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Weed Competitiveness of Popular Maize Varieties of Bangladesh

Mohammad Nasir[1], A K M Mominul Islam[1]✉, Md Shafiqul Islam[1], Sharif Ahmed[2], Md Abdus Salam[1], Md Parvez Anwar[1]

[1] Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

[2] International Rice Research Institute, Dhaka Office, Dhaka 1213, Bangladesh

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Correspondence

A K M Mominul Islam

✉: akmmominulislam@bau.edu.bd

ABSTRACT

Weed competition is a major constraint to maize production, and the selection of weed-competitive varieties can significantly reduce yield losses necessitating the identification of varieties with superior weed competitiveness. This study evaluated the weed competitiveness of 12 popular maize varieties in Bangladesh under weedy and weed-free conditions during the 2018-2019 *rabi* season using a split-plot design. Weed competitiveness was assessed based on crop growth, yield, weed density, and weed dry biomass. Results revealed significant variability in weed competitiveness among the tested varieties. BARI Hybrid Bhutta 13 exhibited the highest weed competitiveness, with the lowest relative yield loss (40%) and the highest weed competitive index (6.9). In contrast, Hiramon showed the highest relative yield loss (85%), closely followed by Mohabir and PacD22, while Khoi Bhutta recorded the lowest weed competitive index. Under season-long weedy and weed-free conditions, BARI Hybrid Bhutta 13 achieved the highest grain yield (9.8 t ha^{-1}), whereas BARI Hybrid Bhutta 12 and Mohabir produced the lowest yields in both conditions. These findings highlight substantial varietal differences in weed competitiveness, emphasizing the potential of selecting weed-tolerant maize varieties to mitigate yield losses and improve productivity. This study provides valuable insights for farmers and breeders in identifying and promoting weed-competitive maize varieties, contributing to sustainable maize production in Bangladesh.

1. Introduction

Weeds cause major yield losses in crops and also reduce their quality. Worldwide approximately 10% of total crop yields are lost every year by the effects of 1800 kinds of weeds (Li et al., 2003). Weeds produced the highest potential loss (34%) compared to animal pests (18%) and pathogens (16%) (Oerke, 2006).

Maize (*Zea mays* L.), is the second most important cereal crop in Bangladesh after rice (BBS 2024). It has significant nutritional value, with 100 g of mature maize seeds providing 9.42 g of protein, 74.26 g of carbohydrates, 0.64 g of sugar, 7.3 g of dietary fiber, and 365 kcal of energy (Wikifarmer, 2022). Despite a growing demand of approximately two million tons of maize annually, Bangladesh's production is only 4.7 million tons, resulting in a significant supply-demand gap (BBS, 2021). The country's favourable weather conditions and maize's wide genetic variability contribute to its successful growth across diverse environments, with potential yields in both winter and summer. Recent data indicates that maize is the highest-yielding cereal in Bangladesh, producing average yield 6.2 t ha^{-1} followed by boro rice (3.9 t ha^{-1}) and wheat (2.60 t ha^{-1}) (Islam and Hossain 2022). Despite its higher yield potential, farmers still receive low yields due to various associated factors (Hossain et al. 2020). Weeds are one of the major production constraints in maize (Deshmukh et al., 2009). Maize is cultivated in Bangladesh during both the rabi and kharif seasons, where it has to compete with various kinds of weeds. A previous study identified *Echinochloa colona* L. as the most dominant weed species in maize fields during the *kharif* season, followed by *Panicum repens* L., *Trianthema portulacastrum* L., and *Digera arvensis* (Rahman et al., 2018). During the *rabi* season, maize fields are often infested with grass weeds *viz. Brachiaria mutica*, *Dactyloctenium aegyptium* L., *Panicum coloratum* L., and *Cynodon dactylon* L.; broadleaf weeds such as *Amaranthus viridis* L., *Portulaca oleracea* L., *Celosia argentea* L., and *Euphorbia hirta* L.; and sedge-like weeds such as *Cyperus rotundus* L. (Islam et al., 2019).

