

Weed control in wheat through different sorghum formulations as an organic herbicide

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Abstract

The impact of phytotoxic potential of sorghum formations and herbicide application along with their comparative economic advantages over each other in the wheat crop, was evaluated in present filed study. The sorghum formulations with their application volumes were as i) the water soaked extract (330 L ha⁻¹), ii) water boiled extract (15, 20, 25 or 30 L ha⁻¹), iii) fine powdered (270, 360, 450 or 540 g ha⁻¹). Most of the sorghum formulations controlled weed density in array 24-61%. The weeds dry weight was declined by 20-59% and crop yield raised upto 25%. The water soaked extract at a volume of 330 L ha⁻¹ and water boiled extract at 20 L ha⁻¹ volume were not only useful in weed control but also enhanced yield and demonstrated economic profitability. These treatments provided higher rates of marginal returns % 154.54 \$ and 47.70 \$, respectively. Although, sorghum powder were effective in weed control but were uneconomical because of their high production cost.

Keywords: Allelopathy, Toxins, Weeds, Wheat, Herbicides

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Introduction

Weeds are the potential competing factor in the agro-ecosystem which can deprive the crops from necessary growth factors including space, water and nutrients (Bilalis et al., 2010). The concerns in changing environments need special consideration for weed management without chemical approach

(Corley, 2015; Kadioglu and Farooq, 2017; Glab et al., 2017). Irrespective of the resource competing factors, the crops are also subjected to the toxic allelochemicals of weeds released by exudation into the rhizosphere and can inhibit germination, growth and yield (Zohaib et al., 2014). The estimated wheat yield losses owing to establishment of weeds are up to 25-30%. There are various approaches for the



management of weeds such as chemical, mechanical, bio-herbicide and agronomic management practices (Cheema and Khaliq, 2000; Bilalis et al., 2010). From the above reports, chemical weed control through herbicides is considered a resourceful weed management method (Torun and Uygur, 2012). However, application of herbicides has posed serious threats to the environment and raised health concerns (Zhu and Li, 2002; Khan and Damla, 2015; Corley, 2015). Certain other problems are also arising because of induced herbicide resistance even against herbicides such as glyphosate. Organic agriculture focuses on the sustainable solution to weed and insect problem through bio-herbicides (Cheema et al., 2004; Smith et al., 2015; Silva et al., 2015). Bio-herbicides are chemicals which originate from the internal metabolism of plants and are entered into ecosystem via leaching process, exudation of roots, volatilized from live plants parts, or from decomposition of residues. Allelopathy phenomenon is due to the allelochemicals which contain various chemical group types. The prominent chemical groups are cummins, flavonoids, alkaloids and terpenes (Mazid et al., 2011). The most commonly observed effects are on growth of seedling and cell meristematic activity (Glab et al., 2017). Sorgoleone (sorghum most studied allelochemical) blocks ATP synthesis, while benzoic acid interrupts essential element absorption in plants, blocks photosystem-II, carbon assimilation and photochromic activity (Mahmood and Cheema, 2004; Farooq et al., 2011, 2013).

Sorghum is established an allelopathic plant, which contain several chemicals of different nature (Anne et al., 2009; Farooq et al., 2013; Weston et al., 2013). These are identified and named as sorgoleone, vanillic acid, syringic acid, ferulic acid, p-hydroxy-benzoic acid, gallic acid, phenols, p-coumaric acid and 3-deoxy anthocyanidin derivatives (Weston et al., 2013). Sorgoleone has been recognized to influence the electron transport chain in photosystem-I and photosystem-II, thus giving it a bio-herbicide recognition (Glab et al., 2017). As far as the application of sorghum allelopathy is concerned, its field appraisal needs to be evaluated under the given circumstances. Therefore, this research was intended to assess the phytotoxic potential of sorghum by making water extract and dried powder in comparison with herbicide.

Material and Methods

Climate of the study site and characteristics of used soil

The study was conducted at Agronomic Research Area, (31°27' N, 73°08' E, 184 meters above sea level), University of Agriculture, Faisalabad, Pakistan. The constituency has a semi-arid climate along with very hot summer and cool up to 2 °C in January. Wheat growing season spans from October to the first quarter of May.

Soil samples were analyzed for physico-chemical properties including texture, saturation paste pH, soil organic matter (SOM), available phosphorus and potassium following Iqbal et al. (2017). The obtained data are presented in Table 1.

