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Organic Weed Management in Wheat through Allelopathy

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Abstract

Modern agriculture is productivity oriented and depends mainly on synthetic inputs (herbicides) to manage weeds. However, non-judicious use of these synthetic herbicides could cause environmental, health and herbicides resistance issues. Therefore, a focus has been given since last two decades on the use of plant derived organic substances as alternative to inorganic herbicides for weed control. Allelopathy is an eco-friendly and organic weed management approach, which may be used as a tool in controlling weeds. In this study, allelopathic water extracts of sorghum, sunflower and brassica were applied at 25, 40 and 55 DAS each at 18 and 20 L ha^{-1}, for weed management in wheat. For comparison, a standard herbicide i.e. idosulfuron + mesosulfuron (Atlantis) and a weedy check were maintained as control. Reduction in total weed density and biomass by the application of two foliar sprays of tank mixed sorghum, sunflower and brassica each at 18 L ha^{-1} were 48-59 and 48-58%, respectively. Maximum wheat grain yield was recorded from the application of two foliar sprays of sorghum, sunflower and brassica mixture at 18 L ha^{-1} at 25 and 40 DAS. This treatment was also economically the most feasible than other crop water extract treatments, with the maximum net benefits. This study suggests that allelopathy offers an attractive and environmental friendly organic method of weed control in wheat. © 2015 Friends Science Publishers

Keywords: Allelopathy; Water extracts; Weed control; Wheat

Introduction

Wheat is a staple food of masses in Pakistan; grown almost in every corner of the country. Amongst the several factors hindering the productivity of wheat, weed infestation is one of the major constraints hampering the harvest of potential yield, causing 20-40% reduction in wheat yield (Ahmad and Shaikh, 2003), which in monetary terms is Rs. 146 billion per annum (Razzaq *et al*., 2012). Present agricultural system is productivity oriented and depends mainly on inorganic inputs (herbicides) to control pests (weeds) (Sadeghi *et al.*, 2010). Although herbicides provide promising rise in crop yield by efficient control of weeds, but, unwise use of these synthetic herbicides could cause several ecological and health related issues. Therefore, it is imperative to devise non-chemical and organic ways of controlling weeds in field crops (Farooq *et al.*, 2011). Allelopathy offers an innovative and attractive option for organic farming (Yongqing, 2005) and may be employed for weed management as well (Cheema *et al*., 1997, 2001, 2002a-c; Farooq *et al*., 2011).

In previous reports, allelopathy has been used for weed management in several crops including wheat (Cheema *et al*., 2000a), cotton (Cheema *et al*., 2000b), rice (Irshad and Cheema, 2004), maize (Cheema *et al*., 2004), canola (Jabran *et al*., 2008) and mungbean (Cheema *et al*., 2001). In this regard several potential allelopathic crops including sorghum (*Sorghum bicolor* L.), brassica (*Brassica campestris* L.), sunflower (*Helianthus annuus* L.), rice (*Oryza sativa* L.), eucalyptus (*Eucalyptus camaldulensis* D.), sesame (*Sesamum indicum* L.) and tobacco (*Nicotiana tabacum* L.) have been used for managing weeds in field crops (Purvis and Jones, 1990; Narwal, 1994; Cheema and Khaliq, 2000; Weston and Duke, 2003; Farooq *et al*., 2008; Joseph *et al*., 2008; Cheema *et al*., 2009; Jamil *et al*., 2009; Huerta *et al*., 2010; Jabran *et al*., 2010). Allelopathic crops had been used through multiple approaches including crop rotations, cover crops, intercropping, mulching, crop residue incorporation and water extracts application (Farooq *et al*., 2013). Allelochemicals present in these water extracts act as natural herbicide. For instance, Cheema (1988) found several allelochemicals such as gallic acid, protocateuic acid, syringic acid, vanillic acid, *p*-hydroxybenzoic acid, *p*-coumaric acid, benzoic acid, ferulic acid, *m*-coumaric acid, caffeic acids, dhurrin, *p*-hydroxybenzaldehyde and sorgoleone in sorghum. In later experiments, Cheema *et al*. (1997) found that one spray of sorghum water extract (sorgaab) inhibited the weed dry weight by 20-40% and enhanced wheat yield by 14%; however in another study two sprays of sorgaab inhibited weed density and biomass by 22- 46%, respectively, enhancing wheat yield by 21% (Cheema *et al*., 2000b).

