	35.6	77.0	1.0
August	i	25.9	34.0	77.0	6.1	26.9	35.3	78.0	0.0
	ii	25.0	34.8	78.0	0.0	26.0	35.9	79.0	140.6
	iii	25.8	33.6	79.0	0.0	26.2	36.0	77.0	8.0
	iv	25.0	33.2	80.0	0.0	26.0	35.0	78.0	40.8
September	i	24.7	33.0	80.0	1.0	26.5	35.3	76.0	142.0
	ii	24.3	32.5	81.0	11.3	25.9	36.2	74.0	195.2
	iii	23.0	32.3	75.0	9.3	26.1	35.0	72.0	1.0
	iv	22.6	31.4	73.0	0.0	25.0	35.2	70.0	0.0
October	i	22.2	31.0	72.0	0.0	24.8	35.8	66.0	0.0
	ii	20.3	32.3	67.0	0.0	24.0	34.5	62.0	0.0
	iii	19.6	31.9	60.0	0.0	20.7	34.2	57.0	0.0
	iv	19.3	31.2	61.0	0.0	20.3	34.0	58.0	0.0

Source: *Regional Agro-meteorology Centre Tandojam, Pakistan*

and sunflower applied twice showed more allelopathy in comparison with their single application. Application of water extracts at higher doses was found more effective as compared to lower dose. It is inferred from the results that reduction in weed density was due the presence of allelochemicals in sorghum and sunflower water extract. The lowest weed density observed in integrated application of water extracts of sorghum and sunflower with Dual Gold demonstrated inhibitory effect of the water extracts. The above trend of results confirmed the hypothesis that water extracts of allelopathic plants can be applied to suppress weeds and the allelopathic activity of such extracts were increased when applied in combination with lower doses of Dual Gold. Thus Dual Gold doses can be reduced to a considerable level. The water extracts of allelopathic crops have been used successfully for management of weeds in many crops. Sorghum water extract is most extensively used as natural herbicide. Application of allelopathic crops water extracts in combination with reduced doses of herbicides significantly inhibited the weed density (Farooq et al., 2013; Afridi and Khan, 2014; 2015). The inhibition in weed density through mixing of herbicide at 33% of its label rate with allelopathic water extracts of sunflower, sorghum and brassica has also been reported by Iqbal et al. (2010). The results corroborate the findings of earlier workers Iqbal et al. (2007) who stated that sunflower water extracts at 12 and 15 L ha^{-1}, mixed with reduced label rate of glyphosate, decreased density of *C. rotundus* (L.) by 59 to 99%.

Fresh/dry biomass of weeds (g m^{-2})

The results (Table 2) showed that various levels of sorghum and sunflower water extracts as well as interculturing and Dual Gold treatments exerted significant ($P<0.05$) negative effect on weeds biomass. Application of sorghum water extract @ 15 L ha^{-1} with Dual

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Table 2: *Allelopathic impact of sorghum and sunflower water extracts on weeds*

Treatments	Weed density (m^{-2})	Weed fresh biomass (g m^{-2})	Weed dry biomass (g m^{-2})	Weed mortality (%)
Weedy check (no weeding)	172.4 a	1357.9 a	500.4 a	0.0 i
Interculturing twice: 30+60 days after sowing (DAS)	55.3 i	237.3 g	98.6 i	67.7 a
Dual Gold 960-EC (s-metolachlor): 2.5 L ha^{-1}	76.7 h	516.0 f	216.8 h	55.9 b
Sorghum water extract: 15 L ha^{-1} (twice:15+30 DAS)	99.6 e	678.9 cde	285.2 e	42.7 e
Sorghum water extract: 25 L ha^{-1} (once: 15 DAS)	119.9 c	811.9 bc	341.0 c	31.0 g
Sorghum water extract: 25 L ha^{-1} (twice: 15+30 DAS)	84.1 g	563.1 ef	236.1 g	51.5 c
Sunflower water extract: 15 L ha^{-1} (twice: 15+30 DAS)	108.7 d	763.1 bcd	320.4 d	37.5 f
Sunflower water extract: 25 L ha^{-1} (once: 15 DAS)	125.3 b	862.4 b	376.2 b	27.8 h
Sunflower water extract: 25 L ha^{-1} (twice 15+30 DAS)	91.8 f	646.1 def	271.4 f	47.2 d
Sorghum water extract:15 Lha^{-1}+Dual Gold 960 EC: 1.25 Lha^{-1}	57.0 i	245.8 g	103.1 i	66.6 a
Sunflower water extract:15 Lha^{-1} +Dual Gold 960 EC:1.25 Lha^{-1}	59.9 i	249.7 g	105.8 i	65.5 a
S.E ±	2.51	69.07	3.56	1.33
$LSD_{0.05}$	5.24	144.08	7.44	2.78