Table-1: Physico-chemical properties of soil used for experiment and meteorological data

Parameter	Value
Soil type	Clay Loam
Sand (%)	20
Silt (%)	45
Clay (%)	35
pH	7.5
Soil Organic Matter (%)	0.97
Total Nitrogen (%)	0.10
Available Phosphorus (mg kg ⁻¹)	15.2
Available Potassium (mg kg ⁻¹)	240
Meteorological data	(2011-12)
Climate (<i>Köppen-Geiger classification</i>)	Semi-arid (very hot and humid summers and dry cool winters.)
Annual ave. Temperature (°C)	
Ave. Highest Temp. (°C)	31.6
Ave. Lowest Temp. (°C)	17.4
Total precipitation (mm)	346

Sorghum formulations

The following treatments were planned with a concentration on per hectare basis viz, a weedy check (control), herbicide application, water-soaked, boiled and powdered sorghum formulations in various concentrations. Boiled sorghum extract solutions were made with concentrations @ 15, 20, 25 or 30 L ha⁻¹, which were further added into 100 liters water containers as to make the volume upto enough level for spray over the one hectare. Likewise, the powder formulations were 270, 360, 450 and 540 g ha⁻¹. Moreover, sorghum water soaked extract 330 L ha⁻¹



and pre-emergence herbicide iodosulfuron + mesosulfuron (Atlantis 3.6 WG) 14.4 g ha⁻¹ a.i. were also included in this study.

Sorghum water extract was geared up in allelopathy laboratory subsequent the procedures adopted by Cheema and Khaliq (2000). In procedure, mature sorghum crop (cultivar JS-263) was used for all these treatment formulations. Sorghum above ground parts were harvested and placed in the shade for a couple of days to avoid leaching by rain. After drying in the shade, it was chopped by ordinary fodder cutter. Thereafter, it was used for water-soaked, boiled water extraction, and powder formulations. The small cut pieces of sorghum were immersed in 1:10 ratio (1 kg in 10 liters) for 24 hours and concentrated to reduce its volume by 95% via boiling at 212°F for boiled water extractions. Sorghum powder was prepared through a spray drier and prepared through hot evaporation method. One liter of sorghum extract yielded about 18 g of sorghum powder. The calibrated volume of spray was equivalent to 330 L ha⁻¹. The application of formulations was made by means of Knapsack sprayer with T-jet nozzle. Sorghum application was made 30 days after sowing and after the emergence of wheat. At 30 DAS, wheat was at the stage of tillering (GS-29 i.e., growing stage 29 with 5-9 tillers; *Phalaris minor*: 3-4 leaf stage, *Avena fatua*; 3 leaf stage).

Crop management practices

The experiment was divided into six blocks and planned as randomized complete block design. Wheat was planted in 25 cm apart rows in plot dimensions (2m×7m) with 8 rows in each plot. Planting was made in uniformly-prepared soil with seeding rate 125 kg ha⁻¹. Fertilization was done at 100-90-75 kg ha⁻¹ as N:P:K half on soil formulations and remain in two slits. Irrigation was applied at stage 2 (tiller beginning), stage 7 (formation of secondary node of stem), stage 10.4 (three-quarter head emerged) and stage 11.1 (milky ripe stage) according to the Feekes scale of cereal crops (Large, 1954).

Data collection and interpretation

Weed density measurement was made by using a quadrat (1m×1m) dimension at 3 places after 35 and 60 days of sowing. Weeds (*Phalaris minor* and *Chenopodium album*) were also removed for dry weight measurement from the same plots. The yield

and other related traits were measured at maturity. Harvesting was done manually and threshed with a small mechanical thresher. The data presented is the average of various recorded observations. The weeds dry weight was determined by oven-drying at 75°C for the period of 48 hours and weighed till constant observation. Data interpretation was made by Fisher's analysis of variance technique using Statistix 8.2 and treatment differences were estimated employing the LSD test at 5% probability. Data normally distributed and used without any transformation to execute ANOVA.

Economic analysis

Economic efficiency of various treatments was evaluated according to the method devised by Byerlee (1988). According to this method, the fixed cost (non-treatment) comprise seed, fertilizer and machinery inputs and variable cost (treatment expenditure). A 10% yield reduction (Adjusted yield) is made for economic analysis, taking into consideration the loss that occurs due to harvesting and transport from field to market by the farmers (Arif et al., 2015). Net benefits were obtained by subtracting every variable cost (i.e. herbicide, cost of formulations of water soaked extractions, sorghum allelopathic powder, rent of sprayer machine or spray labour cost) as of gross income. The calculations are in local currency (Pak rupee) for estimation of various costs and to make easy calculations (1 Dollar = 104.82 Rs.).