Sunflower also contains several allelochemicals like chlorogenic acid, isochlorogenic acid, scopolin, annuionones and α-naphathol (Macias *et al*., 2002; Anjum and Bajwa, 2005), which may be used as natural herbicides. In a field experiment, Naseem *et al*. (2009) reported that

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application of sunflower water extracts inhibited the weeds dry weight up to 41% and enhanced the wheat yield by 17% compared with weedy check. *Phalaris minor* density and biomass were reduced by 50 and 65% when sunflower extract was applied as pre-emergence spray (Shahid *et al.*, 2006). In another study, Naseem *et al.* (2010) also found weed dry weight was reduced up to 70% when three sprays of sunflower water extract were applied at 25, 35 and 45 days after sowing in wheat crop. Similarly brassica species also possess several allelochemicals like ferulic acid, caffeic acid, vanillic acid, chlorogenic acid, glucosinolates, and isothiocyanates (Brown and Morra, 1995; Branca *et al.*, 2002), which may be used for organic weed management (Weston, 1996; Siemens *et al*., 2002). For instance, Arslan *et al*. (2005) reported that rapeseed shoot extract and turnip root extract inhibited the seed germination of *Physalis angulata* L. by 58.7% and 54.3%, respectively.

Researchers have investigated the synergistic effects of mixture of allelopathic water extracts at different rates against weeds in various crops (Cheema *et al*., 2002a; Jamil *et al*., 2009; Elahi *et al*., 2011; Awan *et al*., 2012). Cheema *et al*. (2003a) used mixture of sunflower, sorghum and eucalyptus aqueous extracts on wheat crop and observed ≥70% weed inhibition in wheat than sole sorghum application. Furthermore, Farooq *et al*. (2011) reported that insects and pests (weeds) could be controlled more efficiently by utilizing mixture of allelopathic crop water extracts rather than by applying single-plant water extract. Allelopathic activity is more probably due to the consequence of the interaction of numerous allelochemicals (Einhellig, 1995) that work in a synergistic way to inhibit the germination and weeds growth (Putnam *et al*., 1983).

Although a lot of information about the allelopathic potential of different crops is available as mentioned earlier, but information regarding allelopathic potential of sorghum, sunflower and brassica in mixture at higher rates with different application intervals for organic weed management in wheat crop is scarce. Prior to field trial, laboratory experiments also confirmed that sorghum, sunflower and brassica water extracts were more inhibitory to both narrow and broad leaved weeds of wheat than other crop water extracts and application of allelopathic water extracts at high concentrations substantially suppresses the weed density and biomass (Farooq *et al*., 2013). These allelochemicals may thus be used as natural pesticides at high concentrations (Farooq *et al*., 2011). This field study was, therefore, conducted to evaluate the potential of foliar applied mixture of sorghum, sunflower and brassica water extracts at two different levels (18 and 20 L ha^{-1}) applied at three intervals (25, 40 and 55 DAS) for weed control in wheat.

Materials and Methods

A two-year field study was conducted to explore the phytotoxic potential of sorghum along with other plant water extracts (sunflower, brassica) against weeds in wheat at the Agronomic Research Area, University of Agriculture, Faisalabad-Pakistan during 2009-2010 and 2010-2011. The trial was laid out in randomized complete block design replicated thrice having plot size during both years 2.20 m × 7.0 m.

The wheat variety Lasani-2008 was used as a test crop. Sowing of crop was made with single row hand drill having seed rate of 100 kg ha^{-1} in 8 inches spaced rows. Fertilizers nitrogen, phosphorus and potassium (N, P, K) were applied at 120, 90 and 62.5 kg ha^{-1}, respectively. The sources of fertilizers were urea (46% N), DAP (di-ammonium phosphate) (18% N, 46% P_2O_5) and SOP (sulfate of potash) (50% K_2O). All of the P and K and 1/2 of the N were applied as a basal dose, whereas the remaining half of the N was applied with 1st irrigation. The 1st irrigation was given 20 DAS and subsequent irrigations were applied at different growth stages of wheat according to crop needs. Based on a series of laboratory experiments, the allelopathic plants selected for this filed study were sorghum, sunflower and brassica. At maturity, the herbage (stem + leaves) of these plants was harvested to make crop water extracts of these. Preparation of crop water extracts was made by the method devised by Cheema and Khaliq (2000) and kept at room temperature. To avoid the leaching from plant material by rainwater, the plant material was dried and stored under shelter. The plant material was chopped into 2-cm pieces with the help of an electric fodder cutter machine. The chopped plant herbage was soaked with a ratio of 1:10 (w/v) at room temperature (21 ± 2°C) in distilled water for 24 h and was sieved through 10 and 60-mesh sieves. To reduce and concentrate the extracts volume these aqueous extracts were boiled at 100°C for easy handling and use. In the respective plots, the post-emergence spray of these plant water extract mixtures and the herbicide were applied. Knapsack hand sprayer was used for spraying, fitted with a T-Jet nozzle. Sorghum, sunflower and brassica water extracts were tank-mixed, each at 18 and 20 L ha^{-1}. All the allelopathic crop water extracts at different doses (18 L ha^{-1} and 20 L ha^{-1}) were applied at 25, 40 and 55 days after sowing (DAS) of wheat, while herbicide, idosulfuron + mesosulfuron (Atlantis 3.6 WG) at 14.4 g *a.i.* ha^{-1} (recommended rate) was applied at 25 DAS of wheat sown and a weedy check was used as a control treatment.

