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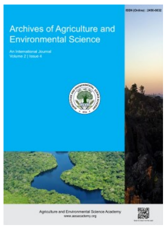

ORIGINAL RESEARCH ARTICLE

Comparative advantages of aqueous extract of mustard crop residues with herbicide to weed control and crop performance of wheat

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ABSTRACT

The detrimental effects of excessive synthetic herbicide use on the environment and yield losses from weeds in low-input agricultural systems have made sustainable weed management imperative. In this respect, a field experiment was conducted at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh, from November 2021 to March 2022, to explore the effects of mustard crop residue extracts on weed control and yield performance of wheat. The study considered three varieties: BARI Gom-32, BARI Gom-33, and BWMRI Gom-1 and six different treatment such as, no weeding (control), recommended dose of herbicide (RDH), 90% RDH + 1:20 aqueous extract of mustard (AEM), 80% RDH + 1:20 AEM, 70% RDH + 1:20 AEM, 60% RDH + 1:20 AEM. Three replications of a randomized complete block design (RCBD) were used in the experiment. The AEM and variety significantly influenced weed population (WP) and dry weight (DW), with BWMRI Gom-1 showing the highest WP and BARI Gom-32 the lowest. BARI Gom-32 also produced the highest grain yield (GY) and other yield-contributing characteristics. The best results, including the highest numbers of effective tillers (NET) hill^{-1} (7.67), number of grains spike^{-1} (NGS) (47.67), 1000-grain weight (TGW) (57.67g), GY (5.02 t ha^{-1}), and straw yield (SY) (6.93 t ha^{-1}), were observed in plots treated with the RDH and the BARI Gom-32 variety, followed by 90% RDH + 1:20 AEM. These findings suggested that aqueous mustard crop residue extracts could be an effectively source to suppress WP and enhance yield.

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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. In Bangladesh, rice is the most significant grain crop, with wheat coming in second. The yearly wheat yield amounts to 1.17 million metric tons, cultivated on 0.78 million acres of land (BBS, 2023). Bangladesh's food production needs to keep up with the country's population expansion. 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). As mechanical weeding is usually expensive, farmers in poverty cannot afford it. Furthermore, the overuse of herbicides and other chemicals to control weeds in wheat resulted in significant environmental degradation and resistance seen in different weed species (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 another crops (Khan *et al.*, 2015; Khan *et al.*, 2013). These plants produce allelochemicals that can significantly curb weed growth in organic farming systems without disrupting 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, leaves, flowers, fruits, roots, and root exudates (Weir *et al.*, 2004). The allelopathic activity of rotation crop residues on weed control and crop selectivity as an alternative strategy for organic farming. All rotation crop residues effectively suppressed weed growth (Uddin & Pyon, 2010). Plants are able to generating a diverse array of chemical compounds including terpenoids, phenolics, coumarins, alkaloids, steroids, tannins, and quinines. These materials may be released into the soil by means of volatile emissions, root secretions, or plant aerial parts leaching (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 & Reigosa, 2011; Alsaadawi & 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 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. These residues can negatively impact various important crops including rice, wheat, mustard, sorghum, rye and buckwheat (Sarker *et al.*, 2020; Pramanik *et al.*, 2019; Ahmed *et al.*, 2018; Sheikh *et al.*, 2017; Ferdousi *et al.*, 2017; Uddin *et al.*, 2014; Won *et al.*, 2013; Uddin & 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.

One of the most promising allelopathic plants is mustard, widely employed as a cover crop or by incorporating its residue into the soil to suppress weeds. The crop residues were once thought of as nothing more than garbage, but due to their value, they are now viewed as a valuable resource that, when added to agricultural land, may produce major improvements. Previously considered little more than trash, they are now seen as a precious resource that may result in significant benefits when put to agricultural land. Crop allelopathy inhibits the growth of weeds by releasing allelochemicals from the live plants or allowing phytotoxic plant leftovers to decompose. Almost no one knew about the mustard allelopathy reports. As is experimentally established, mustard competes well in fields with weeds. It's rapid rise in the early stages of growth could be partially responsible for this. These findings indicate the allelopathic potential of mustard, highlighting its usefulness for biological weed control. In Bangladesh, information on using crop residues to suppress weeds is sparse. However, there have only been a few attempts made in Bangladesh to use plants' crop residue to reduce weeds in the agricultural sector potentially. Only minimal efforts have been made to harness plant crop residues for weed management in agriculture. Based on this mentioned issue, the study was designed to evaluate the aqueous extract of mustard crop residues on weed control and yield performance of wheat.

