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Research Article

Relative Benefits of Aqueous Extract of Sorghum Residues with Herbicide on Weed Control and Yield of Wheat Varieties

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ABSTRACT

Reducing herbicide use in agriculture is key for sustainability, addressing costs, environmental issues, and resistance problems. Using non-chemical methods like allelopathy in weed management offers a viable alternative. In this phenomenon, a field study was carried out at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh, from November 2021 to March 2022, to assess the phytotoxic effects of herbicides combined with aqueous extract of sorghum (AES) on weed management and yield of wheat. This study used three wheat varieties viz. BARI Gom (wheat)-32, BARI Gom-33, and BWMRI Gom-1 and six treatment levels such as, no weeding, recommended dose of herbicide (RDH), 90% RDH + AES (1:20 w/v), 80% RDH + AES (1:20), 70% RDH + AES (1:20), and 60% RDH + AES (1:20). The experiment followed a randomized complete block design (RCBD) with three replications. The RDH with AES and wheat variety significantly influenced weed population (WP) and dry weight (DW) of weeds. BARI Gom-32 produced the highest grain yield (GY) and other yield-contributing characteristics. The best results, including the highest numbers of tillers (NET) hill^{-1} (6.47), spike length (SL) (15.10 cm), number of spikelet spike^{-1} (NSS) (19.38), 1000-grain weight (TGW) (57.67g), GY (5.10 t ha^{-1}), and straw yield (SY) (7.07 t ha^{-1}) and harvest index (HI) (41.95%) were observed in plots treated with the RDH and the BARI Gom-32 variety, followed closely by those receiving 90% RDH + AES (1:20). The results demonstrate that varying concentrations of AES crop residue can effectively suppress weed growth and enhance wheat yield, suggesting that sorghum residues might be utilized to manage weeds effectively and sustainably while boosting wheat production. The study supports the potential of AES crop residue as an effective means to control weeds and significantly improve wheat yields.

Introduction

Wheat (*Triticum aestivum* L.) is a highly used cereal grain. It originates from a kind of grass cultivated in several global variations. Rice is surpassed by wheat due to its elevated protein level, nutritional value, and reduced manufacturing expenses. Rice is the most crucial grain crop in Bangladesh, followed by wheat (Dola et al., 2024). The yearly wheat yield amounts to cultivated on 0.78 million acres of land (BBS, 2023). Production of food in Bangladesh must keep pace with the increasing population growth. The estimated wheat production for the financial year 2022-23 is 1.17 million metric tons, representing a 7.77% increase compared to the 1.08 million metric tons produced in the annual year 2021-22 (BBS, 2023).

Some challenges, such as weed, disease and pest infestations, prevent farmers from producing their maximum crop (Akondo et al., 2024). For example, weed infestation causes a significant 24–40% drop in wheat crop yield (Dola et al., 2024; Akondo et al., 2024). Several weed control techniques are used in wheat crops, including chemical, mechanical, and traditional methods. Each type of weed control technique has its own set of drawbacks. For example, hand weeding takes much time and effort and is impractical for southern regions (Khan et al., 2016). Mechanical weeding is usually expensive, making it unaffordable for impoverished farmers. Additionally, the excessive use of herbicides and other chemicals to control weeds in wheat has led to significant environmental degradation and resistance in different types of weeds (Delye et al., 2013).

Weed management in wheat production necessitates consistent efforts to control weeds. Research has

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shown that aqueous extracts from various allelopathic plants are effective in managing weeds not only in wheat but also in other crops (Khan et al., 2015; Khan et al., 2013). These plants produce allelochemicals that can significantly curb weed growth in organic and inorganic farming systems without harming the environment, thereby enhancing crop yields (Soltys et al., 2013). These naturally occurring chemicals are derived from various parts of plants such as the bark, flowers, leaves, roots and fruits (Weir et al., 2004). The allelopathic activity of rotational crop residues offers an alternative strategy for weed control and crop selectivity in organic farming. All rotational crop residues effectively suppressed weed growth (Uddin and Pyon, 2010).

Plants can produce a wide variety of chemical compounds such as terpenoids, coumarins, phenolics, steroids, quinines, alkaloids, and tannins (Sarker et al., 2020). These substances can be released into the soil through volatile emissions, root secretions, or leaching from the plant's aerial parts (Xuan et al., 2005). Specific species such as Parthenium hysterophorus and Sorghum halepense are noted for their rich content of allelochemicals, with the former containing compounds like sesquiterpene lactones and parthenin, and the latter rich in both hydrophilic phenols and hydrophobic sorgolenone (Hussain and Reigosa, 2011; Alsaadawi and Dayan, 2009). The study examines the herbicidal effectiveness of sorgoleone across different weed species and identifies sorghum cultivars with high levels of sorgoleone in a diverse collection (Uddin et al., 2009). Sorgoleone impact on growth inhibition and chlorophyll fluorescence in a variety of different types weed species under in-vivo conditions (Uddin et al., 2012).