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Effective weed management in maize cultivation in Bangladesh has shown the potential to increase yields by up to 30% (Ahmed et al., 2020). Cultural practices such as timely sowing, use of competitive cultivars, and adoption of integrated weed management (IWM) strategies play a crucial role in minimizing weed interference. Studies have emphasized that maize competes effectively with *Cynodon dactylon* L. when established early, underscoring the importance of crop vigour during initial growth stages (Hasan et al., 2017). Traits such as plant height, leaf area index, and canopy architecture significantly influence maize's competitiveness against weeds (Chowdhury et al., 2021). The use of allelopathic crops in rotations and the selection of competitive maize cultivars show promise for weed suppression in adjacent areas and could be incorporated into Bangladesh's maize production systems (Chowdhury et al., 2021). However, the development and adoption of competitive maize cultivars in Bangladesh remain limited, necessitating further research. The use of competitive crop varieties might be an alternative to reduce the detrimental effect of herbicides (Jabran et al., 2010; Razzaq et al., 2010; Milchunas et al., 2011). However, no studies on weed competitiveness of maize varieties have so far been conducted in Bangladesh to screen the weed competitiveness of maize. This gap in research highlights the urgent need for comprehensive studies that evaluate various cultivars under diverse environmental conditions. The proposed research is therefore conducted to identify weed-competitive of maize varieties in Bangladesh as well as identify the traits that are responsible for their weed competitiveness.

2. Materials and Methods

2.1. Description of the experimental site

The trial was conducted at the Agronomy Field Laboratory, Department of Agronomy, Bangladesh Agricultural University in rabi 2019. The site is situated at 24.720258 N latitude, 90.428872 E longitude and 18 meters above sea level, having a subtropical monsoon climate with humid conditions. The soil in the area belongs to the Sonatola series, which consists of medium-high land and non-calcareous dark grey floodplain soil from the Old Brahmaputra Floodplain (AEZ-9). Most soils in this series are silty loam, dark grey in color, with a pH of 6.8. They are low in organic matter content and overall fertility.

Average monthly air temperatures in the experiment site ranged from 12°C during the cooler months to 33°C during the hottest months, particularly from April to July. Rainfall was substantial during this period, especially during the monsoon months, with monthly precipitation totals ranging from 10 mm to over 450 mm, with the heaviest rainfall recorded between June and August, reaching up to 455 mm in some months (BMD, Mymensingh).

2.2. Treatments and design

A total of 12 maize varieties were collected from Bangladesh Wheat and Maize Research Institute (BWMRI), Bayer Crop Science Pvt. Ltd., Lal-teer Pvt. Ltd., and Syngenta. The varieties were BARI Hybrid Maize 7, BARI Hybrid Maize 9, BARI Hybrid Maize 12, BARI Hybrid Maize 13, BARI Hybrid Maize 14, Don 112, Hiramon, Khoi Bhutta, Mohabir, PacD22, Samit, Uttaran. All the variety were tested under two weeding regimes *i.e.* (i) season long weedy and (ii) season-long weed-free. In weed-free treatment weeds are not allowed to grow. Weeds were removed regularly through hand polling as soon as they arose, ensuring no competition between weeds and rice. Weed-free treatment aims to maintain a weed-free environment throughout the maize growing season. While in weedy conditions weeds are allowed to grow freely alongside the crop throughout the crop's life cycle. No weed control measures (such as manual weeding, chemical herbicides, or cultural practices) are applied in this treatment. This treatment helps understand the competitive pressure of weeds on different rice variety. The experimental design was a split-plot where weeding regimes were allocated at the main plots and crop varieties were in the sub-plot. The size of the sub-plot was 4.0 m × 2.5 m and the replication numbers of the trial were three. The total number of experimental plots were 72.