Marginal rate of returns (MRR%)

The marginal analysis determines the dominance of a treatment on the preceding treatment and estimated through ordering the treatments in increasing direction and the MRR was calculated using following formula:

$$\text{MRR\%} = \frac{\text{marginal net benefits (Rs.)}}{\text{marginal expenditures (Rs.)}} \times 100$$

Results

Weed flora at the investigational place mainly include two weed species i.e., little seed canary grass (*Phalaris minor*) and lambquarters (*Chenopodium album*).



Table-2: Effect of sorghum water extract, sorghum powder formation, and sorghum soaked water extract on weed density

Treatments	Weed density (30 DAS)	Weed density (60 DAS)	Density of <i>P. minor</i> (30 DAS)	Density of <i>P. minor</i> (60 DAS)	Density of <i>C. album</i> (30 DAS)	Density of <i>C. album</i> (60 DAS)
Weedy check	36.2a	49.0a	19.7ab	17.0a	16.5a	9.2a
Water application (25 DAS)	33.2ab (9%)	48.7a (1%)	21.5a (13%)	13.0abc (23%)	11.7ab (28.78%)	4.2 ab (54.04%)
Herbicide application* (25 DAS)	9.5e (73%)	18.0e (64%)	5.0d (75%)	3.7d (78%)	4.5c (72.72%)	2.7b (70.27%)
Sorghum water soaked extract solution @330 L ha ⁻¹ (25 DAS)	25.7abcd (28%)	27.5cde (43%)	16.2abc (18%)	7.2cd (57%)	9.5 bc (42.42%)	3.7 ab (59.45%)
Sorghum boiled water extract @ 15 L ha ⁻¹ (25 DAS)	27.5 abc (24%)	44.5 ab (9%)	14.2 abc (27%)	14.2 ab (16%)	13.2ab (19.69%)	3.7 ab (59.45%)
Sorghum boiled water extract @ 20 L ha ⁻¹ (25 DAS)	16.7 de (53%)	31.2 cd (34%)	9.0 cd (56%)	7.7 cd (53%)	7.7 bc (53.03%)	4.2 ab (54.05%)
Sorghum boiled water extract 25 L ha ⁻¹ (@ 25 DAS)	26.7abcd (26%)	20.7 de (57%)	16.0 abc (19%)	8.7 d (51%)	10.7abc (34.48%)	2.7 b (70.27%)
Sorghum boiled water extract @ 30 L ha ⁻¹ (25 DAS)	22.2cd (38.76%)	36.0 bc (26%)	13.7 abc (31%)	11.0abcd (35%)	8.5 bc (48.48%)	7.0 ab (24.32%)
Sorghum powder @ 270 g ha ⁻¹ (25 DAS)	25.2 bcd (38.7%)	21.2 de (58%)	14.5 abc (26%)	8.0 cd (53%)	10.7 abc (34.48%)	3.0 b (67.56%)
Sorghum powder @ 360 g ha ⁻¹ (25 DAS)	21.5 cd (41%)	26.7 cde (45%)	13.5 bc (31%)	9.0 bcd (47%)	8.0 bc (51.51%)	4.0 ab (56.75%)
Sorghum powder @ 450 g ha ⁻¹ (25 DAS)	24.5 bcd (32%)	34.5 bc (30%)	15.0 abc (24%)	13.2 abc(22)	9.5 bc (42.42%)	7.2 ab (21.62%)
Sorghum powder @ 540 g ha ⁻¹ (25 DAS)	30.5 abc (16%)	22.5 de (56%)	17.0 ab (13%)	8.5 d (50%)	13.5 ab (18.18%)	3.7 ab (59.45%)
LSD value p<0.05	10.6	6.3	7.8	6.3	12.0	4.3

*=(Iodosulfuron + mesosulfuron 14.4 g ha⁻¹ Atlantis @3.6 WG active ingredients)
DAS stands for: Days after sowing
Figures in parentheses denote the percentage reduction in weed density as compared to weedy check

Weed density

Weed density was considerably inclined by diverse sorghum formulations and applied herbicide. The maximum weed density was observed in control (weedy check). Whereas, herbicide application resulted in minimum values (Table 2).