MATERIALS AND METHODS

Experimental site

A study was carried out at the AFL of BAU, Mymensingh, from November 2021 to March 2022 to investigate the suppression of weed growth in wheat by using an aqueous extract derived from mustard crop residue. The experimental field is situated at a geographical position of 24°75' N latitude and 90°50' E longitude, with an elevation of 18 m above sea level. The experimental region is defined by non-calcareous dark grey floodplain soil from the Sonatola Soil Series in Agroecological Zone 9 of the Old Brahmaputra Floodplain (FAO & UNDP, 1988). The soil in the study field had a nearly neutral reaction, with a pH of 6.5 and limited quantities of organic matter and fertility. The topography was moderate to high, while the soil composition had a silty loam texture. The region experiences a tropical climate characterized by elevated temperatures, substantial rainfall in the Kharif season (April to September), and limited rainfall and relatively cooler temperatures in Rabi (October to March).

Experimental design and treatment factors

The experiment consisted of two components. Factor A contains three wheat cultivars: 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, T_3 - 90% of RDH+ AEM (1:20), T_4 - 80% of RDH+ AEM (1:20), T_5 - 70% of RDH+ AEM (1:20), T_6 - 60% of RDH + AEM (1:20). Each plot was 4 m x 2.5 m (10 m^2), with total number of plots 54. Spacing between replication was 1 m and that between plots was 0.5 m.

Experimental material

In this study, an AEM 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 cultivar 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 plot was prepared with a tractor-drawn disc plough 15 days before sowing. The area required further ploughing, being cross-ploughed four times with a traditional plough, then using a ladder to level the soil and break up any clods. 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 area 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 fie were given irrigation twice, once at 21 days and again at 45 days. The AEM 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 AEM crop residues was administered using a hand sprayer. The crops were harvested after they had reached complete maturity. The maturity of crops was determined when 90% of the grains reached a golden yellow colour. Weed data was taken 35 days after sowing (DAS). GY and SY data were gained from one area in the center of every 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 calculated to a moisture content of 14% and converted into metric tons ha^{-1}.

Data collection

Data about the height and tillering capacity of rice plants throughout various phases of growth were obtained. After reaching maturity, data was collected on yield-contributing characteristics such as GY and SY. Additionally, BY and HI were determined.

Statistical analysis

The data was arranged properly for statistical analysis. An analysis of variance (ANOVA) 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 & Gomez, 1984).

RESULTS AND DISCUSSION

Four weed species from three different families were infesting the experimental field. As shown in Table 1, the table includes the local names (LN), scientific names (SN), families, morphological types (MT), and life cycles (LC) of the weeds found in the experimental plot. The specific weeds identified were *Cynodon dactylon*, *Echinochloa crus-galli*, *Persicaria lapathifolia*, and *Oldenlandia corymbosa*. The weed population consisted of two perennial species and two annual species. (Ahmed *et al.*, 2018) observed a similar pattern of weed infestation in wheat fields, which was influenced by the application of sorghum crop residues used as a growth inhibitor.

Effect of variety on WP and DW of weeds

Varietal differences significantly influenced the WP and DW of durba (*C. dactylon*). The highest WP of *C. dactylon* was recorded in BWMRI Gom-1 (3.94), while BARI Gom-32 had the lowest (3.33). Similarly, the highest DW for this weed was 3.97 g in BWMRI Gom-1, and the lowest was 3.01 g in BARI Gom-32 (Table 2). Similarly, the wheat variety significantly affected the WP and DW of other weed species. For shama (*E. crusgalli*), BWMRI Gom-1 exhibited the highest WP at 15.06 and the highest DW at 4.53 g, whereas BARI Gom-32 showed the lowest WP (13.11) and DW (3.98 g) (Table 2). Ahmed *et al.* (2018) found similar results, stating that wheat variety significantly affects WP, specifically for shama (*E. crusgalli*) and biskatali (*P. lapathifolia*). The WP and DW of bishkatali (*P. lapathifolia*) also varied by variety. BWMRI Gom-1 recorded the highest WP (12.22) and DW (4.15 g), while the lowest for BARI Gom-32 were 10.56 for WP and 3.63 g DW (Table 2). Ashraf *et al.* (2021) found that the type of transplanted (T.) *aman* rice and the after effects of grass pea have a major impact on the effectiveness of weed management.