2.3. Crop management

Using a motorized tiller, the land was first broken up, and then it was laddered to level it. The field's weeds and remnants from the previous crop were gathered and cleared. The land was initially prepared using a motorized tiller to break up the soil, followed by leveling with a ladder. Weeds and crop residues from the previous season were cleared to ensure a clean field for planting. The experimental plot was fertilized with 630, 267, 280, 220, 12 and 10 kg ha^{-1} Urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), Gypsum, Zinc Sulphate and Boric acid, respectively. Urea was applied in 3 splits at early vegetative stages (at 4-6 leaves), knee-high stage, and tasseling stage, respectively. The seed rate was standardized at 20 kg ha^{-1} for all varieties. A row spacing of 60 cm was maintained between the rows and plant to plant distance was 20 cm to optimize plant population and growth. Plots were irrigated based on the crop's water requirements. A total of four irrigations were applied during the growing season at 25, 45, 65, and 85 days after transplanting (DAT), corresponding to the key growth stages of maize: the 4-6 leaf stage, knee-high stage, tasseling, and grain-filling stage, respectively. The experimental field was regularly monitored for pests and diseases to ensure timely detection and management. The experimental plots were not infested by any insects or not infected by any diseases. Therefore, no pesticide was used to control the insect/diseases.

2.4. Data collection

Weed data were collected at 30, 45, and 60 DAT from a randomly placed 1 m by 1 m quadrat in two locations of each season-long weedy plot. Weeds were uprooted at ground level, identified, counted by species, and dried in an oven at 70°C until reaching a constant weight. Weed density and biomass were reported as number per square meter and grams per square meter, respectively. The summed dominance ratio (SDR) was calculated to determine the dominant weed species using the provided equations as per Arefin et al. (2018).

$$\text{SDR of a weed species} = \frac{\text{Relative density} + \text{Relative weed biomass}}{2} \ldots\ldots\ldots\ldots (i)$$

Where,

$$\text{Relative density (\%)} = \frac{\text{Density of a given weed species}}{\text{Total weed density}} \times 100 \ldots\ldots\ldots\ldots (ii)$$

$$\text{Relative weed biomass (\%)} = \frac{\text{Biomass of a given weed species}}{\text{Total weed biomass}} \times 100 \ldots\ldots\ldots\ldots (iii)$$

The contributions of grasses, broad-leaved, and sedges to the weed vegetation were calculated based on their relative density and biomass.

The weed competitive index (WCI) of the maize varieties was calculated to find the most weed competitive cultivar using the following formula [Ahmed et al. 2021].

$$WCI = \left[\frac{\frac{MGYw}{MGYm}}{\frac{WBw}{WBm}}\right] \ldots\ldots\ldots\ldots (v)$$

Where, *MGYw* is the yield of the individual cultivar of maize under weedy condition. The *MGYm* is the mean yield of all maize cultivars under weedy conditions. *MWBw* is the weed biomass of individual cultivar under weedy condition, and *WBm* is the mean weed biomass of all cultivars under weedy condition.

The maize plant height was measured at 30, 45, 60 DAS and at harvest from randomly selected 10 plants of each variety. Maize biomass was measured at 30 and 60 DAS from randomly selected five maize plants for each variety. The SPAD value was measured at 30, 45, and 60 DAS from randomly selected five plants.

Ten maize plants were harvested manually at maturity stage. The harvested crop was bundled separately as per treatments and properly tagged. The cobs were threshed using a mini maize sheller and then sun-dried to 12% moisture content. The stover was also sun-dried. At the end, grain and stover yield plot^{-1} were recorded and converted to t ha^{-1}. The relative yield loss (%RYL) due to weed competition was also calculated as follows:

$$\text{RYL (\%)} = \frac{\text{Weed free yield} - \text{Season long weedy yield}}{\text{Weed free yield}} \times 100 \ldots\ldots\ldots\ldots (iv)$$

2.5. Statistical analysis

Collected data were checked for homogeneity and normality and then statistically analyzed using software JMP 17. The plant height, biomass, SPAD value, grain yield, and stover yield data were analyzed using a two-way ANOVA (weeding regimes and varieties), and for weed data one-way ANOVA (varieties).

3. Results and Discussion

3.1. Floristic composition of weeds

Seven weed species belonging to three different families were observed in weedy plots, among which two were broadleaves, two sedges and three each from grasses (Table 1). Based on the summed dominance ratio (SDR), the most dominant weed species in the weedy plots was *Echinochloa crus-galli* (L.) P. Beauv (SDR value 20.25%, relative density 9.5%, relative biomass 45.32%) followed by *Digitaria sanguinalis* L. (SDR value 18.36%, relative density 11.14% and relative biomass 22.56%), whereas *Cyperus iria* was the least dominant species. Grass species make up the largest proportion of the weed population, accounting for 47% of the relative density.