Previously considered crop residues and wastes are now recognized for their potential to alter soil properties significantly when decomposed, to supply content of potent allelochemicals (Sarker et al., 2022). Moreover, several studies have been revealed the induction of phytotoxic effects by plants and their residues for many crops, comprising major grain crops like rice, wheat, sorghum, rye, mustard, buckwheat and other crop residues (Sarker et al., 2020; Pramanik et al., 2019; Ahmed et al., 2018; Sheikh et al., 2017; Ferdousi et al., 2017; Uddin et al., 2014; Uddin et al., 2013; Won et al., 2013; Uddin and Pyon, 2010). Effective weed management strategies in wheat cultivation include rotating crops, growing high-yielding wheat varieties, and utilizing allelopathic plant extracts (Ullah et al., 2023). Researchers are now focusing more on using various plant/crop residues to manage weeds. Even though crop residues are widely accessible and reasonably priced in Bangladesh, little research has been done to determine which specific crop/plant residues are most effective in controlling weeds. In order to achieve sustainable weed management in wheat production, extracts from sorghum crop residue may be used to implement crop allelopathy. Using less herbicide may be possible by mixing allelopathic crop water extracts with a lower herbicide rate to get the right level of weed control. Considering this, the current study project was created to ascertain if AES and lower herbicide rates had synergistic or additive phytotoxic effects that could improve crop performance and weed management in highland wheat crops.

Materials and Methods

Description of the experimental site

A field study was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh from November 2021 to March 2022. The research focused on evaluating the weed-suppressing capabilities of an AES crop residue on wheat cultivation. The experimental site, located at a latitude of 24°75' N and a longitude of 90°50' E, with an elevation of 18 meters, this area features non-calcareous dark grey floodplain soil from the Sonatola Soil Series, classified under Agro-Ecological Zone 9 of the Old Brahmaputra Floodplain. The soil, with a pH of 6.8, is moderately fertile and rich in organic matter, with a silty loam texture. The area experiences a tropical climate, with high temperatures and substantial rainfall during the *Kharif* season and cooler, drier conditions during the *rabi* season. The temperature ranges from 15-30^0 C with no rainfall.

Experimental treatments

The experiment consists of two components. Factor A contains three wheat varieties: V_1 - BARI Gom-32, V_2 - BARI Gom-33, and V_3 - BWMRI Gom-1. Factor B formed T_1 - no weeding (control), T_2 – RDH (Panida 33EC @2000 ml ha^1, at 5 DAS as pre- emergence), T_3 - 90% of RDH+ AES (1:20), T_4 - 80% of RDH+ AES (1:20), T_5 - 70% of RDH+ AES (1:20), and T_6 - 60% of RDH+ AES (1:20).

Experimental material

In this study, an AES crop residue was used. Crops were produced at the AFL of BAU and collected at the ripening stage to gather crop residue. After collecting, the crop residues were dried in a shaded area on the covered threshing floor of the AFL. The crop residues were finely minced with a sickle. The study used variety seeds (BARI Gom-32, BARI Gom-33, and BWMRI Gom-1) sourced from the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institution (BARI), located near Jamalpur.

Crop husbandry

The experimental field was prepared using a tractor-drawn disc plough 15 days prior to sowing. The area required further ploughing, being cross-ploughed four times with a power tiller, followed by laddering to break up clods and level the soil. The spades curved the edges and surfaces of the ground while wooden hammers shattered apparent huge clods into smaller fragments. The field's layout was established after the final land preparation was completed. The experimental land was split into blocks and 54-unit plots while maintaining the correct spacing. According to the BARI, the recommended application rate for fertilizers was 220-110-157-110 kg ha^{-1} of urea, MoP, DAP, and gypsum, respectively. These fertilizers were administered during the final stage of land preparation. 220 kg of urea was used in three equal portions during the final land preparation and 45 and 60 days after sowing. The seeds were planted on November 25, 2021, at a depth of 3 cm for each treatment and subsequently covered with soil. Measures were taken to shield the seedlings from birds for the first 15 days post-sowing. Thinning and gap filling activities were conducted to secure and sustain the optimal growth and development of the crops. The experimental plots were given irrigation twice, once at 21 days after sowing (DAS) and again at 45 DAS after fertilizer application. Aqueous extract of sorghum was used in this study. Crops were grown at the Agronomy Field Laboratory, Bangladesh Agricultural University and were harvested at the time of ripening stage to collect crop residues. After collection, the crop residues were dried under shade in the cover threshing floor of Agronomy Field Laboratory of BAU. The studied crop residues were cut as small as possible by using sickle. Small sized sorghum crop residues were soaked in water at the ratio of 1:20 (w/v) for 24 hours at ambient room temperature. This mixture (leaves + water) was boiled for 3-4 hours and then water extract was filtered using a coarse mash to remove the plant residue. The AES was applied twice (at 20 and 40 days) after sowing the seeds. The application was made at a ratio of 1:20, following the experimental recommendations, and at room temperature. The AES crop residues was administered using a hand sprayer. The crops were harvested after they had reached complete maturity. The maturity of the crops was determined when 90% of the grains turned golden yellow.

Data collection

Weed data was taken 35 days after sowing (DAS). Data about the height and tillering capacity of wheat plants throughout various phases of growth were obtained. GY and SY data were collected from one area in the center of each plot. The data on other crop characteristics were collected using a process of random sampling from the surrounding area, removing the hills that form the boundary of a 1 m^2 section. This area was dedicated explicitly to gathering statistics on the GY and SY. The grains were dried in the sun after being cleaned. The straws were well-dried in the sun. Ultimately, the GY was adjusted to a moisture content of 14% and converted into metric tons ha^{-1}. Additionally, the BY and HI were determined.