Among the sorghum formulations, a significant weed reduction (53%) in weed density was observed through the sorghum boiled water extract @ 20 L ha⁻¹ in comparison with control (weedy check) after 30 days of wheat sowing. While 25 L water boiled sorghum extract was effective (57% reduction) 60 days after sowing. It was observed a considerable variation in weed control between different species. For example, the sorghum formulations controlled *Phalaris minor* by 20-57% and *Chenopodium album* by 21-67%. Irrespective of considerable reductions by sorghum formulations, herbicide reduced weed density by 73% and 64% after 30 and 60 DAS.

Weeds dry weight

Weeds DW determined the biomass reduction of weeds under study. Most of the treatments suppressed weeds, thereby reducing the DW (Table 3). It was observed that sorghum powder in an amount of 360 g ha⁻¹ considerably declined the weeds DW by 59%, and sorghum water extract at application of volume 20 L ha⁻¹ was efficient to lessen the overall weeds dry

weight by 61% than control. The decrease in the weeds DW by the boiled water extracts of sorghum (at volumes of 15, 20, 25 and 30 L ha⁻¹) extend from 35% to 61%, estimated on 30 and 60 DAS. While sorghum powder weights viz. 270, 360, 450 and 540 g ha⁻¹, declined weed DW 24% to 59% at the respective observational durations. The application of water soaked extraction, declined weeds DW from 50 to 59% estimated at the same 30 and 60 DAS. Overall the highest reduction in DW was observed under herbicide application.

Growth and yield-related attributes

Highest growth and yield-related attributes were observed, when herbicide Atlantis (3.6 WG; iodosulfuron + mesosulfuron) at a concentration of 14.4g ha⁻¹. For wheat, the biological and economic yields were increased significantly (p≤0.05) due to sorghum formulations application in the range of 9-25% than control.

Economic analysis

Economic analysis is presented in the Tables 5 and 6 and it was observed that sorghum treatments remained economically valuable. The highest net benefits 1056 \$ over control came from the sorghum boiled water treatment when it was applied at a volume of 20 liters per hectares.



Table-3: Effect of application of various sorghum formulations on weeds dry weight present in wheat (g/m²)

Treatments	Weeds dry weight (30 DAS)	Weeds dry weight (60 DAS)	Dry weight of <i>Phalaris minor</i> (30 DAS)	Dry weight of <i>Phalaris minor</i> (60 DAS)	Dry weight of <i>Chenopodium album</i> (30 DAS)	Dry weight of <i>Chenopodium album</i> (60 DAS)
Weedy check	0.9 a	11.5 a	0.35 a	2.6 a	0.64 a	3.33 a
Water application (25 DAS)	0.80 ab (11%)	9.74 a (15%)	0.30 a (14%)	2.3 ab (12%)	0.50 ab (22%)	2.81 ab (15%)
Herbicide application* (25 DAS)	0.15 e (83%)	1.49 d (88%)	0.07 c (80%)	0.40 d (84%)	0.07 e (90%)	0.23 e (93%)
Sorghum water soaked extract solution @330 L ha ⁻¹ (25 DAS)	0.45 cd (50%)	4.59 bcd (59%)	0.21 ab (40%)	1.04 cd (60%)	0.30 cd (54%)	1.54 cd (54%)
Sorghum boiled water extract @ 15 L ha ⁻¹ (25 DAS)	0.59 bc (35%)	6.89 b (41%)	0.16bc (54%)	1.89 abc (28%)	0.40 bc (38%)	2.02 bc (39%)
Sorghum boiled water extract @ 20 L ha ⁻¹ (25 DAS)	0.41 cd (54%)	4.56 bcd (61%)	0.14 bc (59%)	1.16 bcd (56%)	0.27 cde (58%)	1.43 cd (58%)
Sorghum boiled water extract 25 L ha ⁻¹ (@ 25 DAS)	0.47 cd (48%)	4.62 bcd (59%)	0.18bc (50%)	1.24 bcd (52%)	0.22 cde (63%)	1.37 cd (59%)
Sorghum boiled water extract @ 30 L ha ⁻¹ (25 DAS)	0.56 bc (38%)	6.52 b (44%)	0.19 bc (46%)	2.11 abc (19%)	0.35 cd (46%)	1.97 bc (41%)
Sorghum powder @ 270 g ha ⁻¹ (25 DAS)	0.59bc (34%)	5.83 bc (49%)	0.27 ab (23%)	1.31 bcd (50%)	0.32 cd (50%)	1.57 cd (53%)
Sorghum powder @ 360 g ha ⁻¹ (25 DAS)	0.36 (59%) de	5.70 bc (50%)	0.23 ab (35%)	1.18 bcd (55%)	0.24 cde (61%)	1.46 cd (57%)
Sorghum powder @ 450 g ha ⁻¹ (25 DAS)	0.38 (58%) de	5.350 bc (54%)	0.21bc (40%)	1.96 abc (24%)	0.25 cde (60%)	1.95 ab (42%)
Sorghum powder @ 540 g ha ⁻¹ (25 DAS)	0.69 (24%) b	5.73 bc (50%)	0.32 A (13%)	1.27 bcd (51%)	0.39 bc (40%)	1.52 cd (53%)
LSD Value p<0.05	0.24	2.63	0.23	1.23	0.17	1.1344
* = Represents the (Iodosulforun + mesosulform 14.4 g ha ⁻¹ Atlantis @3.6 WG active ingredients) DAS stands for: Days after sowing Figures in parentheses denote the percentage reduction in weed dry weight as compared to weedy check						

