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DIFFERENTIAL WEED SUPPRESSION ABILITY IN SELECTED WHEAT VARIETIES OF BANGLADESH

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ABSTRACT

Weed is one of the major pests of wheat causing substantial yield losses and hence sustainable weed management is a huge challenge for its cultivation. Weed competitive crop variety is considered to be a vital and eco-friendly tool for integrated weed management. Therefore, it is necessary to evaluate the weed competitiveness of the available Bangladeshi wheat germplasms for their possible inclusion as a component of integrated weed management. The present research was designed to evaluate the weed competitiveness of ten recently released wheat varieties of Bangladesh by growing them under weedy and weed-free conditions. Plots without wheat (weed monoculture) were also maintained. The experiment was carried out in a randomized complete block design and replicated thrice. Results showed that wheat varieties varied widely in their weed competitiveness and yielding ability. Among the wheat varieties studied, BARI gom 27 allowed the minimum weed growth (87.0 gm^{-2}) while BARI gom 21 allowed maximum weed growth (188.9 gm^{-2}). Grain yield ranged between 1.9 t ha^{-1} (BARI gom 23) and 3.7 t ha^{-1} (BARI gom 24) under weed-free condition, and between 1.3 t ha^{-1} (BARI gom 21) and 2.9 t ha^{-1} (BARI gom 28) under weedy condition. Weed inflicted relative yield loss ranged from 17.8 to 51.2% among the varieties. Although BARI gom 24 was the highest yielder but its competitive ability against weed was very poor. On the other hand, BARI gom 28 and BARI gom 30 appeared as the most weed competitive varieties (17.8 and 24.9% relative yield losses, respectively) with moderate grain yield. BARI gom 30 was the best in terms of yield, but BARI gom 28 ranked first in terms of weed competitiveness. Therefore, considering high feasibility of growing weed competitive variety as a tool for sustainable weed management, breeding for strongly weed competitive wheat variety with high yield potential is necessary.

KEYWORDS

Wheat germplasm, weed competitiveness, weed pressure, weed management, relative yield loss

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) ranks first in area (219 million hectares) and third in production (713 million metric tons per year) among the cereal crops in the world [1]. It is the second most important cereal crop of Bangladesh next to rice, but the average yield of Bangladeshi wheat cultivars is very low compared to that of other wheat growing countries of the world [1]. In addition, the national average yield of Bangladeshi wheat is much lower than the potential yields of wheat varieties as obtained in the research field. Among the several reasons, weed infestation is one of the most important one reducing wheat yield by 24-92% [2–6]. Even a lower weed density of only 15 plants m^{-2} resulted in significant decrease (14%) in wheat yield. A study reported more than 30 weeds that infest the wheat around the world [7]. Manual or hand pulling is mainly practiced method of weeding by the famers in Bangladesh and some other wheat growing South Asian countries since ancient time. But due to high labor wages and migration of labors from agriculture to industry and other non-agriculture sectors, farmers have no other way but to use herbicides, a promising and cost-effective alternative to manual weeding, for weed control. The use of herbicides in Bangladesh has been almost a 27-fold increase in the last two decades (from 149.5 metric tons in 1996 to 4015.3 MT in 2016) [8]. However, the over-reliance on herbicides may cause severe environmental hazards and development of herbicide resistant weed biotypes [9-12]. Therefore, herbicide should be thought of one of the options, but not necessarily the only option when formulating weed control program.

Integrated weed management (IWM) approach offers several options, but risks of developing resistant weeds and environmental hazard resulting from herbicides [13–14], and labor-intensive manual weeding methods demand an environment friendly, less laborious and cost-effective weed management package for a sustainable crop production system. For the purpose of obtaining such eco-friendly and cost-effective weed management system, competitive crop cultivar may play a vital role [15–16], and therefore weed competitive crop variety is one of the vital component of integrated weed management [17]. The effect of weed competition on crop yield depends on the competitive ability of weeds, which is counter balanced by the competitive ability of crops. There are two aspects of crop competitiveness; the ability of the crop to reduce the fitness of a competitor (suppressive ability), and the ability of the crop to withstand the competitive impact of weeds and resist yield loss (tolerance ability) [16, 18]. Role of weed competitive variety as a key tool for sustainable weed management in different crops has been suggested by many researchers [14, 15, 19-21]. Research findings on the weed competitiveness of Bangladeshi wheat varieties are very few [5], and unfortunately no information is available regarding the recently released wheat varieties. Therefore, extensive research is required to identify which variety of wheat sustains well against weeds. It is also further required to find out the agronomic traits of wheat responsible for weed suppression in the context of Bangladesh.

The present research work was, therefore, undertaken to determine the relative competitive ability of modern Bangladeshi wheat varieties against weeds and to identify the agronomic traits of wheat conferring weed competitiveness. The findings of the research will be helpful to select competitive wheat varieties that can be grown successfully with least weed management.

2. METHODOLOGY

2.1 Description of the Experimental Site

The experimental site is located at 24º75´N latitude and 90º50´ E longitude at an elevation of 18 m above the sea level belonging to non-calcareous dark grey floodplain soil under Sonatala series of Old Brahmaputra Floodplain Agro-ecological zone (AEZ-9) of Bangladesh. The experimental field was a medium high land with silty clay loam soil texture having pH value of 6.8.