Statistical Analysis

The data was arranged properly for statistical analysis. An analysis of variance was performed using the RCBD approach with the assistance of the computer program R-Studio. The mean differences were evaluated using Duncan's Multiple Range Test (DMRT) with a significance threshold of $p \leq 0.05$ (Gomez and Gomez, 1984).

Results and Discussion

Four different weed species found in the experimental plots, spanning three families: *Cynodon dactylon, Echinochloa colonum, Polygonum hydropiper*, and *Oldenlandia corymbosa*. The study identified two annual and two perennial species among the weeds present (Table 1). Similar patterns of weed infestation, influenced by the use of AES crop residues as a growth inhibitor, were also reported by Ahmed et al., (2018) during their studies on wheat cultivation.

Table 1. Infested weed species were found in the experimental wheat plots

Sl. No.	Local name	Scientific name	Family	Morphological type	Life cycle
1	Durba	*Cynodon dactylon*	Poaceae	Grass	Perennial
2	Khude Shama	*Echinochloa colonum*	Poaceae	Grass	Annual
3	Biskatali	*Polygonum hydropiper*	Polygonaceae	Broad leaved	Annual
4	Khet Papri	*Oldenlandia corymbosa*	Molluginaceae	Sedge	Perennial

Varietal effect on WP and DW of weeds

Varietal differences significantly influenced the WP and DW of *C. dactylon*. The highest WP of *C. dactylon* was recorded in BWMRI Gom-1 (7.28), while BARI Gom-32 had the lowest (3.06). Similarly, the highest DW for this weed was (2.57g) found in BWMRI Gom-1, and the lowest was (1.82 g) observed in BARI Gom-32 (Table 2). Similarly, the wheat variety significantly affected the WP and DW of other weed species. For *E. colonum*, BWMRI Gom-1 exhibited the highest WP (15.61) and the highest DW (3.70 g), whereas BARI Gom-32 showed the lowest WP (12.89) and DW (2.37 g) (Table 2). The lower weed population and dry weight in Gom-32 compared to BWMRI can be attributed to its stronger competitive ability, more aggressive canopy structure, and greater allelopathic potential, which effectively limit light and resources for weeds. In contrast, BWMRI, despite higher biomass, is less effective in weed suppression due to weaker competition and allelopathic influence, resulting in higher weed infestation and dry weight. Dola et al., (2024) found similar results, stating that wheat variety significantly affects weed populations, specifically for *Echinochloa crusgalli*, *Solanum torvum*, *Paspalum scrobiculatum* and *P. hydropiper*. The WP and DW of *P. hydropiper* also varied by variety. BWMRI Gom-1 recorded the highest WP (13.33) and DW (3.34 g), while the lowest for BARI Gom-32 were 7.78 for WP and 1.80 g DW (Table 2). Ashraf et al., (2021) reported that the variety of transplanted *aman* rice and the residual effect of grass pea significantly influence the control efficacy of weeds. Also, Uddin et al., (2012) found that sorgoleone significantly reduced the Fv/Fm ratio and chlorophyll fluorescence in all tested weed species, particularly in *Galium spurium, Aeschynomene indica*, and *Rumex japonicus*.

Table 2. Effect of variety on WP and DW of weeds

Varieties	WP (no. m^{-2})				DW of weeds (g m^{-2})			
	C. dactylon	*E. colonum*	*P. hydropiper*	*O. corymbosa*	*C. dactylon*	*E. colonum*	*P. hydropiper*	*O. corymbosa*
V_1	3.06 c	12.89 c	7.78 c	5.33 c	1.82 c	2.37 c	1.80 c	1.24 c
V_2	4.83 b	15.61 b	10.33 b	8.06 b	2.28 b	2.99 b	2.51 b	1.93 b
V_3	7.28 a	17.61 a	13.33 a	10.78 a	2.57 c	3.70 a	3.34 a	2.51a
SEm (±)	0.24	0.36	0.30	0.27	0.06	0.03	0.04	0.03
Level of Significance	**	**	**	**	**	**	**	**
CV (%)	14.48	7.11	8.57	9.96	8.47	12.93	5.20	6.03

Here, means with the same letters within the same column do not differ significantly, ** - Significant at 1% level of probability, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3-BWMRI Gom-1

Effect of AES crop residues on WP and DW of weeds

The AES crop residues significantly influenced the WP and DW of *C. dactylon*. The highest WP (8.67) was observed in the control treatment, while the lowest (3.44) occurred in the RDH treatment and second lowest (3.78) was found in90% of RD + AES (1:20). Similarly, the highest DW of weeds (2.91 g) was noted in no weeding treatments, with the lowest (1.92 g) in RDH and second lowest (2.01 g) DW was found in 90% of RD + AES (1:20). (Table 3). For *E. colonum*, the AES crop residues also had a marked effect. The highest WP (18.22) appeared in no weeding and the lowest (13.67) in RDH and second lowest (14.44) was observed in 90% of RD + AES (1:20). The maximum DW was 4.80 g in no weeding treatment, and the minimum was 2.31g in RDH and second lowest (2.49 g) DW was found in 90% of RD + AES (1:20) (Table 3). The WP and DW of *P. hydropiper* were similarly affected. The highest WP (15.00) was found in no weeding, with the lowest (8.44) in RDH and followed by 90% of RD + AES (1:20). The highest DW was 3.90 g in no weeding, and the lowest was 1.90 g in RDH (Table 3). Lastly, the extract significantly impacted the *O. corymbosa* WP and DW. The highest WP (11.56) and DW (2.81 g) were recorded in no weeding, while the lowest figures (6.22 WP and 1.47 g DW) were observed in RDH and followed by 90% of RD + AES (1:20). (Table 3). These findings are consistent with observations by Akondo et al., (2024). All rotation crop residues effectively suppressed weed growth, particularly at a 90:10 crop-to-soil ratio, completely inhibiting all tested weed species (Uddin and Pyon, 2010).