Means not sharing the same letter in a column show significant difference at 0.05 probability level.

Table 3: *Effect of sorghum and sunflower water extracts on growth and yield traits of cotton*

Treatments	Plant height(cm)	Sympodial branches $plantt^{-1}$	Opened bolls $plant^{-1}$	Seedcotton yield (kg ha^{-1})
Weedy check (no weeding)	107.4 f	18.5 e	27.1 f	2053.8 i
Interculturing twice: 30+60 days after sowing (DAS)	117.0 a	24.9 a	38.0 a	3977.8 a
Dual Gold 960-EC (s-metolachlor): 2.5 L ha^{-1}	112.5 c	21.7 b	34.5 b	3212.7 b
Sorghum water extract: 15 L ha^{-1} (twice:15+30 DAS)	111.8 cd	20.5 c	30.9 c	3066.4 e
Sorghum water extract: 25 L ha^{-1} (once: 15 DAS)	111.2 de	20.2 cd	29.3 de	2968.4 g
Sorghum water extract: 25 L ha^{-1} (twice: 15+30 DAS)	112.3 c	21.6 b	34.4 b	3166.9 c
Sunflower water extract: 15 L ha^{-1} (twice: 15+30 DAS)	111.3 de	20.2 cd	29.9 cd	3027.1 f
Sunflower water extract: 25 L ha^{-1} (once: 15 DAS)	110.7 e	19.9 d	28.3 ef	2929.0 h
Sunflower water extract: 25 L ha^{-1} (twice 15+30 DAS)	111.8 cd	21.3 b	33.4 b	3127.5 d
Sorghum water extract:15 L ha^{-1}+Dual Gold 960 EC:1.25 L ha^{-1}	116.8 ab	24.7 a	37.5 a	3961.4 a
Sunflower water extract:15 L ha^{-1}+Dual Gold 960 EC:1.25 L ha^{-1}	116.2 b	24.3 a	37.0 a	3949.7 a
S.E ±	0.34	0.28	0.62	15.49
$LSD_{0.05}$	0.70	0.58	1.29	32.32

Means not sharing the same letter in a column differ significantly at 0.05 probability level.

Gold @ 1.25 L ha^{-1} resulted in fresh and dry biomass of 245.8 and 103.1 g m^{-2}. The fresh and dry biomass of 249.7 and 105.8 g m^{-2} was noted in sunflower water extract @ 15 L ha^{-1} +Dual Gold @ 1.25 L ha^{-1}. The lowest values of 237.3 and 98.6 g m^{-2} weed fresh and dry biomass was observed in interculturing twice. Similarly, sole application of (Dual Gold 960-EC 2.5 L ha^{-1}) ranked fourth showing 516.0 and 216.8 g m^{-2} fresh and dry biomass, respectively. However, statistically the differences among sorghum and sunflower water extracts applied in integration with Dual Gold, and interculturing twice were non-significant. As regards, applications of water extracts applied as sole, weeds fresh and dry biomass of 563.1 and 236.1 g m^{-2} was recorded in sorghum water extract @ 25 L ha^{-1} (two sprays) in contrast to sunflower water extract @ 25 L ha^{-1} (two sprays) showing 646.1 and 271.4 g m^{-2}. The application of sorghum and sunflower water extracts at higher rates showed more allelopathic effect as compared to their application at lower rates.