The climate of the experimental area is characterized by high temperature accompanied by moderately high rainfall during April to September, and low temperature during October to March. During the growing season (November 2015 to March 2016), monthly average temperature, relative humidity, air pressure, wind speed, solar radiation, dew point and water temperature were 18.0–25.5 °C, 75-84%, 1009.1–1013.8 mb, 2.33–5.17 km h^{-1}, 194.0–239.9 W m^{-2}, 14.1–20.0 °C and 16.1–24.8°C, respectively, while monthly total rainfall and sunshine hours were 0–104.8 mm and 84.7–200 h, respectively. The soil temperature at a depth of 5, 10, 20 and 30 cm were 19.0–27.5, 19.6–27.4, 19.9–26.8 and 18.7–25.4°C, respectively.

2.2 Experimental Treatments and Design

The experiment comprised two weeding regimes *viz.*, (a) weed free and (b) weedy condition, and ten high yielding Bangladeshi wheat varieties *e.g.*, (i) BARI gom 21, (ii) BARI gom 24, (iii) BARI gom 22, (iv) BARI gom 23, (v) BARI gom 25, (vi) BARI gom 26, (vii) BARI gom 27, (viii) BARI gom 28, (ix) BARI gom 29, (x) BARI gom 30. Plots without wheat (weed monoculture) were also maintained to study the natural growth of weeds in absence of wheat. A brief description of the wheat varieties is given in Table 1.

Table 1: Salient features of the wheat varieties used in this experiment

Variety	Year of release	Field duration (days)	Yield potential (t ha^{-1})
BARI gom 21	2000	100-105	3.6-5.0
BARI gom 22	2005	100-110	3.6-4.8
BARI gom 23	2005	103-112	4.3-5.0
BARI gom 24	2005	102-110	3.5-5.1
BARI gom 25	2010	102-112	3.6-4.6
BARI gom 26	2010	104-110	3.5-4.5
BARI gom 27	2012	105-110	3.5-4.5
BARI gom 28	2012	102-108	4.0-5.5
BARI gom 29	2014	105-110	4.0-5.0
BARI gom 30	2014	100-105	4.5-5.5

All the ten varieties were developed and released by Wheat Research Centre, Bangladesh Agricultural Research Institute (BARI). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The unit plot size was 10 m^2.

2.3 Crop Husbandry

The land was first opened with a power tiller and subsequently leveled by laddering. Weeds and stubbles of the previous crop were collected and removed from the field. The land was fertilized with urea, triple super phosphate (TSP), muriate of potash (MoP) and gypsum at the rate of 200, 160, 50 and 120 kg ha^{-1}, respectively. The entire amount of TSP, MoP and gypsum and two third of urea were applied at the time of final land preparation. The rest one third of urea was top dressed at crown root initiation (CRI) stage, *i.e.*, 20 days after sowing (DAS). Seeds were sown on 15 November 2015 in 20 cm apart lines @ 120 kg seed ha^{-1}. Care was taken to avoid bird damage up to 15 days after sowing. Irrigation was given twice at 20 and 50 DAS.

2.4 Data Collection

2.4.1 Weed related data

A quadrate of size 0.5 m × 0.5 m was placed randomly in two places of each weedy plots for collecting weed samples. Weeds were clipped to ground level, identified and counted by weed species, and separately oven dried at 70 ºC to constant weight. According to a study, dominant weed species were identified using the summed dominance ratio (SDR) as follows - [22].

$$\text{SDR} = \frac{\text{Relative density (RD)+Relative dry weight (RDW)}}{2}$$

$$\text{Where, RD (\%)} = \frac{\text{Density of a given weed species}}{\text{Total weed density}} \times 100$$

$$\text{RDW (\%)} = \frac{\text{Dry weight of a given weed species}}{\text{Total weed dry weight}} \times 100$$

In weedy treatments, weed growth was visually rated at 9 weeks after sowing on a 1 to 9 scale, with 1 for minimum weed growth and 9 for maximum weed growth. Relative yield loss of wheat due to weed competition was also calculated according to a study as follows - [23].

$$\text{Relative yield loss (RYL)} = \frac{\text{Weed free yield} - \text{Treatment yield}}{\text{Weed free yield}} \times 100$$

2.4.2 Crop related data

Early visual vigor (EVV) of wheat plants was evaluated at 3 weeks after sowing following the scale 1 to 9 where 1 indicates the least crop growth and 9 indicates the most crop growth. The crop was harvested at full maturity *i.e.* when about 80% of the spikes became golden yellow in color. Five hills (excluding border hills) were randomly selected in each plot and uprooted before harvesting for recording the necessary data on yield contributing characters. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The crop was threshed by a pedal thresher. Grains were sun dried and cleaned. Straws were also sun dried properly. Finally, grain and straw yields were converted to t ha^{-1}.

2.5 Statistical Analysis

The collected data were compiled and tabulated in proper form and were subjected to statistical analysis. Data were analyzed using the analysis of variance (ANOVA) technique with the help of computer package MSTAT-C and mean difference were adjudged by Duncan's Multiple Range Test [24].

3. RESULTS

3.1 Weed Dynamics

The weed species found in the weedy plots of the experimental field are presented in Table 2.