The data on total weed count and weed dry biomass was recorded at 40, 65 and 90 DAS respectively during both the years from two selected quadrates randomly, measuring 0.5 m × 0.5 m, then converted into m^{-2} from each experimental unit. To determine total weed density, weeds were counted individually and for total weed dry biomass, weeds were dried at 70°C in an oven till constant weight was obtained. All the (spike bearing) tillers were counted from two selected quadrates at random, measuring 0.25 m^2 and then converted into per square meter from each experimental unit to count fertile tillers. To record the number of grains per spike, grains from ten selected spikes randomly were counted and then averaged. Each plot was harvested manually to record biological and grain yield, were kept in the field for drying up to three days, tied with ropes to make bundles, weighed through spring balance, threshed manually and then changed into t ha^{-1}, whereas harvest index (%) was determined by dividing economical yield to total biomass multiplied by 100. The data obtained, were analyzed statistically by applying Fisher's analysis of variance technique and least significance difference test (LSD) at 5% was applied to compare the differences among treatment means (Steel *et al.*, 1996).

Economic analysis was done to determine the most cost-effective treatment. It was carried out on the basis of variable costs and prevailing market prices of herbicide and wheat crop to look into comparative benefits of different treatments following procedures of CIMMYT (1988).

Results

Weed flora of the experimental site comprised mainly of *Phalaris minor* L. (canary grass), *Chenopodium album* L. (lambs quarters), *Avena fatua* L. (wild oat), *Coronopus didyma* L. (swine cress), *Rumex dentatus* L. (broad leaf dock), while a few plants of *Convolvulus arvensis* L. (fieldbind weed), *Melilotus parviflora* L. (sweet clover), *Medicago polymorpha* L. (wild medic), and *Anagallis arvensis* L. (blue pimpernel) were also found in the experimental field.

A) Weeds Control

Total weed density was significantly reduced in all treatment combinations during both years (2009-2010 and 2010-2011) of study as compared to control (Table 1). Two sprays of sorghum+ sunflower+ brassica each at 18 L ha^{-1} at 25 and 40 DAS inhibited the total weed density by 55-59, 55-56 and 48-59% recorded at 40, 65 and 90 DAS, respectively during both the years and it was followed by two sprays of sorghum+sunflower+brassica each at 20 L ha^{-1} at 25 and 40 DAS controlling the weeds by 38-48%. However, the herbicide was most effective treatment with 78- 90% weed control. Application of two foliar sprays (25 and 40 DAS) of tank mixed sorghum+brassica +sunflower at 18 L ha^{-1} each, inhibited the total weed dry weight by 56-57, 48-58 and 52-56%, recorded at 40, 65 and 90 day after sowing respectively, during both the years of experimentation and it was statistically similar with treatment combination i.e., 2 sprays of sorghum+brassica+sunflower each at 20 L ha^{-1} applied at 25 and 40 DAS that suppressed total weed biomass by 39-48% than control. Remaining treatments were usually less inhibitory than above mentioned treatments for their suppressive effects to weeds. While, the herbicide (recommended) was most efficient treatment reducing 76-89% weed dry weight over control.

B) Wheat Crop

Number of productive tillers was significantly influenced by all treatment combinations with respect to control (Table 3). Among the plant water extract, number of productive tillers was significantly higher in the treatment where two foliar sprays of mixture of sorghum+ brassica + sunflower each at18 L ha^{-1} at 25 and 40 DAS were applied and these were highest than rest of the extract treatments during both the years of study except where two foliar sprays of mixture of sorghum+ brassica + sunflower each at 20 L ha^{-1} at 25 and 40 DAS during 1st year (2009-2010) were applied. Recommended dose of herbicide (idosulfuron + mesosulfuron) was relatively more effective than crop water extract combinations producing significantly more fertile tillers during both the years of experimentation than water extract combinations. Number of grains per spike of wheat was significantly improved by all the treatments than control during second year (2010-2011) and among these treatments, two foliar sprays of these extracts at 18 L ha^{-1} and at 20 L ha^{-1} were statistically at par with recommended herbicide (idosulfuron + mesosulfuron) that produced maximum number of grains per spike during this year (Table 3). However, during first year (2009-2010) maximum no of grains/spike was noted in recommended herbicide (idosulfuron + mesosulfuron) and among water extracts, treatment combinations i.e., one and two sprays of sorghum+ sunflower+ brassica each at18 L ha^{-1} in mixture at 25 and 25+40 DAS, respectively performed better than rest of the treatments. Maximum 1000-grain weight was recorded by foliar application of two sprays of mixture of sorghum, sunflower and brassica at 18 L ha^{-1} at 25 and 40 DAS during first year and it was followed by two sprays of mixture of sorghum, sunflower and brassica twice at 20 L ha^{-1} at 25 and 40 DAS. Rests of the treatments had little effect on 1000-grain weight and were statistically at par with control treatment except recommended herbicide and treatment combination i.e., Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} applied at 25 DAS, which performed comparatively better than said treatments (Table 3). Whereas, during second year, 1000-grain weight was significantly increased by all the weed control treatment combinations than control and maximum 1000-grain weight was recorded in recommended herbicide (idosulfuron + mesosulfuron).