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

S. No.	LN	SN	Family	MT	LC
1	Durba	*Cynodon dactylon*	Gramineae	Grass	Perennial
2	Shama	*Echinochloa crusgalli*	Gramineae	Grass	Annual
3	Bishkatali	*Persicaria lapathifolia*	Polygonaceae	Broad leaved	Annual
4	Khetpapri	*Oldenlandia corymbosa*	Molluginaceae	Sedge	perennial

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

Varieties	WP (no. m^{-2})				DW of weeds (g m^{-2})			
	Durba	Shama	Bishkatali	Khetpapri	Durba	Shama	Bishkatali	Khetpapri
V_1	3.33 c	13.11 b	10.56 b	4.56 b	3.01 c	3.98 b	3.63 b	2.60 c
V_2	3.61 b	14.11 ab	10.78 ab	5.56 ab	3.47 b	4.29 ab	3.97 a	2.97 b
V_3	3.94 a	15.06 a	12.22 a	5.94 a	3.97 a	4.53 a	4.15 a	3.47 a
SEm (±)	0.37	0.61	0.59	0.55	0.19	0.18	0.15	0.16
Level of Significance	NS	*	*	*	**	*	**	**
CV (%)	10.36	13.07	15.87	10.99	15.00	12.35	11.13	15.81

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.

Table 3. Effect of AEM crop residues on WP, DW of weeds.

Treatments	WP (no. m^{-2})				DW of weeds (g m^{-2})			
	Durba	Shama	Bishkatali	Khetpapri	Durba	Shama	Bishkatali	Khetpapri
T_1	6.11 a	17.22 a	13.11 a	7.67 a	4.23 a	5.14 a	5.28 a	4.21 a
T_2	1.11 d	11.22 e	8.78 d	3.00 d	2.58 d	3.30 e	2.85 d	1.98 e
T_3	2.22 c	12.33 de	9.89 cd	4.22 cd	2.90 cd	3.64 de	3.24 d	2.29 de
T_4	3.11 bc	13.44 cd	10.78 bc	4.78 c	3.35 bc	4.08 cd	3.68 c	2.63 d
T_5	4.00 b	14.44 bc	12.00 ab	5.67 bc	3.74 ab	4.58 bc	4.01 c	3.22 c
T_6	5.22 a	15.89 ab	12.56 a	6.78 a	4.09 a	4.85 ab	4.43 b	3.74 b
SEm (±)	0.52	0.87	0.84	0.78	0.26	0.25	0.21	0.22
Level of significance	**	**	**	**	**	**	**	**
CV (%)	10.36	13.07	15.87	10.99	15.00	12.35	11.13	15.81

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 RDH + AEM (1:20), T_4 - 80% of RDH + AEM (1:20), T_5 - 70% of RDH + AEM (1:20), T_6 - 60% of RDH + AEM (1:20).

Table 4. Combined effect of variety and AEM with herbicide on WP and DW of weed.