Table 2: Dominant weed species with family name, type, relative density (RD), relative dry weight (RDW) and summed dominance ratio (SDR)

Scientific Name	Family Name	Weed Type	RD (%)	RDW (%)	SDR
Digitania sanguinalis	Gramineae	Grass	50	65.82	57.91
Polygonum hydropiper	Polygonaceae	Broad Leaf	12.13	22.57	17.35
Chenopodium album	Chenopodiaceae	Broad Leaf	8.25	1.793	5.02
Hedyotis corymbosa	Rubiaceae	Broad Leaf	7.28	2.621	4.94
Echinochloa crusgalli	Gramineae	Grass	6.31	3.175	4.74
Echinochloa colonum	Gramineae	Grass	7.76	0.466	4.11
Physalis haterophylla	Solanaceae	Broad Leaf	2.91	0.679	1.79
Solanum torvum	Solanaceae	Broad Leaf	0.97	1.052	1.01
Vicia sativa	Leguminosae	Broad Leaf	1.45	0.126	0.788
Mazus rugosus	Scrophulariaceae	Broad Leaf	0.97	0.455	0.71
Cyperus rotundus	Cyperaceae	Sedge	1.94	1.233	1.58

Eleven weed species belonging to seven families infested the experimental field (three from family Gramineae, two from Solanaceae, and one from each of Polygonaceae, Cyperaceae, Scrophulariaceae, Chenopodiaceae, Rubiaceae and Leguminosae). The five most dominant weed species encountered were *Digitania sanguinalis, Polygonum hydropiper, Chenopodium album, Hedyotis corymbosa* and *Echinochloa crusgalli* (Table 2).

Grassy weeds dominated the community contributing 69.5% and 64.0% of the total density and dry matter, followed by broadleaf weeds (29.3 and 34.0%, respectively) and sedges (1.2% and 2.0%, respectively) (Figure 1 and 2).

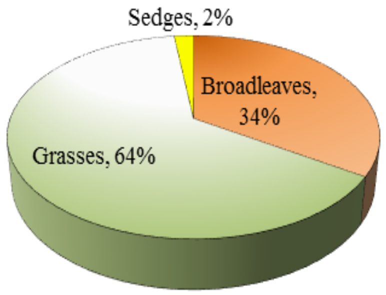

Figure 1: Relative dry weight of different weed groups

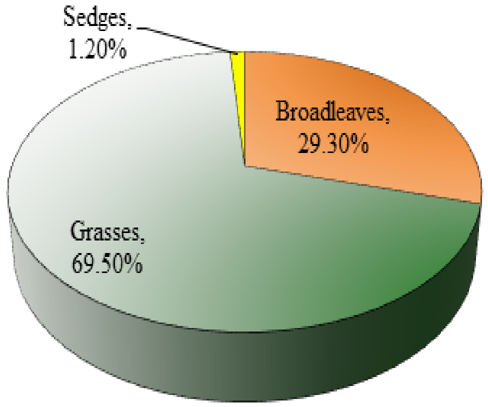

Figure 2: Relative density of different weed groups

Weed density and dry weight varied significantly among wheat varieties (Figure 3 and 4).

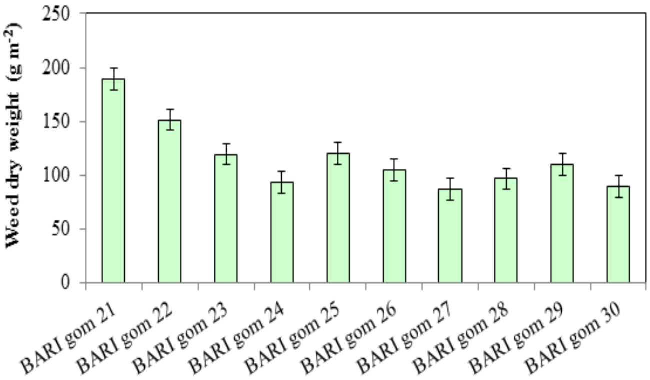

Figure3: Effect of wheat variety on weed dry weight (g m^{-2})

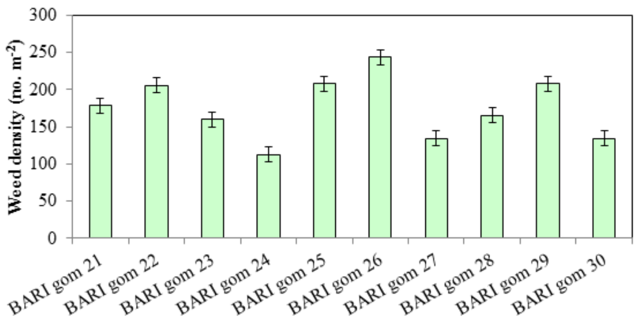

Figure 4: Effect of wheat variety on weed density

Mean weed pressure (average weed dry matter over all weedy plots) across varieties was 199 g m^{-2} against 540 g m^{-2} recorded in weed monoculture, which denotes that on average, wheat varieties reduced weed pressure by about 63%. BARI gom 27 emerged as the most weed suppressive variety reducing weed pressure by 84% followed by BARI gom 30 (83.5%), BARI gom 24 (82.8%) and BARI gom 28 (82%). Highest weed pressure of 188.9 g m^{-2} was found in BARI gom 21 which was only 60% less than weed monoculture, and thus BARI gom 21 was identified as the weakest competitor among the evaluated varieties. Wheat varieties significantly differed with respect to weed density, which was within a broad range from 112 to 243 m^{-2}, whereas in weed monoculture it was as high as 450 m^{-2}. The average weed density across wheat varieties was 175 m^{-2} that means wheat crop itself could reduce more than 60% weed density irrespective of varieties.