Grain yield of wheat was significantly improved by all the weed control treatment combinations with respect to weedy check (control) during both years of experimentation (Table 3). Crop water extracts mixture i.e. two foliar sprays at 25 and 40 DAS at the rate of 18 L ha^{-1} improved wheat grain yield by 24 to 25% in both the years, respectively. Other extract treatments increased the wheat yield from 13 to 21% while the recommended herbicide enhanced the yield by 29 to 31% in both years respectively.

Table 1: Effect of allelopathic water extracts of sorghum, sunflower and brassica on weed density

No	Treatments	Total weed density (m^{-2})					
		40 DAS		65 DAS		90 DAS	
		2009-2010	2010-2011	2009-2010	2010-2011	2009-2010	2010-2011
T_1	Weedy check (control)	101.33 a	173.33 a	124.00 a	136.60 a	136.00 a	124.00 a
T_2	Atlantis 3.6 WG (Ido+mesosulfuron) (Recommended)	16.73 e(-83)	18.67 e(-89)	26.67 e(-78)	13.33 e(-90)	29.33 d(-79)	12.67 e(-90)
T_3	SWE+SNFWE+BWE at 18 L ha^{-1} (one spray)	65.33 b(-36)	113.33 b(-35)	77.33 bc(-38)	92.00 b(-33)	93.33 b(-33)	81.33 b(-34)
T_4	SWE+SNFWE+BWE at 18 L ha^{-1} (two sprays)	41.33 d(-59)	78.67 d(-55)	56.00 d(-55)	60.00 d(-56)	72.00 c(-48)	50.67 d(-59)
T_5	SWE+SNFWE+BWE at 18 L ha^{-1} (three sprays)	64.00 b(-37)	110.67 b(-36)	69.33 c(-44)	85.33 bc(-38)	90.67 b(-35)	74.67 b(-40)
T_6	SWE+SNFWE+BWE at 20L ha^{-1} (one spray)	61.33 bc(-39)	105.33 bc(-39)	81.33 b(-34)	90.67 b(-34)	98.67 b(-29)	80.00 b(-35)
T_7	SWE+SNFWE+BWE at 20 L ha^{-1} (two sprays)	56.00 c(-45)	90.67 cd(-48)	70.67 c(-43)	72.00 cd (-47)	86.67 bc(-38)	65.33 c(-47)
T_8	SWE+SNFWE+BWE at 20 L ha^{-1} (three sprays)	62.67 bc(-38)	109.33 bc(-37)	76.00 bc(-39)	85.33 bc (-38)	93.33 b(-33)	76.00 b(-39)
	LSD (p) 0.05	7.374	19.12	9.123	17.80	17.78	8.566

Table 2: Effect of allelopathic water extracts of sorghum, sunflower and brassica on weed dry weight

