Journal of Agroforestry and Environment

Volume 17, Issue 2, 2024

Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Combined Application of Herbicide and Aqueous Extract of Sorghum and Mustard Crop Residue Enhance Weed Management and Yield of Wheat

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Received: 20/05/2024

Accepted: 02/08/2024

Available online: 04/08/2024

Abstract: The rising costs in agriculture and growing public concern over herbicide use have emphasized the need for non-chemical weed control methods. To evaluate the impact of aqueous extracts from sorghum and mustard crop residues on weed control and wheat crop performance, an experiment was conducted at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh, from November, 2021, to March 2022. The study involved three wheat varieties (BARI Gom-32, BARI Gom-33, and BWMRI Gom-1) and six treatment levels: no weeding, the recommended dose of herbicide (RDH), 80% RDH + aqueous extract of mustard + sorghum (AEMS) (1:20 ratio w/v), 70% RDH + AEMS (1:20), 60% RDH + AEMS (1:20), and 50% RDH + AEMS (1:20). The experiment was designed using a randomized complete block design with three replications. Results demonstrated that the aqueous extracts significantly reduced weed population (WP) and dry weight (DW) of weeds. Among the wheat varieties, BARI Gom-32 achieved the highest grain yield (GY) (3.62 t ha^{-1}) and other yield-contributing traits. The highest numbers of effective tillers (NET) per hill (4.56), numbers of grains per spike (NGS) (34.57), 1000 grain weight (TGW) (57.81 g), GY (4.09 t ha^{-1}), straw yield (SY) (6.05 t ha^{-1}), and biological yield (BY) (10.14 t ha^{-1}) were observed in the RDH treatment, followed by the combined application of 80% RDH and AEMS crop residue (1:20). These findings suggest that AEMS crop residue extracts could be an effective source for suppressing weed population and enhancing yield.

Keywords: Wheat varieties; Herbicide; Weed control; Crop residue; Grain yield.

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 it due to its elevated protein level, nutritional value, and reduced manufacturing expenses. Rice is the most crucial grain crop in Bangladesh, followed by wheat. The yearly wheat yield amounts to 1.17 million metric tons, 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 and disease-pest infestations, prevent farmers from producing their maximum crop. For example, weed infestation causes a significant 24–40% drop in wheat crop yield (Oad et al. 2007). 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 larger 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 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 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, root exudates, flowers, roots, leaves 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. 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 herbicidal activity of sorgoleone across various weed species and identifies sorghum cultivars with high sorgoleone content within 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). Mustard, widely cultivated for its seeds, oil, and greens, holds significant agricultural importance due to its potential allelopathic properties. These properties enable mustard to suppress weed growth effectively, making it a valuable crop in sustainable agriculture (Dola et al., 2024).

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. Additionally, several studies have demonstrated that plants and their residues can induce phytotoxic effects on various crops, including major grain crops such as rice, wheat, sorghum, rye, mustard, buckwheat, and others (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 phytotoxic plant extracts (Ullah et al. 2023). Researchers are now focusing more on using various agricultural 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 agricultural residues are most effective in controlling weeds. In order to achieve sustainable weed management in wheat production, extracts from sorghum and mustard crop waste 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 AESM lower herbicide rates had synergistic or additive phytotoxic effects that could improve crop performance and weed management in highland wheat crops.

MATERIALS AND METHODS

Experimental site

From November 2019 to March 2020, an experiment was carried out at the AFL of BAU in Mymensingh to study the effects of zinc and its application methods on wheat varieties' yield and yield components. The experimental field is located at a latitude of 24°75' N and a longitude of 90°50' E, at 18 meters above sea level. This area is characterized by non-calcareous dark grey floodplain soil from the Sonatola Soil Series in Agro-Ecological Zone 9 of the Old Brahmaputra Floodplain, with a nearly neutral pH of 6.5, limited organic matter, and moderate fertility (FAO and UNDP, 1988). The area's topography is moderately high and features a silty loam soil texture. The region experiences a tropical climate with high temperatures and substantial rainfall during the Kharif season (April to September) and cooler temperatures with limited rainfall during the Rabi season (October to March).