3.2 Early Visual Vigor of Wheat and Weed Rating

Early visual vigor was significantly different among the wheat varieties. BARI gom 27 appeared as the most vigorous with early visual vigor scores of 8 (Table 3).

Table 3. Effect of variety and weeding regime on early visual vigor and weed rating of wheat

Variety	Early visual vigor	Weed rating
BARI gom 21	3.66d	4.33a
BARI gom 22	4.00cd	3.83b
BARI gom 23	4.83c	3.66bc
BARI gom 24	7.50a	3.00d
BARI gom 25	6.33b	3.66bc
BARI gom 26	4.83c	3.16cd
BARI gom 27	8.00a	2.33e
BARI gom 28	7.83a	3.33cd
BARI gom 29	7.16ab	3.33cd
BARI gom 30	7.83a	3.16
% CV	8.83	11.45
Level of significance	**	**
Weeding regime		
Weed free	6.56a	-
Weedy	5.83b	-
CV%	8.83	-
Level of significance	**	-

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). **= Significant at 1% level of probability NS= Not significant DAS=Days after sowing

The more vigorous varieties with vigor scores of more than 7 were BARI gom 28 (7.8), BARI gom 30 (7.8), BARI gom 24 (7.5) and BARI gom 29 (7.1). BARI gom 21, on the other hand, was the least vigorous scoring around 3.6. Higher vigor was observed under weed free condition than weedy condition with average scores of 6.6 and 5.8, respectively (Table 3). Yield and weed competitiveness can be effectively predicted by early visual vigor. Early visual vigor (R^2=0.70) maintained a strong and negative correlation with weed dry matter (Figure 5).

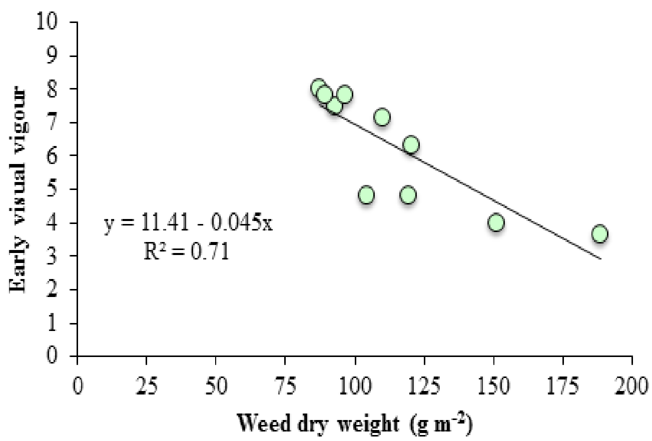

Figure 5: Relationship between early visual vigor and weed dry matter

Weed rating also varied significantly among varieties (Table 3). In terms of weed rating, BARI gom 27 appeared as the most competitive variety since weed rating against this variety was only 2.3, whereas, highest weed rating (4.33) was recorded with BARI gom 21 signified its poor competitiveness against weeds.

3.3 Wheat Plant Height

Wheat varieties exhibited differences in plant height at all sampling dates, but most significantly at the final stage (Table 4).

Table 4: Effect of variety and weeding regime on plant height of wheat

Variety	Plant height (cm)		
	15 DAS	30 DAS	Harvest
BARI gom 21	13.77c	33.02d	97.53ab
BARI gom 22	14.08bc	33.65cd	92.92abc
BARI gom 23	14.62bc	35.98bc	94.37abc
BARI gom 24	18.12a	43.63a	98.30a
BARI gom 25	14.47bc	33.82cd	89.30cd
BARI gom 26	15.35bc	34.68cd	92.25bc
BARI gom 27	18.10a	44.95a	91.98bc
BARI gom 28	16.23ab	43.82a	90.10cd
BARI gom 29	14.92bc	37.10b	84.75d
BARI gom 30	17.47a	44.58a	85.17d
CV%	13.26	5.42	5.13
Level of significance	**	**	**
Weeding regime			
Weed free	16.11a	39.54a	93.55a
Weedy	15.30a	37.50b	89.77b
CV%	13.26	5.42	5.13
Level of significance	NS	**	**

Other details are same as Table 3.

At harvest, plant height ranged from 84 to 98 cm. BARI gom 24 appeared as the tallest variety, which was marginally taller than BARI gom 21, whilst BARI gom 29 was the shortest in stature closely followed by BARI gom 30 (Table 4).

At all the growth stages, plant height of wheat varied significantly among wheat varieties studied. Weed infestation reduced plant height of wheat at all the growth stages (Table 4). The magnitude of reduction in plant height varied with growth phases, and reduction rate in weedy treatment followed a declining trend with the advancement of crop growth stages. However, weedy treatment at harvest recorded more than 4% reduction in plant height compared to weed free treatments. Presence of weed markedly decreased plant height by 5 and 5.5% at 15 and 30 DAS, respectively. At harvest, BARI gom 21 and BARI gom 22 suffered the greatest height loss in weedy treatment as compared with weed free one. The reduction percentages were 6.7 and 8.5, respectively. Such loss is understandable as both the cultivars had greater reduction in height at earlier stage. In other words, those cultivars had slower growth rate at earlier stage, which resulted in such reduction. Conversely, BARI gom 24 and BARI gom 30 performed better in weedy circumstances as the reduction in plant height were 2.4 and 2.7%, respectively during harvest. The reduction percentage for both BARI gom 24 and BARI gom 30 was mostly 4.5% during earlier stage.