No	Treatments	Total weed dry weight (g m^{-2})					
		40 DAS		65 DAS		90 DAS	
		2009-2010	2010-2011	2009-2010	2010-2011	2009-2010	2010-2011
T_1	Weedy check (control)	32.43 a	24.13 a	30.94 a	36.13 a	70.48 a	32.43 a
T_2	Atlantis 3.6 WG (Ido+mesosulfuron) (Recommended)	4.05 d(-88)	3.45 d(-86)	7.46 d(-76)	4.00 d(-89)	11.80 e(-83)	7.20 d(-78)
T_3	SWE+SNFWE+BWE at 18 L ha^{-1} (one spray)	21.33 b(-34)	17.33 b(-28)	22.23 b(-28)	22.66 b(-37)	50.66 b(-28)	21.93 b(-31)
T_4	SWE+SNFWE+BWE at 18 L ha^{-1} (two sprays)	13.93 c(-57)	10.66 c(-56)	16.00 c(-48)	15.33 c(-58)	30.66 d(-56)	15.46 c(-52)
T_5	SWE+SNFWE+BWE at 18 L ha^{-1} (three sprays)	21.33 b(-34)	16.66 b(-31)	21.65 b(-30)	24.00 b(-34)	44.00 bc (-38)	20.53 b(-36)
T_6	SWE+SNFWE+BWE at 20L ha^{-1} (one spray)	20.00 b(-38)	17.33 b(-28)	21.33 b(-31)	22.66 b(-37)	48.25 bc (-32)	22.80 b(-29)
T_7	SWE+SNFWE+BWE at 20 L ha^{-1} (two sprays)	18.00 bc(-44)	14.66 bc(-39)	19.33 bc(-38)	18.66 bc(-48)	40.00 cd(-43)	18.66 bc(-42)
T_8	SWE+SNFWE+BWE at 20 L ha^{-1} (three sprays)	20.66 b(-36)	16.00 bc(-34)	21.66 b(-30)	24.00 b(-34)	44.37 bc(-37)	21.66 b(-32)
	LSD (p) 0.05	5.29	5.72	5.17		10.04	4.92

Table 3: Effect of plant water extracts on yield and yield components of wheat

Treatments		Productive tillers (m^{-2})		No. of grains $spike^{-1}$		1000-grain weight (g)		Grain yield (t ha^{-1})		Harvest index (%)	
		Year I	Year II	Year I	Year II	Year I	Year II	Year I	Year II	Year I	Year II
T_1	Weedy check (control)	253.9 e	275.0 e	33.9 e	36.2 d	35.1 d	36.3 c	3.1 e	3.7 e	34.5 b	36.4 d
T_2	Atlantis 3.6 WG (Recommended)	305.6 a	324.4 a	37.9 a	40.7 a	36.1 bc	38.0 a	3.93 a(29)	4.83 a(31)	37.85 a	41.52 a
T_3	SWE+SNFWE+BWE at 18 L ha^{-1} (one spray)	267.78 d	288.89 d	36.33 b	38.83 b	35.59 cd	37.33 ab	3.58 d(16)	4.28 cd(16)	36.08 ab	39.36 bc
T_4	SWE+SNFWE+BWE at 18 L ha^{-1} (two sprays)	290.56 b	309.45 b	36.00 bc	40.17 a	37.26 a	37.90 ab	3.82 b(24)	4.59 b(25)	37.34 a	40.43 ab
T_5	SWE+SNFWE+BWE at 18 L ha^{-1} (three sprays)	269.44 d	292.22 cd	35.47 bcd	38.83 b	35.92 bcd	37.17 b	3.62 cd(18)	4.30 cd(17)	36.41 ab	38.10 cd
T_6	SWE+SNFWE+BWE at 20L ha^{-1} (one spray)	282.22 c	288.89 d	34.60 de	37.67 c	36.06 bc	37.27 ab	3.60 cd(17)	4.16 d(13)	36.03 ab	37.29 cd
T_7	SWE+SNFWE+BWE at 20 L ha^{-1} (two sprays)	284.44 bc	299.44 c	35.57 bcd	40.00 a	36.59 ab	37.47 ab	3.74 bc(21)	4.39 bc(19)	36.97 a	39.05 bc
T_8	SWE+SNFWE+BWE at 20 L ha^{-1} (three sprays)	269.44 d	288.33 d	35.00 cde	38.66 bc	35.67 bcd	37.19 ab	3.56 d(16)	4.23 cd(15)	35.69 ab	38.01 cd
LSD at 5% probability Level		6.436	9.766	1.321	1.115	0.939	0.811	0.147	0.223	2.239	2.134

† Means not sharing a letter in common differ significantly at 0.05 p; Figures in parenthesis show percent increase over control

T_1=Control (weedy check),T_2=Atlantis 3.6 WG (Recommended), T_3=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 DAS), T_4=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 + 40 DAS), T_5=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 + 40 +55 DAS),T_6=Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} (25 DAS), T_7=Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} (25 + 40 DAS), T_8=Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} (25 + 40 +55 DAS), DAS = days after sowing, SWE = sorghum water extract, SNFWE = sunflower water extract, BWE = brassica water extract