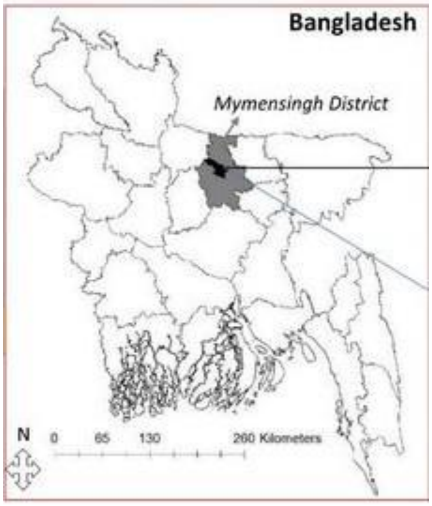

Figure 1. Map of the study area

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 - 80% RDH + AESM (1:20 w/v), T_4 - 70% RDH + AESM (1:20 w/v), T_5 - 60% RDH + AESM (1:20 w/v), and T_6 - 50% RDH + AESM (1:20 w/v).

Experimental materials and design

In this study, an AESM crop residue was used. Crops were produced at the AFL of BAU and collected at the ripening stage to gather crop residue. After collection, the crop residues were dried in a shaded area on the covered threshing floor of the AFL. The residues were then finely

DOI: https://doi.org/10.55706/jae1710

minced with a sickle. The study utilized seeds from three wheat varieties (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) near Jamalpur. The experiment was arranged in a randomized complete block design (RCBD) with three replications, resulting in a total of 54 plots. Each plot was 10 m² in size.

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 traditional plough, 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 configuration 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. Intercultural activities were conducted to secure and sustain the optimal growth and development of the crops. 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.

The experimental plots were given irrigation twice, once at 21 days and again at 45 days. The AESM was first prepared and 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 AESM 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. Weed data was taken 35 days after sowing (DAS). 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 m2 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}.

Harvesting and data collection

Five plants were randomly selected from each plot before harvest (excluding border plants) to collect data on crop and yield-contributing characters. The recorded data included PH (cm), NTT plant^{-1}, NET plant^{-1}, PL (cm), NGS, TGW (g), SL (cm), GY (t ha^{-1}), and SY (t ha^{-1}). Additionally, BY (t ha^{-1}) and HI were determined.

Statistical analysis

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

RESULT 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.

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 BARI Gom-32 (4.11), while BWMRI Gom-1 had the lowest (3.72). Similarly, the highest DW for this weed was (2.15g) found in BARI Gom-32, and the lowest was (1.97 g) observed in BWMRI Gom-1 (Table 2). For the other weed species E. colonum, P. hydropiper, and O. corymbosa no significant differences were noted among the varieties in either WP and DW. 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. Ahmed et al. (2018) found similar results, stating that wheat variety significantly affects weed populations, specifically for *Echinochloa crusgalli, Solanum torvum, Paspalum scrobiculatum* and *P. hydropiper.*

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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

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	4.11 a	6.33	5.67	3.28	2.15 a	1.92	1.96	2.01
V_2	4.00ab	6.33	5.67	3.28	2.00 ab	1.99	1.88	2.04
V_3	3.72 b	6.44	6.06	3.56	1.97 b	1.99	1.95	1.99
SEm (±)	0.15	0.25	0.27	0.28	0.07	0.08	0.09	0.09
Level of Significance	*	NS	NS	NS	*	NS	NS	NS
CV (%)	11.68	11.96	13.76	14.73	11.62	13.32	14.96	13.32