The interaction effect of weeding regime and variety produced significant influence on plant height (Table 5).

Table 5: Interaction effect of variety and weeding regime on plant height of wheat

Interaction		Plant height (cm)		
Weeding regime	Variety	15 DAS	30 DAS	Harvest
Weed free	BARI gom 21	13.93b	34.97b-e	100.7a
	BARI gom 22	14.40b	35.43bcd	96.70a-d
	BARI gom 23	15.03ab	36.40bc	96.03a-d
	BARI gom 24	18.77a	44.10a	99.50ab
	BARI gom 25	14.77ab	34.50b-e	91.23b-g
	BARI gom 26	15.77ab	36.20bc	94.47a-e
	BARI gom 27	18.67a	46.13a	93.47a-e
	BARI gom 28	16.77ab	44.30a	90.63b-g
	BARI gom 29	15.33ab	37.53b	86.50efg
	BARI gom 30	17.73ab	45.87a	86.33efg
Weedy	BARI gom 21	13.60b	31.07e	94.37a-e
	BARI gom 22	13.77b	31.87de	89.1c-f
	BARI gom 23	14.20b	35.57bcd	92.70a-f
	BARI gom 24	17.47ab	43.17a	97.10abc
	BARI gom 25	14.17b	33.13cde	87.37d-g
	BARI gom 26	14.93ab	33.17cde	90.03c-g
	BARI gom 27	17.53ab	43.77a	90.50b-g
	BARI gom 28	15.70ab	43.33a	89.57c-g
	BARI gom 29	14.50b	36.67bc	83.00g
	BARI gom 30	17.20ab	43.30a	84.00fg
CV%		13.26	5.42	5.13
Level of significance		**	**	**

Other details are same as Table 3.

At harvest, BARI gom 24 appeared as the tallest variety whilst BARI gom 29 and BARI gom 30 were the shortest ones. At earlier stage, BARI gom 30 was the tallest one closely followed by BARI gom 24, and BARI gom 21 was with the shortest stature. Plant height at 30 DAS maintained a strong negative correlation with weed dry weight (Figure 6). Early plant height at 30 DAS appeared to be the most important trait in predicting weed biomass (R^2=0.58) (Figure 6).

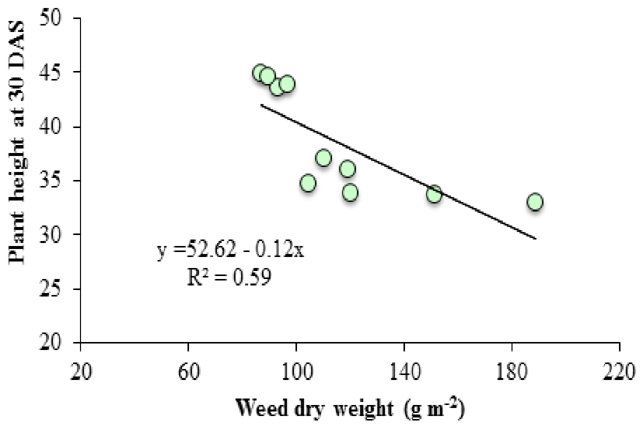

Figure 6: Relationship between plant height 30 DAS and weed dry matter

3.4 Yield Parameters of Wheat

All yield-contributing characters were significantly influenced by variety, weeding regime and their interaction (Table 6 and 7).

Table 6: Effect of variety and weeding regime on different yield contributing characters and yield of wheat

Variety	Spikes m^{-2}	Spike length (cm)	Spikelets $spike^{-1}$	Grains $spike^{-1}$	1000-grain weight (g)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
BARI gom 21	116.0e	15.70a-d	15.65cd	39.33d	40.75f	1.91d	2.36e
BARI gom 22	124.2de	14.43d	15.95bcd	45.33b	42.43e	2.39c	2.95d
BARI gom 23	130.7cd	15.27bcd	14.92d	35.67e	35.60g	1.67e	2.07f
BARI gom 24	145.2ab	16.10abc	16.87abc	46.00ab	48.28a	3.23a	4.01a
BARI gom 25	125.8cde	16.40ab	16.03bcd	43.17c	46.17b	2.51c	3.15c
BARI gom 26	132.3cd	15.98abc	14.85d	40.50d	43.53d	2.37c	2.96d
BARI gom 27	146.2ab	16.55ab	17.80a	47.67a	43.13de	3.01b	3.78b
BARI gom 28	150.2a	16.87a	17.60ab	46.33ab	45.53c	3.18ab	3.89ab
BARI gom 29	126.8cde	11.83e	16.25bcd	36.00e	40.27f	1.84d	2.33e
BARI gom 30	145.2ab	16.10abc	16.87abc	48.00a	48.28a	3.23a	4.01a
% CV	6.87	9.12	10.25	9.16	2.11	11.14	10.71
Level of sig.	**	**	**	**	**	**	**
Weeding Regime							
Weed free	149.73a	16.06a	16.910a	44.27a	43.96a	2.94a	3.64a
Weedy	117.20b	14.73b	15.91b	41.33b	42.56b	2.10b	2.62b
CV%	6.87	9.12	10.25	9.16	2.11	11.14	10.71
Level of significance	**	**	*	**	**	**	**

Here, *= Significant at 5% level of probability, NS= Non significant.
Other details are same as Table 3.