Variety x Residues	WP (no. m^{-2})				DW of weeds (g m^{-2})			
	Durba	Shama	Bishkatali	khetpapri	Durba	Shama	Bishkatali	khetpapri
V_1T_1	5.33 a-d	16.67 a-c	12.33 a-d	6.67 a-d	3.65 c-f	4.86 a-d	4.75 bc	3.73 b-d
V_1T_2	1.00 i	10.00 i	8.33 fg	2.00 g	2.29 i	2.95 g	2.73 g	1.69 j
V_1T_3	2.00 g-i	11.33 hi	9.00 e-g	3.67 w-g	2.61 g-i	3.31 fg	2.84 g	1.96 ij
V_1T_4	3.33 e-g	12.33 f-i	10.00 d-g	4.00 d-g	2.97 e-i	3.89 d-g	3.44 e-g	2.16 h-j
V_1T_5	3.67 d-g	13.00 e-i	11.67 a-e	5.00 c-f	3.10 e-i	4.26 b-f	3.84 d-f	2.96 d-h
V_1T_6	4.67 b-e	15.33 a-f	12.00 a-d	6.00 a-e	3.45 c-g	4.62 a-e	4.17 c-e	3.09 d-g
V_2T_1	6.33 ab	17.00 ab	13.00 a-c	8.00 ab	4.11 a-d	5.15 ab	5.30 ab	4.13 a-c
V_2T_2	1.00 i	11.33 hi	8.00 g	3.00 fg	2.51 hi	3.35 fg	2.80 g	1.97 ij
V_2T_3	2.00 g-i	12.00 g-i	9.67 d-g	4.00 d-g	2.86 f-i	3.72 e-g	3.38 e-g	2.27 g-j
V_2T_4	3.00 e-h	13.33 d-h	10.33 c-g	5.00 c-f	3.33 d-h	4.09 c-f	3.70 ef	2.58 f-j
V_2T_5	4.00 c-f	14.67 b-g	11.33 a-e	6.00 a-e	3.86 b-e	4.57 a-e	4.07 c-e	3.18 d-f
V_2T_6	5.33 a-d	16.33 a-d	12.33 a-d	7.33 a-c	4.15 a-d	4.88 a-d	4.58 b-d	3.67 b-d
V_3T_1	6.67 a	18.00 a	14.00 a	8.33 a	4.93 a	5.42 a	5.79 a	4.77 a
V_3T_2	1.33 hi	12.33 f-i	10.00 d-g	4.00 d-g	2.95 e-i	3.62 e-g	3.03 fg	2.28 f-j
V_3T_3	2.67 f-i	13.67 c-h	11.00 b-f	5.00 c-f	3.24 d-h	3.89 d-g	3.52 e-g	2.6 e-i
V_3T_4	3.00 e-h	14.67 b-g	12.00 a-d	5.33 b-f	3.75 b-f	4.26 b-f	3.88 de	3.15 d-g
V_3T_5	4.33 c-f	15.67 a-e	13.00 a-c	6.00 a-e	4.26 a-c	4.92 a-c	4.12 c-e	3.52 c-e
V_3T_6	5.67 a-c	16.00 a-e	13.33 ab	7.00 a-c	4.67 ab	5.05 a-c	4.55 b-d	4.45 ab
SEm (±)	0.90	1.50	1.45	1.35	0.45	0.43	0.36	0.39
Level of Significance	*	*	*	*	*	*	*	*
CV (%)	10.36	13.07	15.87	10.99	15.00	12.35	11.13	15.81

Here, means with the same letters within the same column do not differ significantly, * - 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 + AEM (1:20), T_4 - 80% of RDH + AEM (1:20), T_5 - 70% of RDH + AEM (1:20), T_6 - 60% of RDH + AEM (1:20).

Effect of AEM crop residues on WP and DW of weeds

The AEM crop residues significantly influenced the WP and DW of durba (*C. dactylon*). The highest WP (6.11) was found in the control treatment, while the lowest (1.11) occurred in the RDH treatment. Similarly, the highest DW of weeds (4.23 g) was noted in no weeding treatments, with the lowest (2.58 g) in RDH (Table 3). For shama (*E. crusgalli*), the AEM crop residues also had a marked effect. The highest WP (17.22) appeared in no weeding and the lowest (11.22) in RDH. The maximum DW was 5.14g in no weeding treatment, and the minimum was 3.30g in RDH (Table 3). The WP and DW of bishkatali (*P. lapathifolia*) were similarly affected. The highest WP (13.11) was found in no weeding, with the lowest (8.78) in RDH. The highest DW was 5.28g in no weeding, and the lowest was 2.85g in RDH (Table 3). Lastly, the extract significantly impacted on WP and DW of khetpapri (*O. corymbose*). The highest WP (7.67) and DW (4.21g) were recorded in no weeding, while the lowest figures (3.00 WP and 1.98g DW) were observed in RDH (Table 3). These findings aligned with those reported by Sarkar *et al.* (2020), who noted similar effects in their studies. Weeds can also be suppressed through the allelochemicals released from crop residues, as demonstrated by Khaliq *et al.* (2015).

Interaction effect on WP and DW of weeds

Significant interactions between wheat varieties and the AEM crop residues were observed in WP and DW. For durba (*C. dactylon*), the highest WP (6.67) and DW (4.93 g) were recorded in the BWMRI Gom-1 and no weeding treatment, while the least numbers of weeds (1.00) and 2.29 g DW were found in BARI Gom-32 and RDH (Table 4). In the case of shama (*E. crusgalli*), the highest WP (18.00) were again seen in BWMRI Gom-1 and no weeding treatment and (5.42 g) DW, and the lowest was in BARI Gom-32 and RDH, showing 10.00 WP and 2.95 g DW of weeds (Table 4). For bishkatali (*P. lapathifolia*), the highest WP (14.00) and (5.79 g) DW of weeds appeared in BWMRI Gom-1 and no weeding, and the lowest WP (8.33) and 2.73 g DW of weeds in BARI Gom-32 and RDH (Table 4). Lastly, khetpapri (*O. corymbose*) displayed the highest WP (8.33) and DW (4.77 g) in BWMRI Gom-1 and no weeding and the lowest WP (2.00) and (1.69 g) DW in BARI Gom-32 and RDH (Table 4). Significant differences due to varietal effects were also observed in another study by Pramanik *et al.* (2019). Hossain *et al.* (2017) also reported significant variation in yield and yield-contributing characters of *T. aman* rice crops grown with the application of mustard crop residues.