Two sprays of sorghum and sunflower water extracts proved stronger in phytotoxic influence than single spray. The reduction in fresh and dry biomass of weeds suggested that sorghum and sunflower water extracts contain allelopathic compounds that can suppress weeds. The mixing of Dual Gold with sorghum and sunflower water extract increased their phytotoxic potential. Sole application of Dual Gold at its standard dose did not prove much effective in inhibiting weeds as it reduced weeds fresh and dry biomass significantly less than its mixture at 50% reduced label dose with water extracts of sorghum and sunflower. This indicates that inhibitory action of allelopathic crops water extracts and Dual Gold was improved when applied in combination. The results of this study are in accordance with those of Asgharipour (2011) who observed substantial suppression in growth of weeds by the application of sunflower water extract. Allelopathic crop water extracts i.e. sorghum and brassica (each at 20 L ha^{-1}) in combination with reduced dose of paraquat decreased the dry biomass of weeds by 85%. The integration of allelopathic crop water extracts and paraquat spray was found practical in reducing paraquat dose upto 67% (Iqbal et al., 2014).

Weeds mortality (%)

It is evident from the data (Table 2) that application of sorghum and sunflower water extract alone or in integration with Dual Gold, interculturing and Dual Gold resulted in substantial ($P \leq 0.05$) weed mortality (%) in comparison with weedy check (no weeding). Numerically, the highest values (67.7%) for weed mortality were observed in interculturing twice. Application of sorghum water extract @ 15 L ha^{-1}+Dual Gold 960-EC @ 1.25 L ha^{-1} showed weed mortality of 66.6%. Integration of sunflower water extract @ 15 L ha^{-1} +Dual Gold 960-EC @ 1.25 L ha^{-1} caused weed mortality of 65.5%. Moreover, the foregoing three treatments showed non-significant differences with each other. The application of Dual Gold at its label rate also demonstrated significant weed mortality of 55.9%. In case of sole application of water extracts, sorghum water extract @ 25 L ha^{-1} (two sprays) exhibited weed mortality of 51.5% as compared to 47.2% weed mortality, noted in sunflower water extract @ 25 L ha^{-1} (two sprays). The foliar application of water extract at higher rate of sorghum and sunflower exhibited more allelopathic effect over lower rate. Two sprays were found more effective than single spray. This weed mortality efficiency of water extracts suggests allelopathic compounds with phytotoxic efficacy in both sorghum and sunflower. The highest mortality of weeds integrated application of water extracts with Dual Gold shows the increase in phytotoxic efficacy of sorghum and sunflower. Application of allelopathic crops water extracts at higher concentrations suppressed the weed density and biomass. The allelopathic compounds interfere with hormone biosynthesis, cell division, as well as uptake and transport of minerals when applied at high concentrations. The allelopathic water extracts have been used as potential herbicides in mixture with reduced herbicide doses by half of standard giving effective control over noxious weeds of major crops (Cheema et al., 2012). The results of this study fully support the previous work that sorgaab (water extract) in combination with reduced doses of s-metolachlor exhibited 62-92% weed control of *C. rotundus* (L.) in cotton (Iqbal and Cheema, 2008). Similarly, Cheema et al. (2004) found that foliar application of sorghum water extract markedly decreased weeds by 18-50% and proved most economical.