Table-4: Effect of application of various sorghum formulations on growth and yield components of wheat

Treatments	Harvest index (%)	Biological yield (tons ha ⁻¹)	Economic yield (tons ha ⁻¹)	Plant height (cm)	Leaf area (cm ²)
Weedy check	33.7 e	9.3 f	3.5 f	87.3 cd	178.9 d
Water application (25 DAS)	33.2 e	9.4 f (10.6%)	3.8 ef (5.7%)	88.7 bcd (1.5%)	212.8 c
Herbicide application iodosulforun + mesosulforun @ 14.4 g ha ⁻¹ (Atlantis @ 3.6 WG)	47.5 a	12.2 a (25%)	5.0 a (29.5%)	98.5 a (11.2%)	267.2 a
Sorghum water soaked extract solution @330 L ha ⁻¹ (25 DAS)	42.7 abcd	10.8 cde (14.6%)	4.6 abc (22%)	93.2 ab (6.3%)	251.7 a
Sorghum boiled water extract@ 15 L ha ⁻¹ (25 DAS)	37.2 cde	10.1 ef (8.0%)	3.9 def (10%)	86.7 d (72%)	224.4 bc
Sorghum boiled water extract@ 20 L ha ⁻¹ (25 DAS)	44.2 ab	11.0 bcd (15%)	4.8 ab (25%)	90.0 bcd (2.9%)	255.6 a
Sorghum boiled water extract@ 25 L ha ⁻¹ (25 DAS)	43.5 abc	11.8 ab (9.1%)	4.6 abc (23%)	92.5 bc (5.5%)	263.2 a
Sorghum boiled water extract@ 30 L ha ⁻¹ (25 DAS)	38.5 bcde	10.1 ef (8.0%)	4.0 cdef (12%)	86.7 d (72%)	227.4 bc
Sorghum powder @ 270 g ha ⁻¹ (25 DAS)	43.7 abc	11.6 abc (20%)	4.7 ab (25%)	88.2 bcd (.99%)	264.4 a
Sorghum powder @ 360 g ha ⁻¹ (25 DAS)	41.2 abcd	11.5 abc (21%)	4.7 ab (24%)	91.0 bcd (3.9%)	258.3 a
Sorghum powder @ 450 g ha ⁻¹ (25 DAS)	36.7 de	10.4 de (14%)	4.2 bcde (16%)	87.5 cd (.14%)	230.3 b
Sorghum powder @ 540 g ha ⁻¹ (25 DAS)	41.0 abcd	10.3 de (13%)	4.4 abcd (20%)	90.0 bcd (2.9%)	256.0 a
LSD Value p<0.05	6.6	0.90	0.59	5.5	16.8
Means sharing an letter in common does not differ significantly at ≤5% probability level					
DAS stands for days after sowing; Lha ⁻¹ represents liters per hectare					

The net benefits of sorghum water boiled extract at the application of 15, 20, 25 and 30 liters per hectare ranged from 872 \$ to 1056 US \$. Whereas, sorghum powder applied amounts in 270, 360, 450 and 540 g ha⁻¹ had benefits at value of 933 \$ to 1044 \$. Applied sorghum water extract at a volume of 330 L ha⁻¹ bestow the benefits of value 1015\$. On the other hand, to the extent of marginal benefits (MRR%), the herbicide application had an expenditure of 16.69 \$, but remained still economical

with 315% MRR. Sorghum extract as soaked water extract application at a volume of 330 liters on per hectare basis gave the marginal rate of return of 154.55 \$, whereas sorghum water boiled extraction at a volume of 25 liters per hectare gave an MRR of 5000%. Application of water (second control) was also economical (1371% MRR). Whereas, the remaining treatments were found dominated owing to high associated costs and less value of benefits, thus can be considered uneconomical.