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 plant height (PH) (102.28 cm) and HI (40.06%). Conversely, BARI GOM-32 demonstrated superior performance in several other categories, recording the highest NET hill^{-1} (6.33), SL (14.59 cm), NGS (43.33), no. of spikelet spike^{-1} (NSS) (14.59), and TGW (52.56 g) (Table 5). The lowest PH (90.06 cm) was noted in BARI GOM-32, while the lowest values for the NET hill^{-1} (5.50), SL (13.87 cm), NSS (15.94), NGS (41.50), TGW (47.17 g), and HI (39.04%) were observed in both BARI GOM-33 and BWMRI Gom-1 (Table 5). Pramanik *et al.* (2019) observed significant varietal effects in their study. Similarly, Sarker *et al.* (2020) stated significant variations in yield and yield-contributing characteristics of wheat crops that were cultivated with the application of mustard crop residues.

Effects of AEM with herbicide on yield and yield contributing characters of wheat

Combining AEM with herbicides markedly affected yield and its contributing factors. The optimal results were observed when RDH were used, 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 (Table 6). In contrast, the lowest outcomes were noted when no AEM was used, resulting in the lowest PH (92.44 cm), NET hill^{-1}(2.89), SL (13.17 cm), NSS (10.33), TGW (37.33 g), and HI (33.37%) (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 weights of 1000 grain spike^{-1} were achieved using the RDH, whereas the lowest were seen with hand weeding. Similar results were reported by Uddin & Pyon (2010), where the aqueous extract of crop residues influenced crop performance.

Interaction effect between variety and AEM with herbicide on the yield contributing characters and yield of wheat

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 AEM and herbicide. The highest PH (105.00 cm) was recorded for BARI GOM-33 treated with RDH. The maximum NET hill^{-1} (7.33), along with the highest values for SL (16.00), NGS (21.33), NGP (47.67), TGW (57.67), HI (42.00 %) was observed in BARI GOM-32 with RDH treatment (Table 7). Conversely, the lowest PH (86.67 cm) was found in BARI GOM-32 with no weeding treatment. The minimum values for NET hill^{-1} (2.67), SL (12.83), NSS (9.67), NGP (27.33), TGW (35.67), HI (32.89%) were recorded in BWMRI Gom-1 and no weeding treatment (Table 7). A similar pattern was noted by Sarker *et al.* (2022), emphasizing the important influence of crop residues and variety interaction on the weight of a thousand grains. Similarly, Ahmed *et al.* (2018) discovered that agricultural residue extracts and variety had a successful combination effect.

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

Variety	PH (cm)	NET hill^{-1}	SL (cm)	NSS	NGS	TGW (g)	HI (%)
V_1	90.06 c	6.00 a	14.59 a	17.94 a	43.33 a	52.56 a	40.06 a
V_2	102.28 a	5.22 b	13.87 b	16.72 b	42.33 ab	47.39 b	40.00 ab
V_3	92.61 b	4.89 b	14.04 b	15.94 b	41.50 b	47.17 b	39.04 b
SEm (±)	0.45	0.22	0.20	0.49	0.50	0.43	0.45
Level of Significance	**	**	**	**	**	**	*
CV%	5.41	12.58	5.34	8.68	6.54	7.63	6.34

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.

Table 6. Effect of aqueous extract of sorghum crop residues with herbicide on yield and yield contributing characters of wheat.