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

Effect of AESM crop residues on WP and DW of weeds

The AESM crop residues significantly influenced the WP and DW of *C. dactylon*. The highest WP (7.11) was observed in the control treatment, while the lowest (3.11) occurred in the RDH treatment and 80% RDH along with AESM. Similarly, the highest DW of weeds (3.68 g) was noted in no weeding treatments, with the lowest (1.62 g) in RDH (Table 3). For *E. colonum*, the AESM crop residues also had a marked effect. The highest WP (11.89) appeared in no weeding and the lowest in other treatments. The maximum DW was 3.11 g in no weeding treatment, and the minimum was in other treatments (Table 3). The WP and DW of *P. hydropiper* were similarly affected. The highest WP (9.22) was found in no weeding, with the lowest in other treatments. The highest DW was 3.11 g in no weeding, and the lowest was 1.53 g in RDH (Table 3). Lastly, the extract significantly impacted the *O. corymbosa* WP and DW. The highest WP (7.78) and DW (3.17 g) were recorded in no weeding, while the lowest figures WP and DW of weeds were observed in other treatments (Table 3). These findings are consistent with observations by Sarkar et al. (2020). 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 AESM 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	7.11 a	11.89 a	9.22 a	7.78 a	3.68 a	3.11 a	3.11 a	3.17 a
T_2	3.11 c	5.00 b	4.78 b	2.33 b	1.62 b	1.66 b	1.53 c	1.69 b
T_3	3.11 c	5.11 b	5.00 b	2.33 b	1.68 b	1.74 b	1.65 bc	1.72 b
T_4	3.33 bc	5.33 b	5.00 b	2.56 b	1.75 b	1.77 b	1.69 bc	1.83 b
T_5	3.44 bc	5.44 b	5.44 b	2.56 b	1.72 b	1.74 b	1.79 bc	1.79 b
T_6	3.56 b	5.44 b	5.33 b	2.67 b	1.77 b	1.79 b	1.81 b	1.88 b
SEm (±)	0.22	0.36	0.38	0.39	0.11	0.13	0.14	0.12
Level of significance	**	**	**	**	**	**	**	**
CV (%)	11.68	11.96	13.76	14.73	11.62	13.32	14.96	13.32

Here, means with the same letters within the same column do not differ significantly, ** - Significant at 1% level of probability, T_1 - No weeding (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

DOI: https://doi.org/10.55706/jae1710

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

Significant interactions between wheat varieties and the AESM crop residues were observed in WP and DW. The highest C. dactylon weed population (8.00) was found in BARI Gom-32 and no weeding control, second highest weed population (7.33) was found in BARI Gom-33 and no weeding control and the lowest (3.00) was found in BARI Gom-32 and RDH treatment and BARI Gom-32 and 80% RDH + AESM. The highest weed dry weight (4.52 g) was found in BWMRI Gom-1 and no weeding control and the lowest weed dry weight (1.60 g) was in BARI Gom-32 and RDH (Table 4). The highest E. colonum population (12.33) was found in both BARI Gom-32 and no weeding control and BARI Gom-33 and no weeding control. The second highest E. colonum population (11.33) was discovered in BWMRI Gom-1 and no weeding control. The lowest khude shama population (4.67) was discovered in BARI Gom-32 and RDH treatment. The highest weed dry weight (3.33 g) was discovered in BARI Gom-33 and no weeding control, the lowest weed dry weight (1.57 g) was discovered in BARI Gom-32 and RDH and the second-lowest weed dry weight (1.70 g) was discovered in BARI Gom-32 and 80% RDH + AESM. The highest O. corymbosa population (8.67) was found in BWMRI Gom-1 and no weeding control and second highest number of weed (7.67) was found in BARI Gom-33 and no weeding control. The lowest O. corymbosa population (2.33) was discovered in BARI Gom-32 and RDH, BARI Gom-32 and 80% RDH + AESM, BARI Gom-33 and RDH, BARI Gom-33 and 80% RDH + AESM, BWMRI Gom-1 and RDH, BWMRI Gom-1 and RDH. The highest weed dry weight (3.33 g) was discovered in BARI Gom-33 and no weeding control, the lowest weed dry weight (1.67 g) was discovered in BARI Gom-32 and RDH, and the second-lowest weed dry weight (1.70 g) was discovered in BARI Gom-33 and 80% RDH + AESM, BWMRI Gom-1 and RDH, BWMRI Gom-1 and 80% RDH + AESM. The highest P. hydropiper population (10.67) was found in BWMRI Gom-1 and no weeding control and second highest number of weed (8.67) was found in BARI Gom-32 and no weeding control. The lowest P. hydropiper population (4.67) was discovered in BARI Gom-32 and RDH and BARI Gom-33 and no weeding control. The second lowest weed population (5.00) was found in BARI Gom-32 and 80% RDH + AESM, BARI Gom-32 and 70% RDH + AESM, BARI Gom-33 and 80% RDH + AESM, BARI Gom-33 and 70% RDH+ AESM, BWMRI Gom-1 and 80% RDH + AESM, BWMRI Gom-1 and 70% RDH+ AESM (Table 4). The highest weed dry weight (3.33 g) was discovered in BWMRI Gom-1 and no weeding control, the lowest weed dry weight (1.47 g) was discovered in BWMRI Gom-1 and recommended dose of herbicide and (1.60 g) was found in BWMRI Gom-1 and 80% RDH + AESM which is close near to BWMRI Gom-1 and no weeding control. (Table 4). Similarly, aqueous extracts of crop residues were effective in reducing both the WP and DW of weeds, as well as in achieving a high percent inhibition of weeds (Ahmed et al. 2018).