Although increase in grain yield with herbicide was 5-6% more than the application of two foliar sprays of sorghum+ brassica + sunflower water extracts each at 18 L ha^{-1} yet the enhancement in economic yield of wheat with the crop extract mixture was fairly good (24 to 25%) in first and second year respectively. Certain crop water extract combinations significantly influenced harvest index of wheat than control during both the experimental years, however, some treatments were less effective and were statistically similar to the control treatment (Table 3). Maximum harvest index was recorded in herbicide treatment i.e. (idosulfuron + mesosulfuron) and it was statistically equal to the treatments i.e., mixed application of two foliar sprays of sorghum, sunflower and brassica WE each at18 L ha^{-1} and 20 L ha^{-1} at 25 and 40 DAS, respectively over control during both the years of study, respectively except treatment combination i.e. Sorghum+ sunflower + brassica WE at 20 L ha^{-1} (25 + 40 DAS), during second year. All the weed control treatment combinations gave higher net benefits than weedy check

Table 4: Economic analysis for the year 2009-2010

	T1	T2	T3	T4	T5	T6	T7	T8	Remarks
Grain yield	3.08	3.98	3.58	3.82	3.62	3.60	3.74	3.56	Mg ha^{-1}
Adjusted grain yield	2.77	3.59	3.22	3.44	3.26	3.24	3.37	3.20	10% less to bring at farmer level (Mg ha^{-1})
Income $ ha^{-1}	856.3	1107.5	993.9	1061.2	1006.5	999.5	1040.2	989.6	$ 12.35 /40kg
Straw yield	5.86	6.55	6.35	6.41	6.33	6.38	6.38	6.42	Mg ha^{-1}
Adjusted yield	5.27	5.89	5.71	5.77	5.70	5.75	5.74	5.78	10% less to bring at farmer level (Mg ha^{-1})
Income $ ha^{-1}	248.1	277.2	268.9	271.4	268.0	270.4	270.2	271.9	$ 1.88/40kg
Gross Income	1104.4	1384.8	1262.7	1332.7	1274.5	1269.9	1310.3	1261.5	$ ha^{-1}
Cost of WE's	-	-	5.3	10.6	15.9	5.9	11.9	17.8	Sorghum, sunflower, brassica, ($ 2, 1.88, 1.41 and 2.24,2.12,1.59) at18 and 20L ha^{-1} respectively
Cost of herbicide	-	19.1	-	-	-	-	-	-	Atlantis 3.6 WG (Idosulfuron + mesosulfuron) at 14.4 g a.i. ha^{-1}, $ 10/acre
Spray application cost	-	3.5	3.5	7.1	10.6	3.5	7.1	10.6	$ 3.53/man/day/ha
Sprayer rent	-	0.6	0.6	1.2	1.8	0.6	1.2	1.8	$ 0.59/spray/ha
Cost that vary	-	23.2	9.4	18.8	28.2	10.0	20.0	30.1	$ ha^{-1}
Net benefits	1104.4	1361.5	1253.3	1313.8	1246.2	1259.8	1290.2	1231.3	$ ha^{-1}

Table 5: Economic analysis for the year 2010-2011

	T1	T2	T3	T4	T5	T6	T7	T8	Remarks
Grain yield	3.68	4.83	4.28	4.59	4.30	4.16	4.39	4.23	Mg ha^{-1}
Adjusted grain yield	3.31	4.34	3.85	4.13	3.87	3.74	3.95	3.81	10% less to bring at farmer level (Mg ha^{-1})
Income $ ha^{-1}	1022.7	1341.6	1188.8	1275.4	1194.2	1155.1	1221.3	1176.1	$ 12.35 /40kg
Straw yield	6.42	6.80	6.59	6.76	6.98	6.99	6.86	6.92	Mg ha^{-1}
Adjusted yield	5.78	6.12	5.93	6.08	6.28	6.29	6.17	6.22	10% less to bring at farmer level (Mg ha^{-1})
Income $ ha^{-1}	272.1	288.1	279.2	286.2	295.6	296.1	290.6	292.9	$ 1.88/40kg
Gross Income	1294.8	1629.7	1468.0	1561.6	1489.8	1451.2	1511.8	1469.0	$ ha^{-1}
Cost of WE's	-	-	5.3	10.6	15.9	5.9	11.9	17.8	Sorghum, sunflower, brassica, ($ 2, 1.88, 1.41 and 2.24,2.12,1.59) at18 and 20L ha^{-1} respectively
Cost of herbicide	-	19.1	-	-	-	-	-	-	Atlantis 3.6 WG (idosulfuron + mesosulfuron) at 14.4 g a.i. ha^{-1}, $ 10/acre
Spray application cost	-	3.5	3.5	7.1	10.6	3.5	7.1	10.6	$ 3.53/man/day/ha
Sprayer rent	-	0.6	0.6	1.2	1.8	0.6	1.2	1.8	$ 0.59/spray/ha
Cost that vary		23.2	9.4	18.8	28.2	10.0	20.0	30.1	$ ha^{-1}
Net benefits	1294.8	1606.5	1458.6	1542.8	1461.6	1441.1	1491.7	1438.8	$ ha^{-1}