Table 7: Interaction effect of variety and weeding regime on yield contributing characters and yield of wheat

Interaction (variety × weeding regime)		Spikes m^{-2}	Spike length (cm)	Spikelets $spike^{-1}$	Grains $spike^{-1}$	1000-grain weight (g)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
Weed free	BARI gom 21	147.0a-d	16.97ab	16.73abc	42.33abc	41.10ijk	2.56d	3.14cde
	BARI gom 22	150.0a-d	15.73abc	16.57abc	46.67a	42.83gh	2.98bc	3.70bc
	BARI gom 23	143.3a-d	16.03ab	15.33abc	37.67bcd	36.03l	1.94ef	2.42fg
	BARI gom 24	157.7ab	16.40ab	17.30abc	47.33a	49.27a	3.66a	4.54a
	BARI gom 25	144.0a-d	17.03ab	16.40abc	44.00abc	47.10bc	2.97bc	3.75bc
	BARI gom 26	144.7a-d	16.73ab	15.37abc	42.67abc	44.00efg	2.72c	3.34cd
	BARI gom 27	158.0ab	16.60ab	18.27a	48.33a	43.90efg	3.34ab	4.16ab
	BARI gom 28	159.3a	17.37a	17.90ab	47.33a	46.33c	3.48a	4.27ab
	BARI gom 29	141.3a-d	12.50de	16.63abc	37.67bcd	41.03ijk	2.16de	2.76def
	BARI gom 30	152.0abc	15.20abc	18.60a	48.67a	47.97b	3.53a	4.30ab
Weedy	BARI gom 21	85.00h	14.43bcd	14.57bc	36.33cd	40.40jk	1.25h	1.57i
	BARI gom 22	98.33gh	13.13cde	15.33abc	44.00abc	42.03hij	1.80efg	2.19fgh
	BARI gom 23	118.0ef	14.50bcd	14.50c	33.67d	35.17l	1.39gh	1.71hi
	BARI gom 24	132.7de	15.80abc	16.43abc	44.67ab	47.30bc	2.80c	3.48c
	BARI gom 25	107.7fg	15.77abc	15.67abc	42.33abc	45.23de	2.04ef	2.55ef
	BARI gom 26	120.0ef	15.23abc	14.33c	38.33bcd	43.07fgh	2.01ef	2.56ef
	BARI gom 27	134.3cde	16.50ab	17.33abc	47.00a	42.37ghi	2.67cd	3.38cd
	BARI gom 28	141.0bcd	16.37ab	17.47abc	45.33ab	44.73def	2.86bc	3.51c
	BARI gom 29	112.3fg	11.17e	15.87abc	34.33d	39.50k	1.52fgh	1.88ghi
	BARI gom 30	122.7ef	14.47bcd	17.63abc	47.33a	45.80d	2.65cd	3.29cd
CV%		6.87	9.12	10.25	9.16	2.11	11.14	10.71
Level of significance		**	**	**	**	**	**	**

Other details are same as Table 3.

BARI gom 28 produced the highest number of spikes m^{-2} (150.2) closely followed by BARI gom 27 (146.2), BARI gom 30 and BARI gom 24 (145.2) (Table 6). The lowest spikes m^{-2} was obtained from BARI gom 21 (116.0) and this was significantly lower than any varieties studied followed by BARI gom 22 (124.2) (Table 6). Higher spikes m^{-2} (149.7) was found in weed free treatment than weedy treatment (117.2). In case of interaction, the highest spike m^{-2} (159.3) was produced by BARI gom 28 under weed free condition, and the lowest one (85.0) was in BARI gom 21 under weedy condition (Table 7). The highest spike length was obtained from BARI gom 28 (16.9 cm) followed by BARI gom 27 (16.6 cm), while the lowest one was obtained from BARI gom 29 (11.8 cm) (Table 6). As expected, higher spike length (16.1 cm) was found in weed free treatment compared with weedy treatment (14.7 cm) (Table 6). In case of interaction, the highest spike length was produced by BARI gom 28 (17.4 cm) under weed free condition followed by BARI gom 25 (17.0 cm) in the same condition, while the lowest one was observed in BARI gom 29 (11.2 cm) under weedy condition (Table 7). The highest number of spikelets spike^{-1} (17.8) was recorded with BARI gom 27, which was marginally higher than that (17.6) produced by BARI gom 28 (Table 6). On the other hand, the lowest number of spikelets spike^{-1} (14.9) was obtained from BARI gom 26 (Table 6). Higher number of spikelets spike^{-1} (16.9) was found in weed free treatment than weedy treatment (15.9). In case of interaction, the highest number of spikelets spike^{-1} (18.6) was produced by BARI gom 30 under weed free condition followed by BARI gom 27 under the same condition, while the lowest one (14.3) was observed in BARI gom 26 under weedy condition (Table 7). The highest number of grains spike^{-1} (48.0) was obtained from BARI gom 30, which was marginally higher than that (47.7) obtained from BARI gom 27 (Table 6). Those values were closely followed by BARI gom 28, BARI gom 24 and BARI gom 22 (Table 6). On the other hand, the lowest number of grains spike^{-1} (35.7) was obtained from BARI gom 23 followed by BARI gom 29 (36.00). Weed free condition resulted in higher number of grains spike^{-1} (44.3) compared with weedy condition (41.33). In case of interaction, the highest number of grains spike^{-1} (48.7) was produced by BARI gom 30 under weed free condition (Table 7) which was statistically identical with those produced by many other varieties including BARI gom 24, BARI gom 22, BARI gom 27 and BARI gom 28 under weed free condition, and surprisingly those varieties produced statistically similar number of grains spike^{-1} under weedy conditions. On the other hand, the lowest number of grains spike^{-1} was recorded with BARI gom 23 (33.3) under weedy condition (Table 7). BARI gom 24 and BARI gom 30 gave the highest 1000-grain weight of 48.3 g followed by BARI gom 25 (46.2 g). The lowest 1000-grain weight (35.6 g) was obtained from BARI gom 23 (Table 6). Higher 1000-grain weight (44.0 g) was found in weed free condition compared to weedy condition (42.5 g). In case of interaction, the highest 1000-grain weight was found in BARI gom 24 (49.3 g) in weed free condition followed by BARI gom 30 under same condition. The lowest 1000-grain weight (35.2 g) was produced by BARI gom 23 in weedy condition, which was statistically identical with the same variety under weed free condition (Table 7).