Table 3. Effect of AES crop residues on WP and DW of weeds

Treatments	WP (no. m^{-2})				DW of weeds (g m^{-2})			
	C. dactylon	*E. colonum*	*P. hydropiper*	*O. corymbosa*	*C. dactylon*	*E. colonum*	*P. hydropiper*	*O. corymbosa*
T_1	8.67 a	18.22 a	15.00 a	11.56 a	2.91 a	4.80 a	3.90 a	2.81 a
T_2	3.44 e	13.67 d	8.44 e	6.22 d	1.92 d	2.31 f	1.90 f	1.47 f
T_3	3.78 de	14.44 cd	8.89 de	6.67 d	2.01 cd	2.49 e	2.09 c	1.60 e
T_4	4.44 cd	14.89 bc	9.56 cd	7.44 c	2.09 bd	2.64 d	2.27d	1.71 d
T_5	4.78 bc	15.33 bc	10.00 c	7.89 bc	2.17 bc	2.84 c	2.48 c	1.81 c
T_6	5.22 b	15.67 b	11.00 b	8.56 b	2.24 b	3.03 b	2.67 b	1.94 b
SEm (±)	0.35	0.52	0.42	0.38	0.09	0.04	0.05	0.04
Level of significance	**	**	**	**	**	**	**	**
CV (%)	14.48	7.11	8.57	9.96	8.47	12.93	5.20	6.03

Here, means with the same letters within the same column do not differ significantly, ** - Significant at 1% level of probability, T_1 - No weeding, T_2 - RDH, T_3 - 90% of RD + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

Interaction effect between variety and AES crop residues with herbicide on WP and DW of weeds

Significant interactions between wheat varieties and the AES crop residues were observed in WP and DW. For *C. dactylon*, the highest WP (9.00) and DW (3.00 g) were recorded in the BWMRI Gom-1 and no weeding treatment, while the lowest numbers of weeds (1.33) and 1.39 g DW were found in BARI Gom-32 and RDH (Table 4). In the case of *E. colonum*, the highest numbers of weeds were again seen in BWMRI Gom-1 and no weeding (19.00) and (4.90 g) DW, and the lowest was in BARI Gom-32 and RDH, showing 10.00 WP and 1.57 g DW of weeds (Table 4). For *P. hydropiper*, the highest WP (15.33) and (4.00 g) DW of weeds appeared in BWMRI Gom-1 and no weeding, and the lowest WP (5.67) and 0.97 g DW of weeds in BARI Gom-32 and RDH (Table 4). Lastly, *O. corymbosa* displayed the highest WP (12.00) and DW (2.90 g) in BWMRI Gom-1 and no weeding and the lowest number of weeds (3.33) and (0.73 g) DW in BARI Gom-32 and RDH (Table 4). Similarly, aqueous e Similarly, aqueous extracts from mustard crop residues applied in wheat fields were effective in significantly reducing both the weed population (WP) and dry weight (DW) of weeds, while also achieving a high percentage of weed inhibition (Dola et al., 2024).