Treatment	PH (cm)	NET hill^{-1}	SL (cm)	NSS	NGS	TGW (g)	HI (%)
T_1	92.44 e	2.89 e	13.17 c	10.33 e	28.67 e	37.33 e	33.37 c
T_2	97.22 a	6.89 a	15.58 a	20.11 a	46.89 a	53.44 a	41.60 a
T_3	96.33 ab	6.33 ab	14.89 b	19.33 ab	46.22 ab	52.44 ab	41.41 ab
T_4	95.67 bc	5.78 bc	14.33 b	18.00 bc	45.44 bc	51.44 bc	41.02 an
T_5	94.56 cd	5.33 cd	13.70 c	17.33 cd	44.22 cd	50.33 cd	40.65 ab
T_6	93.67 de	5.00 d	13.34 c	16.11 d	42.89 b	49.22 d	40.14 b
SEm (±)	0.63	0.32	0.29	0.40	0.71	0.61	0.63
Level of Significance	**	**	**	**	**	**	**
CV%	5.41	12.58	5.34	8.68	6.54	7.63	6.34

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% RDH + Aqueous extract (1:20), T_4 - 80% of RDH + Aqueous extract (1:20), T_5 - 70% of RDH + Aqueous extract (1:20), T_6 - 60% of RDH + Aqueous extract (1:20).

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

Variety: Aqueous extract of sorghum with herbicide	PH (cm)	NET hill^{-1}	SL (cm)	NSS	NGS	TGW (g)	HI (%)
V_1T_1	86.67 j	3.33 gh	13.67 e-h	11.00 h	30.33 f	39.00 k	34.29 c
V_1T_2	92.00 f-h	7.33 a	16.00 a	21.33 a	47.67 a	57.67 a	42.00 a
V_1T_3	91.33 g-i	7.00 ab	15.33 a-c	20.33 ab	47.00 ab	56.33 ab	41.91 a
V_1T_4	91.00 hi	6.67 a-c	14.67 b-e	19.00 a-e	46.00 a-c	55.33 bc	40.91 ab
V_1T_5	90.00 hi	6.00 b-d	14.07 d-g	18.33 b-e	45.00 a-d	54.00 cd	40.58 ab
V_1T_6	89.33 i	5.67 c-e	13.83 e-h	17.67 c-f	44.00 c-e	53.00 de	40.66 ab
V_2T_1	100.33 d	2.67 h	13.00 gh	10.33 h	28.33 fg	37.33 kl	32.93 c
V_2T_2	104.67 a	6.67 a-c	15.67 a-d	20.00 a-c	47.00 ab	51.67 ef	41.89 a
V_2T_3	103.67 ab	6.00 b-d	14.33 c-f	19.33 a-d	46.00 a-c	50.33 f-h	41.40 ab
V_2T_4	102.67 a-c	5.67 c-e	13.67 e-h	18.00 b-f	45.67 a-d	49.33 f-j	41.54 a
V_2T_5	101.67 b-d	5.33 d-f	13.37 f-h	17.00 d-g	44.00 c-e	48.67 g-j	41.56 a
V_2T_6	100.67 cd	5.00 d-f	13.17 f-h	15.67 fg	43.00 de	47.00 j	40.67 ab
V_3T_1	90.33 hi	2.67 h	12.83 h	9.67 h	27.33 g	35.67 h	32.89 c
V_3T_2	95.00 e	6.67 a-c	15.07 a-d	19.00 a-e	46.00 a-c	51.00 e-g	40.91 ab
V_3T_3	94.00 ef	6.00 b-d	15.00 a-d	18.33 b-e	45.67 a-d	50.67 f-h	40.93 ab
V_3T_4	93.33 e-g	5.00 d-f	14.67 b-e	17.00 d-g	44.67 b-d	49.67 f-i	40.60 ab
V_3T_5	92.00 f-h	4.67 ef	13.67 e-h	16.67 e-g	43.67 c-e	48.33 h-j	39.79 ab
V_3T_6	91.00 hi	4.33 fg	13.03 gh	15.00 g	41.67 e	47.67 ij	39.09 b
SEm (±)	1.09	0.55	0.50	1.20	1.23	1.05	1.09
Level of Significance	*	*	*	*	*	*	*
CV (%)	5.41	12.58	5.34	8.68	6.54	7.63	6.34

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 + Aqueous extract (1:20), T_4 - 80% RDH + Aqueous extract (1:20), T_5 - 70% RDH + Aqueous extract (1:20), T_6 - 60% RDH + Aqueous extract (1:20).