Table-5: Economic analysis of the treatments

Parameters	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉	T ₁₀	T ₁₁	T ₁₂	Remarks
Grain yield	3.5	3.8	5.0	4.6	3.9	4.8	4.6	4.0	4.7	4.7	4.2	4.4	
Adjusted yield	3.2	3.4	4.5	4.1	3.5	4.3	4.2	3.6	4.2	4.2	3.8	4.0	t ha ⁻¹ (10% reduction to bring at farmers level)
Gross income	82915	88065	117677	106836	92004	111240	108227	94502	110081	109386	98493	104055	Wheat price at = PKR 25750 tonn
Cost of herbicide	0	0	1750	0	0	0	0	0	0	0	0	0	Herbicide iodosulforun +mesosulforun@ 14.4 g ha ⁻¹ (Atlantis @ 3.6 WG a.i) = Rs.750/160g
Cost of extracts and powder formation	0	0	0	115	150	200	250	300	217.5	290	362.5	435	Sorghum herbage = 40 PKR/40 kg as 1PKR/1kg. Labour cost for soaking sorghum =75 PKR Expenditure on preparation of sorghum water boiled extracts = (Rs10/L) (150/15L Expenditure on sorghum allelopathic powder Via spray dryer = 250 Rs per kg
Sprayer rent	0	50	50	50	50	50	50	50	50	50	50	50	PKR 50 spray ⁻¹
Spray application cost	0	300	300	300	300	300	300	300	300	300	300	300	PKR 300 man ⁻¹ day ⁻¹ (one man-day ha ⁻¹)
Total cost that vary	0	350	2100	465	500	550	600	650	567.5	640	712.5	785	PKR
Net benefits	82915	87715	115577	106363	91475	110690	107627	93852	109513	108746	97780	103270	PKR ha ⁻¹

T₁= weedy check, T₂ = Water application (25 DAS), T₃= Herbicide application Iodosulforun+ meso sulforun @14.4 g ha⁻¹ Atlantis @3.6 WG a.i) (25 DAS), T₄= Sorghum water soaked extract @330 L ha⁻¹ (25 DAS), T₅= Sorghum boiled water extract@ 15 L ha⁻¹ (25 DAS), T₆= Sorghum boiled water extract@ 20 L ha⁻¹(25 DAS), T₇= Sorghum boiled water extract@ 25 L ha⁻¹(25 DAS), T₈= Sorghum boiled water extract@ 30 L ha⁻¹ (25 DAS), T₉= Sorghum powder @ 270 g ha⁻¹ (25 DAS), T₁₀= Sorghum powder @ 360 g ha⁻¹ (25 DAS), T₁₁= Sorghum powder@ 450 g ha⁻¹ (25 DAS), T₁₂= Sorghum powder @ 540 g ha⁻¹ (25 DAS)

Table-6: Marginal rates of returns from the experiment

Treatments	Cost that varies	Net profits	Marginal cost	Marginal net benefits	MRR%
Weedy check	0	82915	-	-	-
Water application (25 DAS)	350	87715	350	4800	1371
Sorghum soaked water extract@ 330 L ha ⁻¹ (25 DAS)	465	106363	115	18648	16200
Sorghum boiled water extract@15 L ha ⁻¹ (25 DAS)	500	91475	D	D	D
Sorghum boiled water extract@ 20 L ha ⁻¹ (25 DAS)	550	110690	85	4327	5000
Sorghum powder @270 g ha ⁻¹ (25 DAS)	567.5	109513	D	D	D
Sorghum boiled water extract@ 25 L ha ⁻¹ (25 DAS)	600	107627	D	D	D
Sorghum powder @ 360 g ha ⁻¹ (25 DAS)	640	108746	D	D	D
Sorghum powder@ 30 L ha ⁻¹ (25 DAS)	650	93852	D	D	D
Sorghum powder @450 g ha ⁻¹ (25 DAS)	712	97780	D	D	D
Sorghum powder @ 540 g ha ⁻¹ (25 DAS)	785	103270	D	D	D
Herbicide application iodosulforun+ meso sulforun @14.4 g ha ⁻¹ Atlantis @3.6 WG a.i)(@ 25 DAS)	2100	115577	1550	4887	315