3.5 Grain and Straw Yield of Wheat

The grain and straw yields were significantly influenced by variety, weeding regime and their interaction (Table 6 and 7). The highest grain yield (3.23 t ha^{-1}) was obtained from the varieties BARI gom 24 and BARI gom 30 (Table 6). The lowest grain yield (1.67) was obtained from BARI gom 23 followed by BARI gom 29 and BARI gom 21 (Table 6). Similar to other parameters weed free treatment gave higher grain yield (2.94 t ha^{-1}) than weedy treatment (2.10 t ha^{-1}) (Table 6). In interaction, the highest grain yield was produced by BARI gom 24 (3.66 t ha^{-1}) in weed free condition, which was statically identical with BARI gom 28 (3.48 t ha^{-1}) and BARI gom 30 (3.53 t ha^{-1}) under the same condition. BARI gom 21, on the other hand, produced the lowest grain yield (1.25 t ha^{-1}) in weedy condition followed by BARI gom 23 under same condition (Table 7). The wheat varieties BARI gom 24 and BARI gom 30 produced the highest straw yield of 4.01 t ha^{-1}, whereas the lowest one (2.07 t ha^{-1}) was obtained from BARI gom 23 (Table 6). Like previous parameters higher straw yield (3.64 t ha^{-1}) was found in weed free treatment than weedy treatment (2.61 t ha^{-1}). For interaction, wheat variety BARI gom 24 produced the highest straw yield (4.54t ha^{-1}) in weed free condition followed by BARI gom 30 (4.30 t ha^{-1}), BARI gom 28 (4.27 t ha^{-1}) and BARI gom 27 (4.16 t ha^{-1}) under the same condition (Table 7). On the other hand, BARI gom 21 under weedy condition produced the lowest straw yield (1.57 t ha^{-1}) followed by BARI gom 23 (1.71 t ha^{-1}) under same condition.

3.6 Relative Yield Loss (%)

The lower the relative yield loss the higher the degree of weed tolerance, since weed tolerance refers to the ability to maintain high yield in the presence of weed competition. The wheat varieties showed wide diversity in relative yield loss, which ranged from 17.8% to 51.2% (Figure 7). The relative yield loss was lowest in BARI gom 28 (17.8%) followed by BARI gom 27, BARI gom 30 and BARI gom 24 which exhibited high weed tolerance. BARI gom 21, on the contrary, showed the lowest tolerance to weeds with the maximum yield penalty of 51.2%. Lower tolerance was also showed by BARI gom 22 with a yield loss of 39.3% and by BARI gom 25 with a yield loss of 31.2% (Figure 7).