T_1=Control (weedy check),T_2=Atlantis 3.6 WG (Recommended), T_3=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 DAS), T_4=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 + 40 DAS), T_5=Sorghum+ sunflower+ brassica WE at 18 L ha^{-1} (25 + 40 +55 DAS),T_6=Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} (25 DAS), T_7=Sorghum+ sunflower+ brassica WE at 20 L ha-^{1} (25 + 40 DAS), T_8=Sorghum+ sunflower+ brassica WE at 20 L ha^{-1} (25 + 40 +55 DAS), DAS = days after sowing, WEs= Water extracts; $=US Dollar (1US$= 85 PKR)

(control) during both years (Tables 4, 5). In both years, mixed application of two foliar sprays of sorghum+ sunflower+ brassica each at18 L ha^{-1} at 25 and 40 DAS gave higher net benefit than control, followed by mixed application of two foliar sprays of sorghum+ sunflower+ brassica each at 20 L ha^{-1} at 25 and 40 DAS. However, in both years, label dose of herbicide i.e., idosulfuron + mesosulfuron gave highest net benefits than all water extract combinations and weedy check control.

Discussion

This study indicated that all weed control methods significantly affected weed dynamics, yield related traits and grain yield of wheat. Combine application of allelopathic water extracts significantly reduced the weed density and dry matter than weedy check during both years (Table 1), and greater reduction in weed density (48-59%) and dry weight (48-58%) was recorded when two foliar sprays (25+40 DAS) of sorghum +brassica + sunflower water extracts in mixture were applied at rate of 18 L ha^{-1}. However, maximum weed suppression was obtained by application of standard herbicide (idosulfuron + mesosulfuron), which reduced weed density by 78-90% and dry weight by 76-89% in both years respectively. This higher weed suppression by chemical herbicide than allelochemicals may be attributed to inhibition of biosynthesis of essential amino acids in weeds by this herbicide (Mason-Sedun, 1986). In another study, maximum weed control (76-82%) and yield increase (74-77%) in rice than weedy check was obtained with the application of chemical herbicide than crop water extracts (Rehman *et al.*, 2010).

Inhibition of the weeds with two sprays (25+40 DAS) of a mixture of sorghum, brassica and sunflower water extracts at 18 L ha^{-1} may be due to the presence of different allelochemicals in these extracts which may have affected the weed growth. In earlier studies, it has been reported that allelochemicals/phytotoxins in sorghum i.e. gallic acid, syringic acid, protocateuic acid, *p*-hydroxybenzoic acid, vanillic acid, benzoic acid, *p*-coumaric acid, ferulic acid, caffeic acids, phydroxybenzaldehyde, *m*-coumaric acid and sorgoleone may inhibit the growth of many weed species (Netzly and Butler, 1986; Cheema *et al*., 2009). Moreover, allelochemicals in brassica i.e. ferulic, caffeic, vanillic acid, chlorogenic, glucosinolates, isothiocyanates (Brown and Morra, 1995; Branca *et al.,* 2002) and sunflower i.e. chlorogenic acid, isochlorogenic acid, scopolin, annuionones and α-naphathol (Macias *et al*., 2002; Anjum and Bajwa, 2005) has been reported to inhibit the growth of weeds (Einhellig, 1996). The presence of phytotoxins in sorghum, sunflower and brassica might have interacted to strengthen the overall phytotoxicity resulting in maximum weed suppression when applied in combination (Putnam and Tang, 1986). In another study, it has been reported that allelochemicals adversely affects the physiological and metabolic processes of weeds due to their phytotoxicity and complementary action which ultimately inhibited growth of weeds (Duke and Laydon, 1993) as was observed in this study. Furthermore, in a mixture, compounds can substitute each other on the basis of their biological exchange rate and may enhance the potency of each other (Gerig and Blum, 1991), which may be the possible reason for the maximum suppression of weeds when allelopathic water extracts were applied in combination. It might be possible that at high concentrations, these allelochemicals have interfered with the cell division, hormone biosynthesis, and mineral uptake/transport (Rizvi *et al*., 1992), membrane permeability (Harper and Balke, 1981), stomatal oscillations, photosynthesis (Einhellig and Rasmussen, 1979), respiration, protein metabolism (Kruse *et al*., 2000) and plant water relations (Rice, 1984), which caused substantial growth reduction (Farooq *et al*., 2013), in weeds in this study. Furthermore, insects and pests (weeds) could be controlled more efficiently by utilizing mixture of allelopathic crop water extracts than their sole application (Farooq *et al.,* 2011). Hence, use of sorghum, sunflower and brassica water extracts in combination, is a useful technique for inhibition of both broad and narrow leaved weeds. Effectiveness of two sprays of allelochemicals than three sprays might be due to the fact that allelochemicals suppress weeds only when weeds are at early growth stages (An *et al*., 1996). Moreover, maximum weed suppression due to combine application of two or more allelopathic water extracts might be due to the more phytotoxic effect of these chemicals when applied in mixture (Duke *et al*., 2000; Jamil *et al*., 2009). In another study, mixtures of sorghum, sunflower and eucalyptus water extracts caused >70% weed suppression in wheat than sorghum water extract alone (Cheema *et al*., 2002b). If wisely planned, allelopathic phenomenon is quite effective in managing agricultural pests and improving the productivity of agricultural systems (Farooq *et al*., 2013).