Plant height (cm)

Statistical analysis of data showed that various levels of sorghum and sunflower water extracts as well as interculturing and Dual Gold treatments showed significant and positive effect on plant height of cotton compared to weedy check (Table 3). Interculturing twice resulted in maximum plant height (117.3 cm), followed by 116.8 cm in combination of sorghum water extract (15 L ha^{-1}) +Dual Gold (1.25 L ha^{-1}). The integrated application of sunflower water extract (15 L ha^{-1})+Dual Gold (1.25 L ha^{-1}) and sole Dual Gold (2.5 L ha^{-1}) ranked 3rd and 4th with 116.2 and 112.5 cm plant height, respectively. Furthermore, statistically the differences between sorghum water extract (15 L ha^{-1}) + Dual Gold (1.25 L ha^{-1}), sunflower water extract (15 L ha^{-1})+ Dual Gold (1.25 L ha^{-1}) and Interculturing twice were non-significant. Sole application of sorghum or sunflower water extracts either at higher or lower rates, two or one spray also showed significant and positive effect on cotton plant height against weedy check. These results illustrated that sorghum or sunflower water extract applied as sole or in combination with reduced dose of Dual Gold controlled weeds and created conducive environment for proper growth of cotton crop. The findings of this study are in agreement with the results of previous research work to sorghum (Iqbal et al., 2007) and sunflower (Narwal et al., 2005) that water extracts suppressed weeds effectively and increased crop growth such as

plant height. The highest plant height of cotton recorded in combination of sorghum and brassica water extracts at 20 L ha^{-1}+1/3 dose of paraquat was due to effective weed control (Iqbal et al., 2014).

Sympodial branches plant^{-1}

The results (Table 3) showed that sorghum and sunflower water extracts applied at higher or lower rates (sole or in combination with 50% reduced label dose of Dual Gold as well as interculturing and Dual Gold treatments significantly ($P \leq 0.05$) enhanced sympodial branches plant^{-1} of cotton in comparison with weedy check. The sympodial branches plant^{-1} is the major yield contributing component which contributes directly to the seedcotton yield. The highest (24.9) values for sympodial branches plant^{-1} were recorded in interculturing twice. The sympodial branches of 24.7 were observed in combined application of water extract of sorghum @ 15 L ha^{-1} +Dual Gold @ 1.25 L ha^{-1}. Sunflower water extract @ 15 L ha^{-1}+ Dual Gold @ 1.25 L ha^{-1} conferred 24.3 sympoding branches plant^{-1}. It is essential to note that values for sympodial branches among foregoing treatment were statistically similar. Sole application of Dual Gold @ 2.50 L ha^{-1} also produced significantly higher (21.7) sympodial branches plant^{-1} over weedy check (18.5 plant^{-1}). In case of water extracts application as sole at higher or lower dose (once or twice) also caused marked increase in sympodial branches as compared to weedy check. Moreover, enhanced sympodial branches of cotton may be attributed to the fact that water extracts of allelopathic crops significantly controlled weeds, resulting in less weed-crop competition for growth resources. Similar trend of allelopathic crops efficiency in enhancing crop growth and yield characteristics was also revealed by earlier workers that sorghum (Narwal et al., 2005) and sunflower (Anjum and Bajwa, 2007) contain many allelochemicals which are responsible for inhibitory allelopathic activity at specific quantity against weeds and ultimately improving crop productivity (Iqbal et al., 2010). Maximum number of sympodial branches plant^{-1} was noted in sorghum and brassica water extracts applied in combination with 1/3 doses of paraquat and pendimethalin and the number of sympodia plant^{-1} increased possibly due to better weed suppression (Iqbal et al., 2014).