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

Variety x Residues	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_1T_1	8.00 a	12.33 a	8.67 b	7.00 b	3.00 c	3.00 a	3.00 a	3.00 a
V_1T_2	3.00 c	4.67 b	4.67 c	2.33 c	1.60 d	1.57 b	1.57 b	1.67 b
V_1T_3	3.00 c	5.00 b	5.00 c	2.33 c	1.70 d	1.70 b	1.70 b	1.73 b
V_1T_4	3.33 c	5.33 b	5.00 c	2.67 c	1.83 d	1.70 b	1.80 b	1.80 b
V_1T_5	3.33 c	5.33 b	5.67 c	2.67 c	1.83 d	1.70 b	1.83 b	1.87 b
V_1T_6	3.33 c	5.33 b	5.00 c	2.67 c	1.87 d	1.87 b	1.83 b	1.97 b
V_2T_1	7.33 a	12.00 a	8.33 b	7.67 ab	3.53 b	3.33 a	3.00 a	3.33 a
V_2T_2	3.33 c	5.00 b	4.67 c	2.33 c	1.67 d	1.63 b	1.57 b	1.70 b
V_2T_3	3.33 c	5.00 b	5.00 c	2.33 c	1.70 d	1.77 b	1.64 b	1.73 b
V_2T_4	3.33 c	5.33 b	5.00 c	2.33 c	1.77 d	1.80 b	1.66 b	1.83 b
V_2T_5	3.67 c	5.33 b	5.33 c	2.33 c	1.60 d	1.73 b	1.70 b	1.83 b
V_2T_6	3.67 c	5.33 b	5.67 c	2.67 c	1.72 d	1.70 b	1.73 b	1.83 b
V_3T_1	6.00 b	11.33 a	10.67 a	8.67 a	4.52 a	3.00 a	3.33 a	3.17 a
V_3T_2	3.00 c	5.33 b	5.00 c	2.33 c	1.60 d	1.77 b	1.47 b	1.70 b
V_3T_3	3.00 c	5.33 b	5.00 c	2.33 c	1.65 d	1.77 b	1.60 b	1.70 b
V_3T_4	3.33 c	5.33 b	5.00 c	2.67 c	1.67 d	1.80 b	1.60 b	1.87 b
V_3T_5	3.33 c	5.67 b	5.33 c	2.67 c	1.72 d	1.80 b	1.83 b	1.67 b
V_3T_6	3.67 c	5.67 b	5.33 c	2.67 c	1.72 d	1.80 b	1.87 b	1.83 b
SEm (±)	0.38	0.62	0.65	0.68	0.19	0.21	0.24	0.22
Level of sig.	*	*	*	*	**	*	*	*
CV (%)	11.68	11.96	13.76	14.73	11.62	13.32	14.96	13.32

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 (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