Broad leaf species contribute 31% to the overall weed density, indicating they are the second most prevalent type (Figure 1). Grass species contribute the largest portion of the total weed biomass, accounting for 76%. This highlights their significant dominance in terms of biomass production. Broadleaf species make up 19% of the total weed biomass, placing them as the second most dominant group, but still considerably lower than grasses. Sedge species represent only 5% of the total biomass, indicating they are the least significant in terms of biomass contribution compared to the other two groups.

3.2. Weed density and dry biomass

At 30 DAS, Hiramon recorded the highest weed density (22.66 plants m^{-2}), followed by Mohabir (19.66 plants m^{-2}). The lowest weed densities were observed in Samit (13.33 plants m^{-2}) and Don 112 (14.33 plants m^{-2}), indicating fewer weeds at this stage. At 45 DAS, Khoibhutta (30 plants m-^{2}) and PacD22 (29.33 plants m^{-2}) showed the highest weed densities, while BARI Hybrid Bhutta 12 (19.66 plants m^{-2}) and Don 112 (16.66 plants m^{-2}) recorded the lowest densities. At 60 DAS, Hiramon again had the highest weed density (26.0 plants m^{-2}), followed by BARI Hybrid Bhutta 14 (23.66 plants m^{-2}). The lowest weed densities were observed in BARI Hybrid Bhutta 13 (15.33 plants m^{-2}) and Uttaran (16.33 plants m^{-2}), showing better weed control in these treatments. The highest weed dry biomass (4.98 g m^{-2}) was found in Mohabir at 30 DAT, followed by Hiramon at 4.56 g m^{-2} indicating the highest weed growth. The lowest biomass was observed in BARI Hybrid Bhutta 9 (1.96 g m^{-2}) and BARI Hybrid Bhutta 7 (2.37 g m^{-2}), suggesting effective weed suppression. At 45 DAS, Hiramon again recorded the highest weed biomass at 14.23 g m^{-2} followed by Mohabir at 13.55 g m^{-2}. The lowest biomass was observed in BARI Hybrid Bhutta 7 (10.16 g m^{-2}) and BARI Hybrid Bhutta 9 (10.83 g m^{-2}). By 60 DAS, Hiramon recorded the highest weed biomass (19.54 g m^{-2}) followed by BARI Hybrid Bhutta 12 (18.71 g m^{-2}) and BARI Hybrid Bhutta 9 (18.64 g m^{-2}). The lowest biomass was recorded in BARI Hybrid Bhutta 13 (13.57 g m^{-2}) and BARI Hybrid Bhutta 7 (14.04 g m^{-2}), indicating better weed suppression by these treatments. Weed suppression is a critical factor influencing the overall productivity of maize, especially under high weed-pressure environments. Maize varieties with lower weed density and biomass are considered better competitive against weeds. The highest weed density at this early stage Hiramon (22.66 plants m^{-2}) had the indicating weak weed suppression. High weed density early in the growth cycle is critical, as it increases competition for nutrients and water, which can impede maize seedling growth and reduce vigor (Rajcan and Swanton, 2001). Such competition can delay maize development and reduce overall crop productivity. In contrast, Samit (13.33 plants m^{-2}) and Don 112 (14.33 plants m^{-2}) exhibited the lowest weed densities, reflecting strong early-stage weed suppression. Limiting weed establishment at the early stages is vital for optimizing resource availability to maize plants, which can improve yield potential (Swanton and Murphy, 1996).

3.3. Weed Competitive Index

BARI Hybrid Bhutta-13 exhibited the highest weed competitive index (6.85), indicating its strong ability to suppress weeds effectively compared to other treatments (Figure 2). BARI Hybrid Bhutta-9 also performed well with a high weed competitive index of 4.93, followed closely by BARI Hybrid Bhutta-12 and Hiramon, both at 4.6.