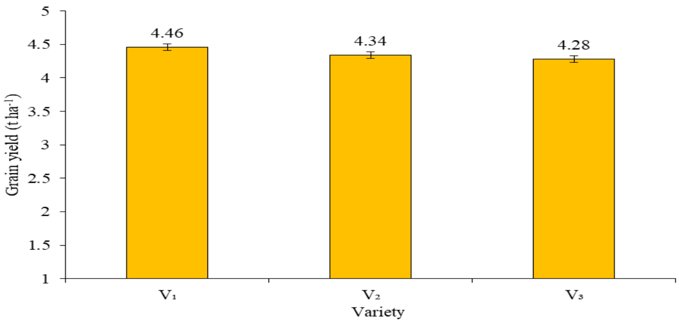

Figure 1. *Effect of variety on the grain yield of wheat. Here, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1*

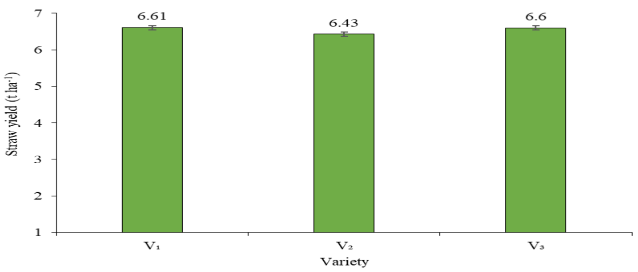

Figure 2. *Effect of variety on the straw yield of wheat. Here, V_1 - BARI Gom-32, V_2 - BARI Gom-33, V_3 - BWMRI Gom-1.*

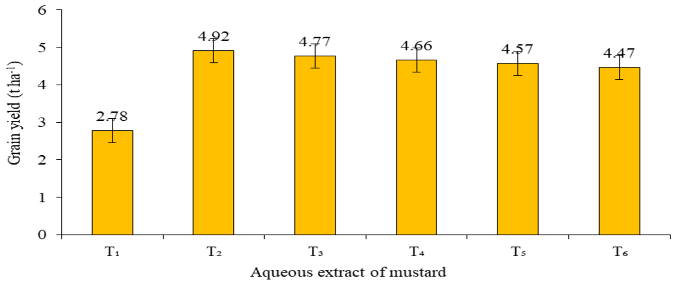

Figure 3. *Effect of aqueous extract of sorghum on the grain yield of wheat. Here, T_1 - no weeding, T_2 - RDH, T_3 - 90% RDH + Aqueous extract (1:20), T_4 - 80% RDH + Aqueous extract (1:20), T_5 - 70% RDH + Aqueous extract (1:20), T_6 – RDH + Aqueous extract (1;20).*

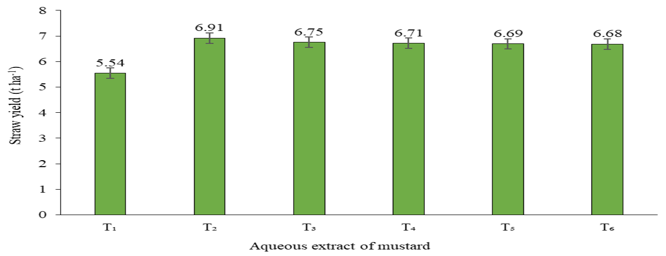

Figure 4. *Effect of aqueous extract of sorghum on the yield of wheat. Here, T_1 - No weeding, T_2 - RDH, T_3 - 90% RDH + Aqueous extract (1:20), T_4 - 80% RDH + Aqueous extract (1:20), T_5 - 70% RDH + Aqueous extract (1:20), T_6 - 60% RDH + Aqueous extract (1;20).*

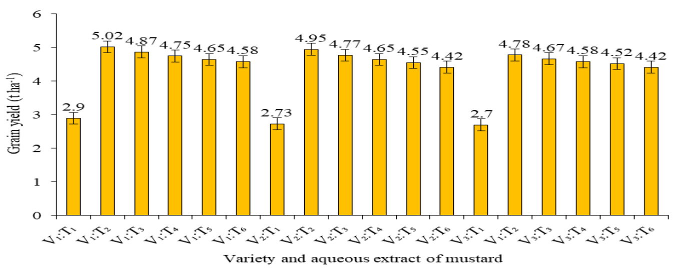

Figure 5. *Interaction effect of variety and aqueous extract of sorghum on the grain yield of wheat. Here, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - no weeding, T_2 - RDH, T_3 - 90% RDH + Aqueous extract (1:20), T_4 - 80% RDH + Aqueous extract (1:20), T_5 - 70% RDH + Aqueous extract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