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

Variety x Residues	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_1T_1	8.00 a	12.33 a	8.67 b	7.00 b	3.00 c	3.00 a	3.00 a	3.00 a
V_1T_2	3.00 c	4.67 b	4.67 c	2.33 c	1.60 d	1.57 b	1.57 b	1.67 b
V_1T_3	3.00 c	5.00 b	5.00 c	2.33 c	1.70 d	1.70 b	1.70 b	1.73 b
V_1T_4	3.33 c	5.33 b	5.00 c	2.67 c	1.83 d	1.70 b	1.80 b	1.80 b
V_1T_5	3.33 c	5.33 b	5.67 c	2.67 c	1.83 d	1.70 b	1.83 b	1.87 b
V_1T_6	3.33 c	5.33 b	5.00 c	2.67 c	1.87 d	1.87 b	1.83 b	1.97 b
V_2T_1	7.33 a	12.00 a	8.33 b	7.67 ab	3.53 b	3.33 a	3.00 a	3.33 a
V_2T_2	3.33 c	5.00 b	4.67 c	2.33 c	1.67 d	1.63 b	1.57 b	1.70 b
V_2T_3	3.33 c	5.00 b	5.00 c	2.33 c	1.70 d	1.77 b	1.64 b	1.73 b
V_2T_4	3.33 c	5.33 b	5.00 c	2.33 c	1.77 d	1.80 b	1.66 b	1.83 b
V_2T_5	3.67 c	5.33 b	5.33 c	2.33 c	1.60 d	1.73 b	1.70 b	1.83 b
V_2T_6	3.67 c	5.33 b	5.67 c	2.67 c	1.72 d	1.70 b	1.73 b	1.83 b
V_3T_1	6.00 b	11.33 a	10.67 a	8.67 a	4.52 a	3.00 a	3.33 a	3.17 a
V_3T_2	3.00 c	5.33 b	5.00 c	2.33 c	1.60 d	1.77 b	1.47 b	1.70 b
V_3T_3	3.00 c	5.33 b	5.00 c	2.33 c	1.65 d	1.77 b	1.60 b	1.70 b
V_3T_4	3.33 c	5.33 b	5.00 c	2.67 c	1.67 d	1.80 b	1.60 b	1.87 b
V_3T_5	3.33 c	5.67 b	5.33 c	2.67 c	1.72 d	1.80 b	1.83 b	1.67 b
V_3T_6	3.67 c	5.67 b	5.33 c	2.67 c	1.72 d	1.80 b	1.87 b	1.83 b
SEm (±)	0.38	0.62	0.65	0.68	0.19	0.21	0.24	0.22
Level of sig.	*	*	*	*	**	*	*	*
CV (%)	11.68	11.96	13.76	14.73	11.62	13.32	14.96	13.32

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 (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

DOI: https://doi.org/10.55706/jae1710

Effect of variety on yield and yield contributing characters of wheat

Varietal differences significantly influenced both yield and yield-related traits. BARI GOM-32 demonstrated superior performance in several other categories, recording the highest PH (97.37 cm), NET hill^{-1} (4.28), SL (15.38 cm), NGS (32.61), TGW (55. 66 g) and HI (39.78 %) (Table 5). The lowest PH (96.47, 96.89 cm), NET hill^{-1} (4.08, 4.02), NGS (31.29), SL (14.94 cm), TGW (54.52 g, 54.78 g), and HI (38.35%, 38.42%) were observed in BARI GOM-32 and BWMRI Gom-1 (Table 5). Pramanik et al. (2019) also observed significant differences due to varietal effects in another study. Likewise, significant variation in yield and yield-contributing characters of wheat crops grown with the application of mustard crop residues was reported by Sarkar et al. (2020).

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

Variety	PH (cm)	NET hill^{-1}	SL (cm)	NGS	TGW (g)	HI (%)
V_1	97.37 a	4.28 a	15.38 a	32.61 a	55.66 a	39.78 a
V_2	96.89 b	4.08 b	15.24 ab	31.86 ab	54.78 b	38.42 b
V_3	96.47 b	4.02 b	14.94 b	31.29 b	54.52 b	38.35 b
SEm (±)	0.76	0.14	0.17	0.57	0.81	0.91
Level of Significance	*	*	*	*	*	*
CV%	5.35	10.35	5.42	5.35	6.11	7.05

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

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

Combining AESM crop residue with herbicides markedly affected yield and its contributing factors. The optimal results were observed when RDH were used and the highest PH (99.07 cm), NET hill^{-1} (4.56), SL (15.70 cm), NGS (34.57), TGW (57.81 g), and HI (40.34%) were recorded (Table 6). In contrast, the lowest outcomes were noted when no AESM was used, resulting in the lowest PH (95.05 cm), NET hill^{-1}(3.21), SL (14.44 cm), NGS (27.87), TGW (50.23 g), and HI (34.52%) (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 RDH, whereas the lowest were seen with hand weeding.