Table 1. Predominant weed species and their relative density (RD), relative dry biomass (RB), and summed dominance ratio (SDR) in untreated weedy plots of the experimental field

#	Scientific name	Family name	Type	RD (%)	RB (%)	SDR
1	*Echinochloa crus-galli* (L.) P. Beauv	Poaceae	Grass	9.5	45.32	20.25
2	*Digitaria sanguinalis* L.	Poaceae	Grass	11.14	22.56	18.36
3	*Amaranthus spinosus* L.	Amaranthaceae	Broad Leaf	22.59	8.07	15.37
4	*Cynodon dactylon* L.	Poaceae	Grass	24.76	2.45	11.45
5	*Amaranthus viridis* L.	Amaranthaceae	Broad Leaf	7.89	9.42	8.66
6	*Cyperus difformis* L.	Cyperaceae	Sedge	13.16	2.69	7.92
7	*Cyperus iria* L.	Cyperaceae	Sedge	7.89	1.97	4.93

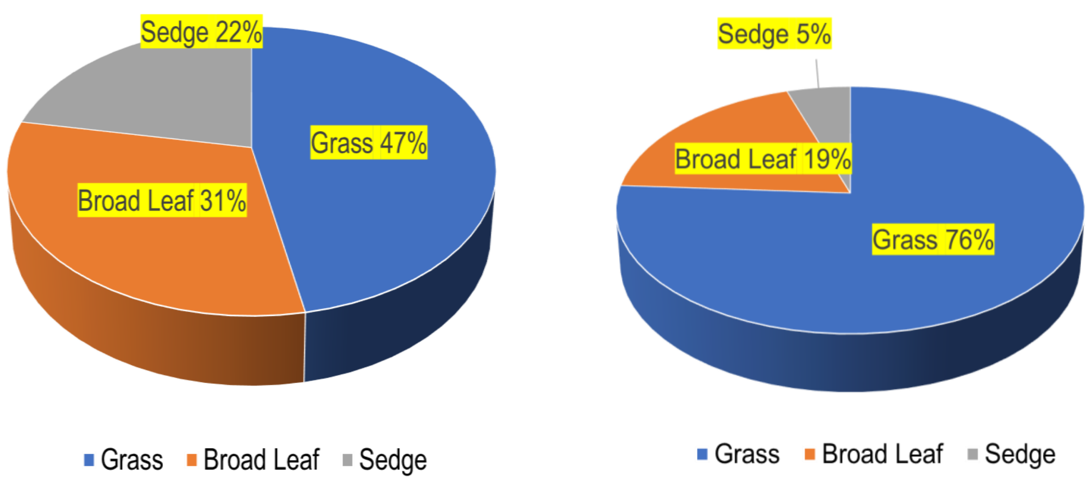

Figure 1 : Relative weed density (A) and biomass (B) of different weed groups (grass, broadleaf, and sedge) in maize

Table 2. Weed density and weed biomass at 30, 45, and 60 days after sowing as influenced by different varieties

Variety	Weed density (no. m^{-2})			Weed biomass (g m^{-2})		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
BARI Hybrid Bhutta 7	17.0ab	24.66ab	19.0abc	2.37bc	10.16c	14.04b
BARI Hybrid Bhutta 9	16.00ab	21.33ab	19.66abc	1.96c	10.83bc	19.64a
BARI Hybrid Bhutta 12	17.66ab	19.66b	18.33abc	2.75abc	11.42abc	15.71ab
BARI Hybrid Bhutta 13	18.66ab	25.33ab	18.0abc	2.52abc	11.37abc	16.57ab
BARI Hybrid Bhutta 14	16.66ab	25.33ab	25.66a	2.16bc	12.61abc	15.83ab
Khoibhutta	16.33ab	30.00a	15.0c	2.90abc	11.52abc	14.48ab
Mohabir	19.66ab	22.66ab	25.0ab	4.98a	13.55ab	16.97ab
Hiramon	22.66a	24.0ab	21.66abc	4.56ab	14.23a	16.54ab
PacD22	16.66ab	29.33a	19.33abc	3.47abc	12.81abc	16.28ab
Samit	13.33b	21.66ab	18.0 abc	3.23abc	11.35abc	17.56ab
Don 112	14.33b	16.66b	19abc	2.92abc	11.30abc	14.16b
Uttaran	16.0ab	23.66ab	16.33 bc	3.83abc	11.17abc	15.43ab