Opened bolls plant^{-1}

The data (Table 3) indicated that various levels of sorghum and sunflower water extracts as well as interculturing and Dual Gold treatments significantly ($P<0.05$) and positively affected the opened bolls plant^{-1} of cotton compared with weedy check. Maximum (38) number of opened bolls plant^{-1} was recorded in interculturing twice (30+60 DAS). Combined application of sorghum (15 L ha^{-1}) +Dual Gold @ 1.25 L ha^{-1} caused opening of 37.5 bolls plant^{-1}. Similarly, 37.0 opened bolls plant^{-1} were noticed in sunflower water extract (15 L ha^{-1})+ Dual Gold (1.25 L ha^{-1}). The sole application of Dual Gold @ 2.5 L ha^{-1} ranked 4th with 34.5 opened bolls plant^{-1}. However, interculturing twice, sorghum and sunflower water extract+Dual Gold showed non-significant differences with each other for opened bolls plant^{-1}. The results envisaged that efficiency of allelopathic crops water extracts in enhancing cotton crop performance in terms of opened bolls was dose specific. The water extracts with higher or lower rates applied one time or two times were also found efficient in increasing yield attributes of cotton as compared to weedy check. The better performance of cotton crop in terms of opened bolls per plant in response to integration of either sorghum or sunflower water extract with reduced dose of Dual Gold revealed that weed inhibiting efficiency of allelopathic compounds was enhanced and more availability of growth resources to cotton crop. The increase in number of bolls plant^{-1} was perhaps due to better suppression of weeds (Iqbal et al., 2014). The findings are in coincidence with those of Iqbal and Cheema (2008) who stated that sorghum and sunflower water extracts in integration with lower rates of herbicides significantly enhanced opened bolls plant^{-1}.

Seedcotton yield (kg ha^{-1})

The data presented in Table 3 suggested that application of sorghum and sunflower water extracts at various levels as well as interculturing and Dual Gold treatments exhibited positive effects on seedcotton yield (kg ha^{-1}) when compared with weedy check. Interculturing twice produced maximum seedcotton yield of 3977.8 kg ha^{-1}. Integrated application of sorghum water extract @ 15 L ha^{-1}+Dual Gold @ 1.25 L ha^{-1} followed in producing seedcotton yield with 3961.4 kg ha^{-1}. Spray of sunflower water extract @ 15 L ha^{-1} in combination with Dual Gold @ 1.25 L ha^{-1} resulted in seedcotton yield of 3949.7 kg ha^{-1}. These three treatments were statistically similar. Sole application of Dual Gold at its label dose of 2.50 L ha^{-1} also resulted in increased seedcotton yield of 3212.7 kg ha^{-1}. Sole spray of sorghum or sunflower water extracts also caused significant increase in seedcotton yield compared with weedy check. The increased seedcotton

Table 4: *Economic analysis for sorghum and sunflower water extracts allelopathy in cotton*

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	Remarks
Seedcotton yield	2054	3978	3213	3066	2968	3167	3027	2929	3128	3961	3950	kg ha^{-1}
Adjusted yield	1848	3580	2891	2760	2672	2850	2724	2636	2815	3565	3555	10% less than actual kg ha^{-1}
Seedcotton value	115526	223751	180714	172485	166973	178138	170274	164756	175922	222829	222171	Rs. 2500 per 40 kg
Dual Gold cost	-	-	2500	-	-	-	-	-	-	1250	1250	Rs. 1000 per Lit
Interculturing cost	-	9600	0	-	-	-	-	-	-			Rs. 200 per Labor, 24 persons per ha
Water extracts cost				1500	1250	2500	600	500	1000	750	300	Rs. 50/L Sorghum WE Rs. 20/L Sunflower WE
Labor charges	-	-	600	1200	600	1200	1200	600	1200	600	600	Labor was used for spray
Spray rent	-	-	200	400	200	400	400	200	400	200	200	-
Cost that vary	0	9600	3300	3100	2050	4100	2200	1300	2600	2800	2350	-
Net benefits	115526	214151	177414	169385	164923	174038	168074	163456	173322	220029	219821	-