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

Treatment	PH (cm)	NET hill^{-1}	SL (cm)	NGS	TGW (g)	HI (%)
T_1	95.05 c	3.21 b	14.44 c	27.87 c	50.23 e	34.52 b
T_2	99.07 a	4.56 a	15.70 a	34.57 a	57.81 a	40.34 a
T_3	98.23 ab	4.34 a	15.50 ab	33.86 a	56.90 ab	40.14 a
T_4	97.11 ac	4.29 a	15.28 ab	32.14 b	55.92 bc	39.57 a
T_5	96.33 bc	4.21 a	15.16 b	32.18 b	55.08 cd	39.36 a
T_6	95.67 c	4.15 a	15.03 b	30.89 b	53.98 d	39.18 a
SEm (±)	1.08	0.20	0.25	0.81	0.80	1.29
Level of Significance	**	**	**	**	**	**
CV%	5.35	10.35	5.42	5.35	6.11	7.05

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 (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

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

Variety has significant effect on the yield contributing characters and yield of wheat (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 AESM and herbicide. The highest PH (99.47 cm), NET hill^{-1} (4.97), SL (15.73 cm), NGS (34.88), TGW (58.20 g), HI (41.70 %) were observed in BARI GOM-32 with RDH treatment (Table 7). Conversely, the lowest PH (92.89 cm), NET hill^{-1} (3.11), was found in BARI GOM-32 with no aqueous extract or no weeding. The minimum values for SL (12.92), NGS (27.00), TGW (49.53), HI (34.34%) were recorded in BWMRI Gom-1 and no weeding treatment (Table 7). Sarker et al. (2022) identified a similar trend, highlighting the significant impact of the interaction between variety and crop residues on the weight of a thousand grains.

DOI: https://doi.org/10.55706/jae1710

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

Interaction	PH (cm)	NET hill^{-1}	SL (cm)	NGS	TGW (g)	HI (%)
V_1T_1	92.89 d	3.11 d	15.50 ab	28.54 fg	50.00 f	35.57 bd
V_1T_2	99.47 a	4.97 a	15.73 a	34.88 a	58.20 a	41.70 a
V_1T_3	98.66 ab	4.53 ab	15.48 ab	33.67 a-d	57.77 ab	41.57 a
V_1T_4	97.50 ac	4.48 ab	15.30 ab	31.83 be	57.10 ab	40.16 ab
V_1T_5	96.60 a-d	4.40 ab	15.17 ab	31.58 ce	56.23 a-d	39.80 ab
V_1T_6	96.22 a-d	4.32 ac	15.02 ab	29.32 e-g	55.13 a-d	39.88 ab
V_2T_1	95.93 a-d	3.52 cd	14.90 ab	28.06 g	51.17 ef	33.63 d
V_2T_2	98.73 ab	4.42 ab	15.70 ab	34.50 ab	57.70 ab	39.87 ab
V_2T_3	97.55 ac	4.24 ac	15.60 ab	33.65 a-d	56.80 ac	39.56 ac
V_2T_4	96.47 a-d	4.18 ac	15.49 ab	31.21 df	55.23 a-d	39.48 ac
V_2T_5	95.47 bd	4.10 bc	15.37 ab	31.67 b-e	54.53 bd	39.26 ac
V_2T_6	94.64 cd	4.04 bc	15.22 ab	31.67 b-e	53.27 de	38.73 ac
V_3T_1	96.33 a-d	2.97 d	12.92 c	27.00 g	49.53 f	34.34 cd
V_3T_2	99.00 ab	4.28 ac	15.67 ab	34.11 ac	57.53 ab	39.45 ac
V_3T_3	98.47 ab	4.25 ac	15.42 ab	34.27 ac	56.13 a-d	39.27 ac
V_3T_4	97.37 ac	4.20 ac	15.07 ab	33.39 a-d	55.43 a-d	39.08 ac
V_3T_5	96.9 2ac	4.12 bc	14.95 ab	33.29 a-d	54.47 bd	39.01 ac
V_3T_6	96.13 a-d	4.10 bc	14.85 b	31.67 b-e	53.53 ce	38.93 ac
SEm (±)	1.86	0.35	0.42	1.39	1.40	2.24
Level of sig.	*	*	**	*	*	*
CV (%)	5.35	10.35	5.42	5.35	6.11	7.05