Table 4. Combined effect of variety and AES on WP and DW of weeds

Variety x	WP (no. m^{-2})				DW of weeds (g m^{-2})			
Residues	*C. dactylon*	*E. colonum*	*P. hydropiper*	*O. corymbosa*	*C. dactylon*	*E. colonum*	*P. hydropiper*	*O. corymbosa*
V_1T_1	8.33 ac	17.67 ac	14.67 ab	11.00 ab	2.80 ab	4.70 b	3.80 bc	2.73 b
V_1T_2	1.33 j	10.00 j	5.67 l	3.33 i	1.39 i	1.57 n	0.97 m	0.73 n
V_1T_3	1.67 ij	11.67 ij	6.00 kl	3.67 i	1.57 hi	1.78 m	1.27 l	0.90 m
V_1T_4	2.00 hj	12.33 i	6.33 kl	4.00 hi	1.62 hi	1.93 l	1.42 l	0.93 lm
V_1T_5	2.33 fh	12.67 hi	6.67 jl	4.67 hi	1.73 gh	2.03 l	1.60 k	1.03 kl
V_1T_6	2.67 gi	13.00 gi	7.33 jk	5.33 gh	1.78 gh	2.20 k	1.77 jk	1.10 k
V_2T_1	8.67 ab	18.00 ab	15.00 a	11.67 a	2.93 a	4.80 ab	3.90 ab	2.80 ab
V_2T_2	3.33 fh	14.33 fh	8.00 hj	6.33 fg	2.00 fg	2.37 j	1.90 ij	1.43 j
V_2T_3	3.67 fg	14.67 eg	8.67 gi	6.67 fg	2.07 eg	2.50 ij	2.00 i	1.57 i
V_2T_4	4.00 ef	15.00 df	9.33 gh	7.33 ef	2.17 df	2.60 i	2.20 h	1.73 h
V_2T_5	4.33 ef	15.67 c-f	10.00 fg	7.67 df	2.20 df	2.80 h	2.43 g	1.9 g
V_2T_6	5.00 de	16.00 bf	11.00 ef	8.67 ce	2.33 cf	2.90 gh	2.60 g	2.13 f
V_3T_1	9.00 a	19.00 a	15.33 a	12.00 a	3.00 a	4.90 a	4.00 a	2.90 a
V_3T_2	5.67 d	16.67 be	11.67 de	9.00 cd	2.37 ce	3.00 g	2.83 f	2.23 e
V_3T_3	6.00 d	17.00 ad	12.00 ce	9.67 bc	2.40 ce	3.20 f	3.00 f	2.33 e
V_3T_4	7.33 c	17.33 ac	13.00 cd	11.00 ab	2.50 bd	3.40 e	3.20 e	2.47 d
V_3T_5	7.67 bc	17.67 ac	13.33 bc	11.33 a	2.57 bc	3.70 d	3.40 d	2.50 cd
V_3T_6	8.00 ac	18.00 ab	14.67 ab	11.67 a	2.60 bc	4.00 c	3.63 c	2.60 c
SEm (±)	0.60	0.89 ab	0.73	0.66	0.15	0.07	0.09	0.06
Level of sig.	**	*	**	**	*	**	**	**
CV (%)	14.48	8.57	8.57	9.96	8.47	12.93	5.20	6.03

Here, means with the same letters within the same column do not differ significantly. ** - Significant at 1% level of probability, * - Significant at 5% level of probability, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - No weeding, T_2 - RDH, T_3 - 90% of RDH + AES (1:20), T_4 - 80% of RDH+ AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

Effect of variety on yield and yield contributing characters of wheat

Varietal differences significantly influenced both yield and yield-related traits. BARI GOM-33 exhibited the highest PH (101.64 cm) and HI (40.65%). Conversely, BARI GOM-32 demonstrated superior performance in several other categories, recording the highest NET hill^{-1} (5.87), SL (14.59 cm), NGS (43.33), NSS (18.31), and TGW (54.86 g) (Table 5). The lowest PH (90.59 cm) was noted in BARI GOM-32, while the lowest values for the NET hill^{-1} (4.72), SL (12.71 cm), NSS (16.33), TGW (49.31 g), and HI (39.44%) were observed in BWMRI Gom-1 (Table 5). Pramanik et al., (2019) also observed significant differences due to varietal effects in another study.

Table 5. Effect of variety on yield and yield contributing characters of wheat

Variety	PH (cm)	NET hill^{-1}	SL (cm)	NSS	TGW (g)	HI (%)
V_1	90.59 c	5.87 a	14.59 a	18.31 a	54.86 a	40.99 a
V_2	101.64 a	5.27 b	13.52 b	17.26 b	52.58 b	40.65 a
V_3	96.11 b	4.72 c	12.71 c	16.33 c	49.31 c	39.44 b
SEm (±)	0.49	0.04	0.10	0.12	0.38	0.51
Level of Significance	**	**	**	**	**	*
CV%	5.54	12.27	12.23	12.13	12.20	13.58

Here, means with the same letters within the same column do not differ significantly. ** - Significant at 1% level of probability, * - Significant at 5% level of probability, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom- 1

Effects of AES crop residues with herbicide on yield and yield contributing characters of wheat

Combining AES crop residue with herbicides markedly affected yield and its contributing factors. The optimal results were observed when RDH were used and the highest PH (97.22 cm), NET hill^{-1} (6.89), SL (15.58 cm), NSS (20.11), NGS (46.89), TGW (53.44 g), and HI (41.60%) were recorded and followed by 90% of RDH + AES (1:20) (Table 6). In contrast, the lowest outcomes were noted when no AES was used, resulting in the lowest PH (99.06 cm), NET hill^{-1}(5.74), SL (14.03 cm), NSS (18.16), TGW (54.22 g), and HI (41.32%) (Table 6). Effective weed management, by improving water, nutrient, and light availability, led to an increased grain count. Sarker et al., (2020) observed that the highest counts and TGW were achieved using the sorghum crop residues extract, whereas the lowest were seen with hand weeding.