Grain yield and yield contributing parameters of wheat were significantly improved by all the combinations with respect to control during both experimental years (Table 3). Maximum number of productive tillers in case of crop water extracts was obtained where sorghum + brassica + sunflower each at18 L ha^{-1} at 25 and 40 DAS were applied with respect to other extract combinations during both the years (Table 3). The rise in number of productive tillers might be due to better weed control, which helped wheat plant to utilize the available resources more efficiently, resulting in increased number of productive tillers that confirm the idea that productive tillers increases with better weed inhibition by exploiting crop allelopathy (Cheema *et al*., 2002a; Jamil *et al*., 2009; Elahi *et al*., 2011; Awan *et al*., 2012). Maximum number of grains per spike was obtained where sorghum + brassica + sunflower aqueous extracts each at18 L ha^{-1} at 25 and 40 DAS was applied (Table 3). Smothering of weeds resulted in more photosynthates assimilation in wheat and subsequently their translocation toward grains (Borras *et al*., 2004), which could be the cause of higher number of grain per spike. It was obvious from the data (Table 3) that all the treatments significantly influenced wheat grain weight compared to weedy check. Maximum grain weight compared to control was found in plots where two foliar sprays of sorghum + sunflower + brassica each at18 L ha^{-1} at 25 and 40 DAS were applied, other treatments also showed increase in grain weight which might be a result of better weed control resulting in the maintenance of grain weight due to less weed competition. In another study, maximum grain weight was obtained in the plots where weeds were controlled (Hussain *et al*., 2009); hence, weed free wheat plants got maximum nutrition and water from available resources to enhance overall growth and 1000 grain weight (Mushtaq *et al*., 2010).

Maximum enhancement in wheat grain yield in case of crop water extracts was obtained by two foliar sprays of sorghum, sunflower and brassica each at18 L ha^{-1} at 25 and 40 DAS but it was less than label dose of standard herbicide (idosulfuron + mesosulfuron). The increased grain yield was possibly due to better weed control which resulted in better leaf area facilitating photosynthesis and hence more grain formation and maintenance of grain weight (Rehman *et al*., 2010). The improvement in grain yield under different treatments might be due to the more weed inhibition, which favoured number of productive tillers, grains number per spike, grain weight, and ultimately grain yield. In addition to weed suppression, allelochemicals enhance mineralization of nutrients and improve their uptake (Barber, 1984; Harms and Oplinger, 1993), which resulted in better nutrient acquisition and better wheat yields. Moreover, they regulate maturity, senescence (Goldthwaite, 1987) water relations, translocation of assimilates and quality (Harms and Oplinger, 1993). Better weed suppression enabled the crop plants to use the available environmental resources in a better way and solar radiation interception without any hindrance (Irshad and Cheema, 2004; Jabran *et al*., 2008), resulting in better crop yields.

In this study, harvest index was increased with the efficient weed control which might be due to more nutrients availability in the plot where there was less weed-wheat competition resulting in more harvest index (Marwat *et al*., 2005). Suitability of any treatment ultimately lies in its economic returns and the costs involved, and also its impact on the environment. All the weed control methods produced significantly higher net profits than control (Table 4, 5). Two sprays of sorghum, brassica and sunflower each at18 L ha^{-1} at 25 and 40 DAS being superior among all water extracts applied in various combinations, which might be attributed to the fact that the allelopathic water extracts can be easily prepared manually without any reliance on the synthetic sources (herbicides) which are to be purchased from the pesticide market after heavy payment (Jabran *et al*., 2008; Jamil *et al*., 2009; Awan *et al*., 2012). Allelopathy offers economical and ecofriendly option for pest management (Farooq *et al*. 2013), without reliance on the chemical and mechanical means of weed control.

Conclusion

Combine exogenous application of sorghum, sunflower and brassica twice (25 and 40 DAS) at higher rates suppressed the weeds, resulting in better crop growth, improved yield related traits and ultimately the yield. Thus use of allelochemicals offer an economical and eco-friendly option to control weeds in wheat.

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