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 (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

Effect of variety on GY, SY and BY

The studied different varieties significantly affected the GY, SY and BY. The highest GY (3.62 t ha^{-1}) was obtained in BARI Gom-32, followed by (4.6 t ha^{-1}). The lowest GY (3.58 tha-1) was obtained in BARI Gom-33 and BWMRI Gom-1 (Figure 2). The highest SY and BY (5.70 t ha$^{-1,}$ 9.27 t ha^{-1}) was found in BWMRI Gom-1, followed by (5.67 t ha^{-1}, 9.03 t ha^{-1}) BARI Gom-33 (Figure 2). Similarly, significant variation in yield and yield-contributing characteristics of wheat crops was observed with the application of mustard crop residues (Dola et al., 2024).

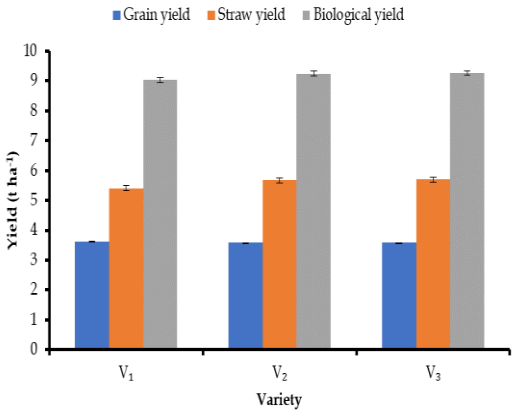

Figure 2. Effect of variety on the GY, SY and BY of wheat.

Here, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1

DOI: https://doi.org/10.55706/jae1710

Effect of AESM crop residues with herbicide on GY, SY and BY

GY, SY and BY were significantly affected by AESM crop residue. The highest GY (4.09 t ha^{-1}) was produced by RDH treatment and the second highest GY was (3.92 t ha^{-1}) in 80% RDH along with AESM treatment which is near to RDH treatment and lowest one (2.33 t ha^{-1}) was produced by no use of extract treatment (Figure 3). Uddin and Pyon (2010) also reported the similar results, where crop residues influenced in crop performance. The highest SY (6.05 t ha^{-1}) was observed in RDH and (5.87 t ha^{-1}), (5.85 t ha^{-1}) was observe in 80% RDH along with AESM and 70% RDH along with AESM treatments which is very close to RDH treatment the lowest SY (3.51 t ha^{-1}) was observed in no use of extract treatment (Figure 3). The highest BY (10.14 t ha^{-1})) was obtained in RDH treatment and (9.77 t ha^{-1}) was in 80% RDH along with AESM treatment. The lowest BY (6.46 t ha^{-1}) was obtained in no use of extract treatment (Figure 3). In an experiment, various phenolic compounds, including p-hydroxybenzoic acid, p-coumaric acid, and trans-cinnamic acid, were identified in the extracts of sorghum leaves. These compounds were found to suppress weed populations (Won et al., 2013). Similarly, Sarker et al. (2020) reported comparable crop performance when water extracted from mustard residue was used. This pattern aligns with findings by Afroz et al. (2018), who observed that crop residues could significantly influence crop performance.