Table 6. Effect of AES crop residues with herbicide on yield and yield contributing characters of wheat

Treatment	PH (cm)	NET hill^{-1}	SL (cm)	NSS	TGW (g)	HI (%)
T_1	92.81 d	4.31 e	13.28 c	15.54 d	49.00 e	39.55 b
T_2	99.06 a	5.74 a	14.03 a	18.16 a	54.22 a	41.32 a
T_3	98.03 ab	5.58 b	13.79 ab	17.95 a	53.56 ab	40.53 ab
T_4	97.07 b	5.48 bc	13.69 b	17.59 b	52.94 bc	40.48 ab
T_5	95.39 c	5.37 c	13.52 bc	17.41 bc	52.17 cd	40.15 ab
T_6	94.33 c	5.23d	13.36 c	17.12 c	51.60 d	40.12 ab
SEm (±)	0.70	0.06	0.14	0.17	0.54	0.73
Level of Significance	**	**	**	**	**	*
CV%	5.54	12.27	12.23	12.13	12.20	13.58

Here, means with the same letters within the same column do not differ significantly. ** - Significant at 1% level of probability, *- Significant at 5% level of probability, T_1 - no weeding, T_2 - RDH, T_3 - 90% of RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

Effects of interaction between variety and AES with herbicide on the yield contributing characters and yield of wheat

Variety has significant effect on total number of branches per plant (Table 7). Among these three varieties, the Significant variations in PH, SL, TGW, NET hill^{-1}, NGS, GY, and SY were noted when different wheat varieties were treated with a combination of AES and herbicide. The highest PH (105.00 cm) was recorded for BARI GOM-33 treated with RDH. The maximum NET hill-1 (6.47), along with the highest values for SL (15.10), NGS (19.38), TGW (57.67), HI (41.95 %) was observed in BARI GOM-32 with RDH treatment (Table 7). Conversely, the lowest PH (87.77 cm) was found in BARI GOM-32 with no aqueous extract or no weeding. The minimum values for NET hill-1 (4.27), SL (12.50), NSS (15.50), TGW (48.00), HI (38.99%) were recorded in BWMRI Gom-1 and no weeding treatment (Table 7). Akondo et al., (2024) identified a similar trend, highlighting the significant impact of the interaction between variety and combined crop residues of sorghum and mustard on the yield contributing characters and yield of wheat.

Table 7. Interaction effect of variety and AES with herbicide on the yield contributing characters and yield of wheat

Interaction	PH (cm)	NET hill^{-1}	SL (cm)	NSS	TGW (g)	HI (%)
V_1T_1	87.77 k	4.37 jk	14.27 bd	15.60 k	49.67 ik	40.65 ac
V_1T_2	92.50 gi	6.47 a	15.10 a	19.38 a	57.67 a	41.95 a
V_1T_3	91.77 hi	6.27 b	14.70 ab	19.19 ab	56.67 ab	41.07 ac
V_1T_4	91.53 ij	6.17 b	14.63 ab	18.77 bc	55.67 bc	41.01 ac
V_1T_5	91.00 ij	6.07 b	14.50 bc	18.67 bc	55.00 bd	40.38 ac
V_1T_6	89.00 jk	5.87 c	14.37 bd	18.23 cd	54.47 ce	40.88 ac
V_2T_1	98.67 de	4.30 jk	13.07 gi	15.53 k	49.33 ik	39.00 c
V_2T_2	105.00 a	5.67 d	14.00 ce	18.00 de	54.00 ce	41.80 ab
V_2T_3	104.00 ab	5.50 de	13.83 df	17.77 df	53.83 cf	40.98 ac
V_2T_4	102.33 bc	5.43 e	13.70 ef	17.53 eg	53.50 df	40.89 ac
V_2T_5	100.17 cd	5.37 e	13.37 fg	17.47 eh	52.83 eg	40.83 ac
V_2T_6	99.67 de	5.33 e	13.17 gh	17.23 fh	52.00 fh	40.39 ac
V_3T_1	92.00 hi	4.27 k	12.50 i	15.50 k	48.00 k	38.99 c
V_3T_2	99.67 de	5.10 f	13.00 gi	17.10 gh	51.00 gi	40.21 ac
V_3T_3	98.33 de	4.97 fg	12.83 gi	16.90 hi	50.17 hj	39.54 ac
V_3T_4	97.33 ef	4.83 gh	12.73 hi	16.47 ij	49.67 ik	39.54 ac
V_3T_5	95.00 fg	4.67 hi	12.68 hi	16.10 jk	48.67 jk	39.25 bc
V_3T_6	94.33 gh	4.50 ij	12.53 i	15.90 jk	48.33 ik	39.09 c
SEm (±)	1.20	0.10	0.25	0.30	0.94	1.26
Level of sig.	*	**	*	**	*	*
CV (%)	5.54	12.27	12.23	12.13	12.20	13.58

Here, means with the same letters within the same column do not differ significantly. ** - Significant at 1% level of probability, * - Significant at 5% level of probability, V_1 - BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - No weeding, T_2 - RDH, T_3 - 90% RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20).

Effect of variety on GY and SY

The studied different varieties significantly affected the GY and SY. The highest GY (4.69 t ha^{-1}) was obtained in BARI Gom-32, followed by (4.30 t ha^{-1}). The lowest GY (3.98 t ha^{-1}) was obtained in BWMRI Gom-1 (Figure 1). The highest SY (6.75 t ha^{-1}) was found in BARI Gom-32, followed by (6.28 t ha^{-1}) BARI Gom-33 (Figure 2). The variation in GY and SY can be attributed to the distinct genetic traits, growth habits, and resource-use efficiency of each variety, which align with findings from similar studies highlighting the role of varietal differences in wheat productivity (Akondo et al., 2024).