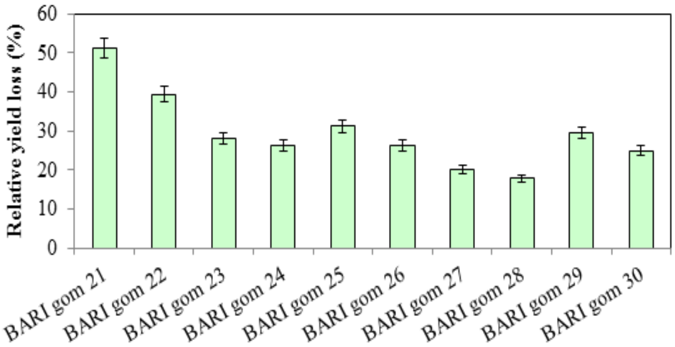

Figure 7: Effect of variety on relative yield loss (%) of wheat

4. DISCUSSIONS

The wheat varieties evaluated in this study varied not only in their yield attributes and yield performance but also in their weed suppressing ability. Competitive ability of a crop can be used as an important tool in integrated weed management [21, 25–27]. Crop species even varieties of the same species differ in their ability to compete for resources [14, 20, 28–30]. Among the wheat varieties studied in this research, BARI gom 27 allowed the minimum weed growth while BARI gom 21 allowed maximum weed growth. However, BARI gom 28 appeared as the most weed competitive variety allowing only 20% relative yield loss followed by BARI gom 27 with relative yield loss of 20% while BARI gom 21appeared as the weakest competitor against weeds resulted in the highest relative yield loss of 51%. Bari gom 24 produced the highest grain yield under both weed free and weedy conditions which confirms that there is no trade of between yield potential and weed competitiveness of a crop. A study also opined that high yield potential and strong weed competitiveness can be combined together [21]. Weed competition negatively and markedly affected all the yield attributes which cumulatively impaired wheat grain yield. Working with eight Bangladeshi wheat cultivars, a researcher also reported that BARI gom 24 (Prodip) had the highest competitive ability against weeds followed by BARI gom 21 (Shatabdi), BARI gom 22 (Sufi), BARI gom 20 (Gourab), while BARI gom 23 (Bijoy) was the weakest competitor. In this study, the wheat variety performed better in weed free condition is likely to perform fairly better under weedy condition [5]. A study also obtained similar findings in case of rice grown under aerobic soil condition [21]. In fact, differences in surrounding species do not bring any change in the competitive ability of a particular species. The performing ability of a particular species due to intra specific (wheat-wheat) or inter specific (wheat-weed) competition may vary in degree but not in kind.

Crop competitiveness is a sum of interaction of several plant attributes for example, plant height, early visual vigor, leaf area index (LAI), tillering ability, canopy structure, crop ground cover, and so on [7, 15]. Early visual vigor is one of the most important characters contributing to crop competitiveness. Cultivar that efficiently utilizes resources during early stage of growth has higher competitive ability against weed. Early visual vigor can be determined on the basis of early seedling size, germination percent, and early crop biomass, therefore early visual vigor could be an important selection protocol while screening wheat varieties/germplasms for weed competitiveness [25, 31]. In our experiment, BARI gom 27 appeared as the most vigorous with early visual vigor scores of 8 followed by BARI gom 28 (7.8) and BARI gom 30 (7.8). Lower relative yield loss was also obtained from these three cultivars indicating their higher weed competitiveness. On the other hand, BARI gom 21 was the least vigorous scoring around 3.6 and enjoyed the highest yield penalty due to poor competitive ability against weeds. A study also found that durum wheat that possessing high early biomass accumulation and greater photosynthetic active radiation was the best competitors against weeds [32]. They also reported a strong negative correlation between first leaf length and width, and seedling biomass accumulation with grain yield loss and weed dry matter. Similar results have been reported in barley, oats, and wheat [33].

Plant height is also one of the most extensively reported and desired attributes with respect to crop competitiveness [21, 34–37]. In this research, early growth in terms of plant height is confirmed as an important trait associated with weed competitiveness. Hence, it is noteworthy that within 15 DAS, the varieties attained 14% - 21% of their respective ultimate plant height with BARI gom 30 topping the list (20.5%) closely followed by BARI gom 27 (19.7%), BARI gom 24 (18.4%) and BARI gom 28 (18%). At early growth stages (15 DAS and 30 DAS), BARI gom 30 was the fastest growing cultivar consistently performed better in height gain but thereafter declined its growth substantially to become a shorter variety at harvest stage. Contrastingly, BARI gom 21 was the slower growing cultivar at earlier stage with poor gain in height, which however, dramatically improved afterward producing the second tallest cultivar next to BARI gom 24. BARI gom 27, BARI gom 24 and BARI gom 28 had considerably greater plant height at early stages of growth, which the former retained till the end, while the latter declined a bit. Conversely, BARI gom 25, BARI gom 22 had the least height at the earlier stage. A study reported that faster developing varieties were better weed suppressors than the slower [38]. A group of researchers also demonstrated the importance of early height over mature height in suppressing weeds [39]. Normally, taller varieties are more competitive than shorter ones [14, 27]. Another group of researchers also observed that taller varieties reduced weed growth to a greater extent by capturing more light than shorter cultivars [40, 19]. However, two shorter varieties were also appeared as strong competitors against weeds suggesting that competitive ability of a cultivar does not depend only one traits, it is the combination of more than one [40]. Varietal differences in weed suppressive ability is reflected by the differences in growth traits especially early faster growth which can be successfully assessed by early plant height and early visual vigor. Early root competition for soil resources might also play a vital role in determining weed competitiveness of a crop [21]. However, the regression analysis showed that early plant height and early visual vigor could explain weed dry matter by 59 and 71%, respectively.

5. CONCLUSION AND RECOMMENDATIONS

Present findings confirm that selection of weed suppressive variety could play an important role in sustainable weed management of wheat. Strong weed suppressive ability of a variety does not always ensure high yields. Hence, breeder should always focus on the development of a variety that has both high yielding ability and strong weed suppressive potential. To date, Wheat Research Center (WRC), Bangladesh Agricultural Research Institute (BARI) has released more than 30 wheat varieties. Unfortunately, none of them has been claimed or reported as a weed suppressive variety. On the other hand, as no variety in our study produced very high yield compared to that of other wheat growing countries, therefore it is recommended to develop new high yielding and strongly weed competitive wheat varieties that can be successfully grown throughout Bangladesh with least weed management. However, the present findings are based on a one-year experiment, and therefore, further research considering more wheat varieties and potential advanced lines should be conducted at different agro-climatic conditions to confirm the findings of the present study before final recommendation

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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