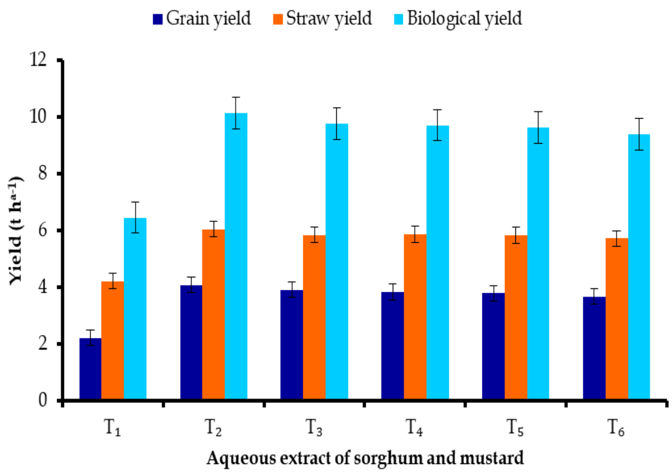

Figure 3. Effect of aqueous extract of sorghum and mustard on GY, SY and BY of wheat

T_1 - No weeding (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

Interaction effect between variety and AESM and mustard crop residues with herbicide on GY, SY and BY

GY, SY and BY were significantly influenced by the interaction between varieties and AESM of crop residues. The highest number of GY was produced by BARI Gom-32 and RDH treatment and the lowest number of grain yield was produced by BARI Gom-32 and no weeding treatment (Figure 4). The highest straw yield (6.10 t ha^{-1}) was produced by BWMRI Gom-1 and RDH treatment and the lowest straw yield (4.00 t ha^{-1}) was produced by BARI Gom-32 and no weeding treatment (Figure 4). Similarly, the combined effect of variety and crop residue extracts was found to be effective (Ahmed et al., 2018). The highest BY of 10.32 t ha^{-1} was produced by BARI Gom-32 under the RDH treatment, while the lowest BY of 6.23 t ha^{-1} was produced by BARI Gom-32 with no weeding treatment (Figure 3). Dola et al. (2024) also reported that the interaction between variety and crop residues plays an important role in increasing GY, SY, and BY.

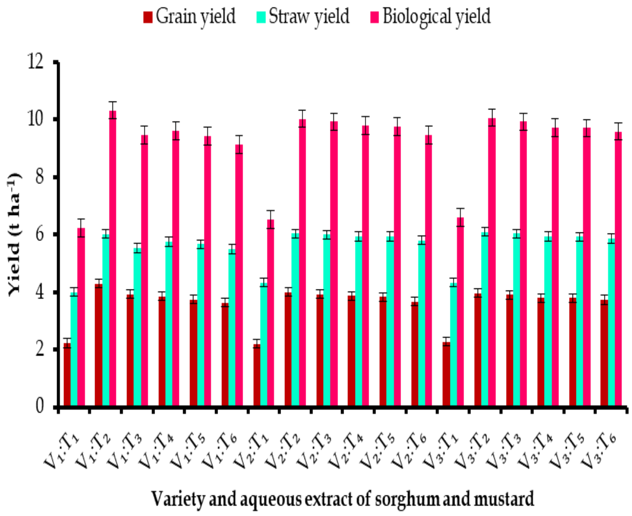

Figure 4. Effect of aqueous extract of sorghum and mustard on GY, SY and BY of wheat

V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1, T_1 - No weeding (control), T_2 - RDH, T_3 - 80% RDH + AESM, T_4 - 70% RDH + AESM, T_5 - 60% RDH + AESM, T_6 - 50% RDH + AESM

CONCLUSION

In conclusion, the findings from this study indicate 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 80% of RDH with AESM (1:20) yielded results that were closely aligned with those achieved using the full RDH alone. This indicates that the 80% RDH with AESM, nearly matched the weed control effectiveness of the full herbicide dose. The research clearly demonstrates that the AESM crop residue not only enhances yield but also serves as an effective herbicidal agent, contributing to the suppression of weed growth.

DOI: https://doi.org/10.55706/jae1710

Acknowledgements

The authors extend their appreciation to University Grants Commission of Bangladesh for financial support.

Conflict of Interest

The authors have declared no conflicts of interest.

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