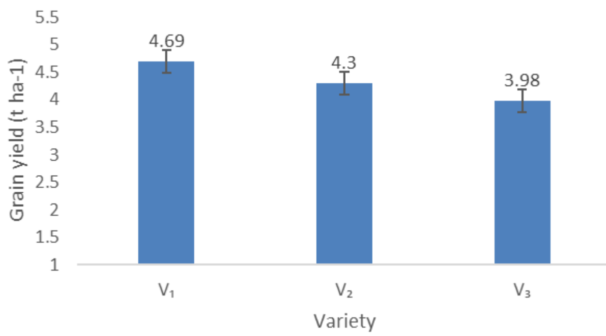

Figure 1. Effect of variety on the grain yield of wheat. Here, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1

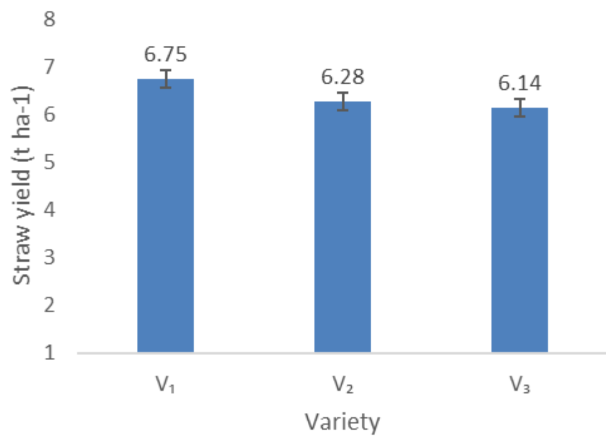

Figure 2. Effect of variety on the straw yield of wheat. Here, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1

Effect of AES crop residues with herbicide on GY and SY

AES crop residues significantly influenced GY and SY. The highest GY (4.59 t ha^{-1}) was achieved by the RDH treatment, followed by 90% of RDH with a 1:20 AES ratio (4.48 t ha^{-1}) and the lowest GY (3.9 t ha^{-1}) occurred with the no weeding treatment (Figure 3). Similarly, SY was significantly impacted by the AES crop residues. The RDH treatment observed the highest SY (6.57 t ha^{-1}), while the lowest SY (5.99 t ha^{-1}) was found in the no-weeding treatment (Figure 4). This pattern is consistent with findings by Sarkar et al., (2020), who observed that crop residues could significantly influence crop performance. Crop residues impact yield data by influencing soil properties, nutrient availability, moisture retention, and weed control. They improve soil fertility through nutrient recycling, enhance moisture retention, and suppress weeds, all contributing to better crop growth and higher yields. However, excessive residues can also hinder seedling emergence, delay soil warming, or harbor pests, potentially reducing yields. Proper management of crop residues is essential to maximize their benefits and avoid negative effects on yield.

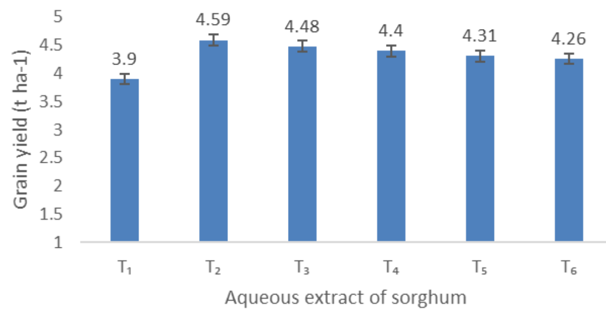

Figure 3. Effect of AES on the GY of wheat. Here, T_1 - no weeding, T_2 - RDH, T_3 - 90% of RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

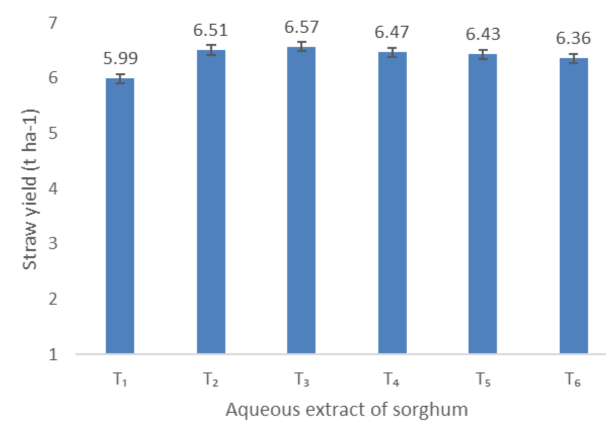

Figure 4. Effect of AES on the SY of wheat. Here, T_1 - no weeding, T_2 - RDH, T_3 - 90% of RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

Interaction effect between variety and AES crop residues with herbicide on GY and SY

The interaction between varieties and AES crop residues significantly affected GY and SY. The highest GY (5.1 t ha^{-1}) was achieved with BARI Gom-31 under RDH treatment, while the lowest GY (3.87 t ha^{-1}) occurred with BWMRI Gom-1 under no weeding treatment (Figure 5). Similarly, the highest SY (7.07 t ha^{-1}) was observed with BARI Gom-32 under RDH treatment. The lowest SY (5.77 t ha^{-1}) was noted with BARI Gom-32 under no-weeding treatment (Figure 6). These findings underscore the critical role of treatment interactions in optimizing wheat crop yields. Similar conclusions were drawn by Afroz et al., (2018), who noted the significant impact of sorghum crop residue extracts on yield and related traits. Additionally, Sarker et al., (2022) reported that the combination of variety and aqueous crop residue extracts effectively enhanced yield. AES affects yield primarily due to its allelopathic properties. It contains bioactive compounds that suppress weed growth, reducing competition for resources like nutrients, water, and light. This improved resource availability for crops leads to better growth, higher biomass accumulation, and ultimately enhanced yield.