MRR% = Marginal rate of return%; D: Dominance due to the high cost of production. Marginal rate of return = Marginal net benefits/marginal cost x100; 1 US Dollar = 104.82 Pak Rupee



Discussion

The phenomena of allelochemicals have been explored in many ways like crop rotation, cover crops, mulching, water extracts, powder formulations, intercropping and residues application (Farooq et al., 2013; Jabran et al., 2015). But here, this experiment was conducted for field appraisal of sorghum in various ways. As, the inhibitory role of allelopathy has been well documented by many researchers (Cheng and Cheng, 2015; Jabran et al., 2015; Glab et al., 2017), It was observed considerable difference among the treatments applied in the form of soaked and boiled water formulations and in the powder form in comparison with the herbicide. The reduction in the weed density observed in this study is also due to this dimension of allelochemicals produced by the sorghum plant when get assorted with the water and its allelopathic interaction. Significant reductions in weed density were described by Cheema and Khaliq (2000) in sorghum allelopathic evaluation. The outcomes are in agreement with the conclusion of Jamil et al. (2009) whom pragmatic a decline in *Phalaris minor* dry weight by 36-55% by sorghum + sunflower water extract at 12 L ha⁻¹.

It was observed that the sorghum water boiled extract, sorghum powder and sorghum soaked water extract drastically reduced weeds DW, as presented in the Table (3). The effect up to various extents is due to variable contact surface made by these formulations. Therefore, a treatment would be more effective in effect, if it covers more surface area weed plant. From some previous related studies, it was found that conclusion of present experiment nearly compatible with Cheema and Khaliq, (2000) and Jamil et al. (2009) whom made use of sorghum water extract for potential allelopathic crops. They have reported a reduction in weeds dry weight as well. The reductions in dry biomass of *Phalaris minor* were 21-58%, whereas, in the case of *Chenopodium album* the reduction was in between 38-60%.

All these results can be followed and for these findings the justification lies in various possible mechanisms revealed about sorghum allelopathic potential. The

allelochemicals can interfere with the hormonal and enzymatic activities. Therefore, it may affect directly or indirectly the processes like nutrient uptake and transport within the plant, stomatal oscillations, cell membrane permeability, and the most important, the photosynthesis and respiration processes (Cheng and Cheng, 2015). The economic and marginal evaluation of the treatments were conducted according to the method prescribed by Byerlee (1988). Farmers are more concerned about profits and acceptability of a practice or technology mainly dependent upon on the value of earnings. Here, estimations were made to review the gains in each treatment and on every increase in cost that diverge. As far as the economics is concerned, higher benefits were observed by herbicide application. Significant rise in yield was owing to weed suppression and it had higher benefits that are well convincing for the farmers. Therefore, it can state that rise in yield was owing to substantial weed control that enhanced the competency potential of crop to exploit the maximum available possessions (Jabran et al., 2015).

Conclusion

It is concluded that allelopathy can be a useful technique to manage the weeds in wheat and foliar applied water-soaked sorghum extract at a volume of 330 L ha⁻¹ or as boiled water extract at 20 L ha⁻¹ can be an economically feasible way for controlling the weeds. It can be recommended as a sustainable approach, while sorghum powder preparation by evaporation process from the above extracts can be too expensive procedure for the farmers.

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Contribution of Authors

Cheema MWA: Conducted Research, analyzed the data and interpreted the results

Rasool T: Helped to shape the research article, data evaluation and manuscript handling

Munir H: Conceived the idea of experiment and hypothesis formulation and implementation of treatments

Iqbal MM: Provided critical feedback in manuscript handling, proof reading and contributed to the final version of the manuscript

Naz T: Proof read for technical details in the manuscript

Haq MIU: Helped in performing the field experimental activities

Mustafa A: Helped in planning of experiment, analytical work and data collection

Nadeem M: Contributed in collection and analysis of data

Ullah S: Assisted in sample collection, handling and yield estimations