T_1= Weedy check, T_2= Interculturing twice, T_3= Dual Gold, T_4= Sorghum water extract (Sorg. WE) (twice), T_5= Sorg. WE: 25 L ha^{-1} (once), T_6= Sorg. WE: 25 L ha^{-1} (twice), T_7= Sunflower water extract (Sunf. WE) 15 L ha^{-1} (twice), T_8= Sunf. WE: 25 L ha^{-1} (once), T_9= Sunf. WE: 25L ha^{-1} (twice), T_{10}= Sorg. WE: 15 L ha^{-1}+Dual Gold: 1.25 L ha^{-1}, T_{11}= Sunf. WE: 15 L ha^{-1}+Dual Gold: 1.25 L ha^{-1}

yield may be ascribed to allelopathic efficiency of sorghum and sunflower water extracts which ultimately resulted in less competition between cotton and weeds. Hence, the resources available were utilized fully by cotton plants for proper growth and yield contributing parameters. Moreover, higher seedcotton yield under the integrated application of sorghum or sunflower water extracts with half label dose of Dual Gold indicates that weed controlling efficacy of allelopathic compounds was enhanced. As integrated application of allelopathic crops water extracts controlled weeds effectively and created an environment where net assimilation rate and growth rate of cotton crop were higher which resulted in increased sympodial branches plant^{-1}, opened bolls plant^{-1} and eventually the seedcotton yield (kg ha^{-1}). The compounds released by allelopathic plants not only suppress weeds but can also improve crop growth and yield (Hozayn et al., 2011). The enhancement in seedcotton yield has also been reported by Cheema et al. (2002) who recorded highest seedcotton yield by the integrated application of concentrated sorghum water extract+herbicide. The results of this study also supported the finding of Baloach et al. (2014) and Afridi and Khan (2014; 2015) who concluded that crop yield was substantially improved due to the application of allelopathic water extracts of *Parthenium hysterophorus* (L.) at 24 L ha^{-1} in combination with reduced doses of herbicides.

Economic analysis

Sorghum and sunflower water extracts caused significant increase in seedcotton yield. The yield obtained in allelopathic water extracts was statistically equivalent to interculturing and higher than sole application of Dual Gold at standard label dose. The maximum net benefit (Table 4) of Rs. 2,20,029 ha^{-1} was obtained under integrated application of sorghum water extract+Dual Gold. The combination of sunflower water extract+Dual Gold ranked 2nd giving net benefit of Rs. 2,19,821 ha^{-1}. The net benefits of Rs. 2,14,151 and Rs. 1,77,414 ha^{-1} were also obtained in interculturing twice and sole application of Dual Gold at label dose, respectively. Weedy check resulted in minimum net benefit of Rs. 1,15,526. The results are in full concurrence with the findings of Iqbal et al. (2014) and Baloach et al. (2014) who revealed the net monetary benefits of applying allelopathic water extracts for weed management and crop yield enhancement.

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Conclusions

It is concluded that interculturing, Dual Gold and various levels of sorghum or sunflower water extracts significantly suppressed weeds which resulted increased seedcotton yield in contrast to weedy check. The application of sorghum and sunflower water extracts at 15 L ha^{-1} in combination with 50% reduced label dose of Dual Gold at 1.25 L ha^{-1} produced statistically at par values for weed mortality and seedcotton yield. This integration of water extracts conferred more net monetary benefits as compared to interculturing twice. Interculturing was found less economical due to higher costs and scarcity of labour. Hence, results suggested that application of sorghum or sunflower water extracts in integration with reduced dose of Dual Gold is economical approach for effective weed management and getting higher cotton yield.

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Authors' Contribution

Muhammad Nawaz Kandhro designed and conducted experiment. Ahmed Naqi Shah and Muhammad Ali Ansari helped Muhammad Nawaz Kandhro in the collection of data on weeds and cotton parameters. Habib-Ur-Rehman Memon helped Muhammad Nawaz Kandhro in statistical analysis of data. Muhammad Nawaz Kandhro prepared manuscript and Habib-Ur-Rehman Memon helped in formatting of references. All the co-authors gave their suggestions during initial preparation of manuscript, and also for improvement of manuscript in the light of reviewers' comments.

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