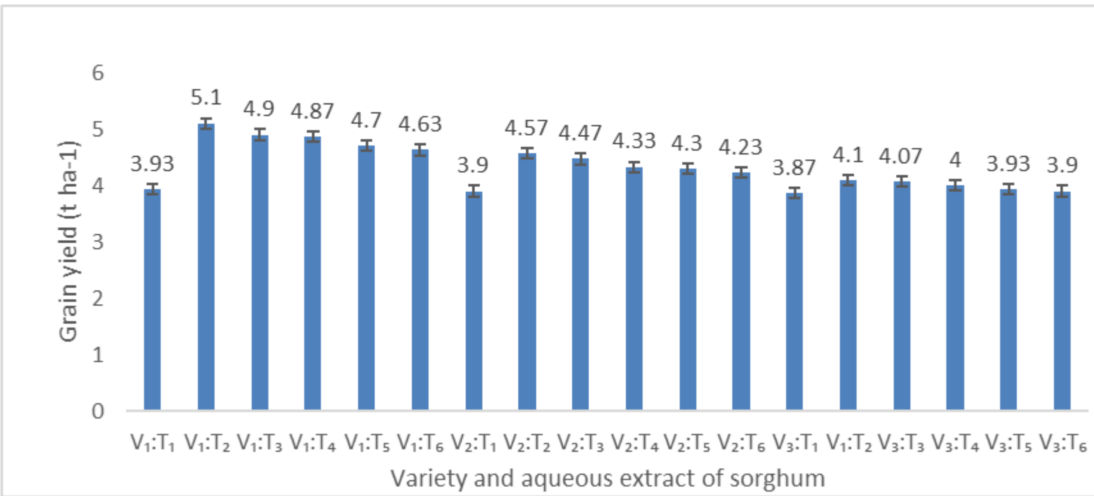

Figure 5. Interaction effect of variety and AES on the GY of wheat. Here, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - no weeding, T_2 - RDH, T_3 - 90% of RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20)

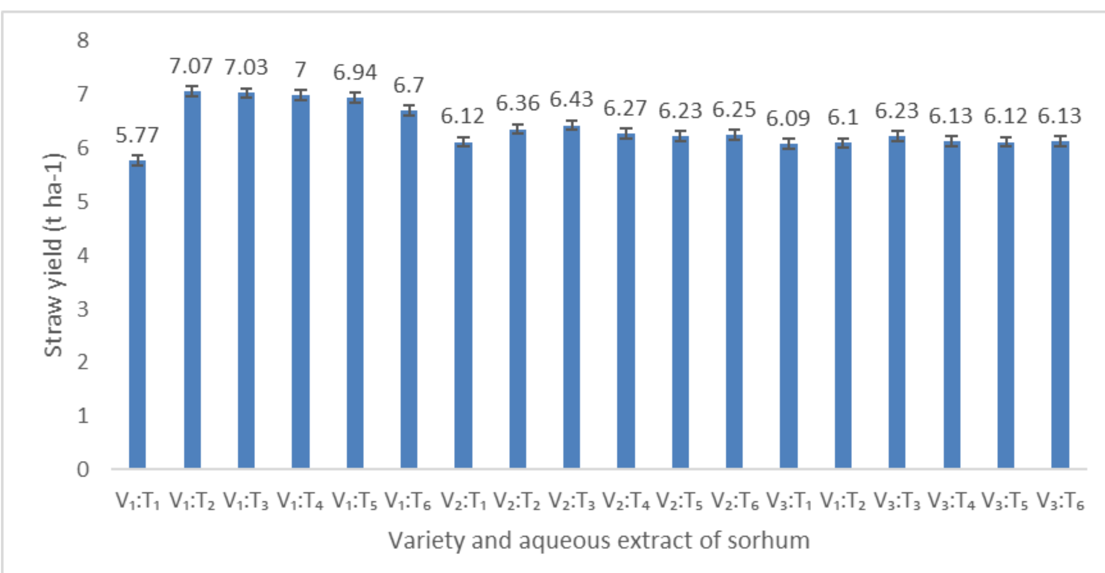

Figure 6. Interaction effect of variety and AES on the SY of wheat. Here, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - no weeding, T_2 - RDH, T_3 - 90% RDH + AES (1:20), T_4 - 80% of RDH + AES (1:20), T_5 - 70% of RDH + AES (1:20), T_6 - 60% of RDH + AES (1:20).

Conclusion

The experimental findings revealed that the combination of the BARI Gom-32 wheat variety with the RDH was particularly effective in controlling weeds, thereby minimizing crop loss and inhibiting weed proliferation. Additionally, the treatment that combined 90% of RDH with AES (1:20) yielded results that were closely aligned with those achieved using the full RDH alone. This indicated that the 90% RDH with AES, nearly matched the weed control effectiveness of the full herbicide dose. The research clearly demonstrated that the AES crop residue not only enhances yield but also serves as an effective herbicidal agent, contributing to the suppression of weed growth.

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