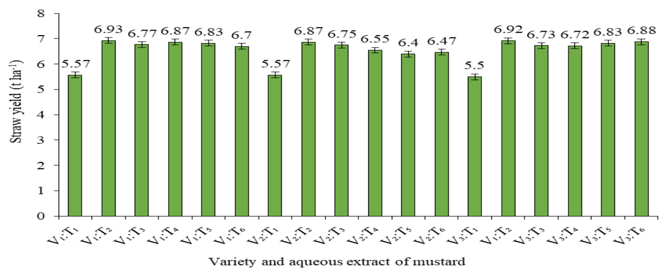

Figure 6. *Interaction effect of variety and aqueous extract of sorghum on the straw yield of wheat. Here, V_1 -BARI Gom -32, V_2 -BARI Gom-33, V_3 -BWMRI Gom-1, T_1 - No weeding, T_2 - RDH, T_3 - 90% RDH + Aqueous extract (1:20), T_4 - 80% of RDH + Aqueous extract (1:20), T_5 - 70% of RD of herbicide + Aqueous extract (1:20), T_6 - 60% of RD of herbicide + Aqueous extract (1:20).*

Effect of variety on GY and SY

The study revealed that different varieties significantly influenced both GY and SY. The highest GY (4.46 t ha^{-1}) for BARI Gom-32, followed by 4.34 t ha^{-1}. The lowest GY (4.28 t ha^{-1}) was observed in BWMRI Gom-1 (Figure 1). Similarly, the highest SY (6.61 t ha^{-1}) was found in BARI Gom-32, followed by BARI Gom-33 (6.43 t ha^{-1}) (Figure 2).

Effect of AEM crop residues with herbicide on GY and SY

The application of the AEM crop residues had a significant impact on GY and SY. The highest GY (4.98 t ha^{-1}) was observed in RDH, followed by a 4.77 t ha^{-1} yield from treatments combining 90% of RDH with 1:20 AEM. The lowest GY (2.78 t ha^{-1}), was observed in no weeding treatment (Figure 3). Similarly, SY was significantly affected, with the highest SY (6.91 t ha^{-1}) recorded in the RDH treatment. The lowest SY (5.54 t ha^{-1}), was noted in no weeding treatment (Figure 4). This trend aligned with the observations of Sarker *et al.* (2022), who noted that crop residues could significantly affect crop performance. Ahmed *et al.* (2018) also confirmed that the aqueous extract of sorghum crop residues significantly impacts yield and yield-contributing traits.

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

The interaction between varieties and AEM crop residues significantly influenced GY and SY. The highest GY (5.02 t ha^{-1}) was produced by BARI Gom-31 and RDH treatment, and the lowest GY (2.7 t ha^{-1}) was produced by BWMRI Gom-1 and no weeding treatment (Figure 5). The highest SY (6.93 t ha^{-1}) was observed in the RDH treatment. The lowest SY (5.5 t ha^{-1}) was observed in the no weeding treatment (Figure 6). These findings underscore the critical role of treatment interactions in optimizing wheat crop yields. Similar conclusions were drawn by Sarker *et al.* (2022) reported that the combination of variety and aqueous crop residue extracts effectively enhanced yield. Similar conclusions were drawn by Afroz *et al.* (2018), who noted the significant impact of marsh pepper and buckwheat crop residue extracts on yield and related traits of *T. aman* rice.

Conclusion

The results indicated that BARI Gom-32 treated with the RDH displayed superior effects, closely followed by BARI Gom-32 treated with 90% of RDH along with AEM (1:20). This suggested that applying AEM crop residues positively influences yield across various traits studied. Furthermore, the study highlights the herbicidal properties of the aqueous extract, effectively suppressing weed growth. These findings underscore the significant potential of AEM residue extract as an effective weed management strategy.

DECLARATIONS

Author contribution statement

Conceptualization: N.A.D, M.H.O.R. and M.R.U.; Methodology: N.A.D.; Software and validation: M.T.A. and S.A.U.; Formal analysis and investigation: N.A.D..; Resources: N.A.D.; Data curation: N.A.D..; Writing—original draft preparation: N.A.D and M.T.A.; Writing—review and editing: U.K.S., M.R.U. and M.H.O.R.; Visualization: N.A.D.; Supervision: M.R.U.; Project administration: M.R.U.; Funding acquisition: M.R.U. All authors have read and agreed to the published version of the manuscript.

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Consent for publication: All authors have given consent for publication of this manuscript.

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