* = Significant at 5% level of probability, the different lowercase letters indicate significant differences at a 5% probability level

BARI Hybrid Bhutta-14 had a moderate competitive index of 3, followed by BARI Hybrid Bhutta-7 and Don 112, indicating moderate competitiveness against weeds. The lowest weed competitive index was recorded for Khoi Bhutta, followed by PacD22, and Mohabir, indicating weaker performance in suppressing weeds. Other treatments like Samit (0.90) and Uttaran (1.22) also had relatively low weed competitive indices, suggesting less weed-suppressing ability compared to the higher-performing varieties.

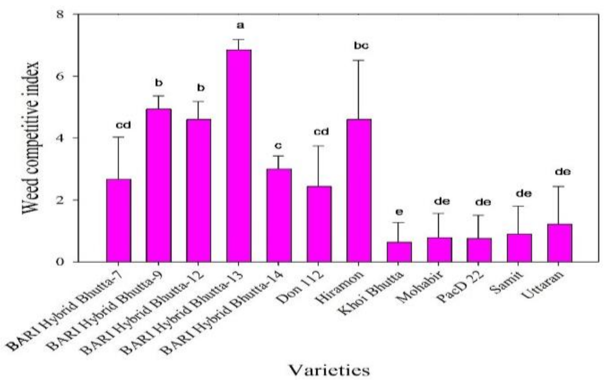

Figure 2. Weed competitive index of maize varieties. Vertical bars indicate the standard errors of the mean. The different lowercase letters indicate significant differences at a 5% probability level

3.4. Grain yield and relative yield loss

Maize grain yield was significantly affected by the weeding regimes. Under weed-free conditions, the highest grain yield was recorded from the BARI Hybrid Bhutta 7 (8.9 t ha^{-1}) which was followed by BARI Hybrid Bhutta 9, and BARI Hybrid Bhutta 12 (Figure 3). In weed-free conditions the variety Don 112 produced the lowest grain yield (2.8 t ha^{-1}). Under the season-long weedy condition, the highest grain yield (6.8 t ha^{-1}) was found from BARI Hybrid Bhutta 13 followed by BARI Hybrid Bhutta 12, BARI Hybrid Bhutta 9 and Khoibutta (Figure 3). The lowest grain yield (0.78 t ha^{-1}) was obtained from Don112 (0.8t ha^{-1}).

Considering the relative yield loss due to weed infestation, the maize varieties showed a wide diversity which ranged from 18 to 90%. The relative yield loss was lowest in BARI Hybrid Bhutta 13 (22%) followed by BARI Hybrid Bhutta 12, BARI Hybrid Bhutta 9 which exhibited high weed tolerance. Variety Don 112 had the lowest tolerance to weeds with a yield penalty of 91% closely followed by Hiramon, Mohabir (Figure 3). The relative yield loss is an excellent indicator of weed tolerance of variety. 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.

3.5. Plant height

Plant height was significantly influenced by variety (Table 3). At 30 DAS, BARI Hybrid Bhutta 9 recorded the highest plant height under weed-free conditions, while Khoibhutta showed the highest plant height under weedy conditions. Varieties such as BARI Hybrid Bhutta 7 (25.78 cm WF, 22.78 cm weedy) and BARI Hybrid Bhutta 14 (24.89 cm WF, 22.67 cm weedy) had moderate plant heights. BARI Hybrid Bhutta 12 had the lowest plant height under weed-free conditions, and Samit recorded the lowest height under weedy conditions. At 45 DAS, BARI Hybrid Bhutta 9 showed the highest plant height under weed-free conditions, and Uttaran recorded the highest height under weedy conditions. Khoibhutta (49.89 cm WF, 40.60 cm weedy) and Mohabir (50.56 cm WF, 41.11 cm weedy) exhibited moderate plant heights. PacD22 had the lowest plant height under both weed-free (39.55 cm) and weedy conditions (35.00 cm). At 60 DAS, BARI Hybrid Bhutta 9 showed the highest plant height in weed-free conditions, while Uttaran had the highest height under weedy conditions. Khoibhutta (79.00 cm WF, 74.72 cm weedy) and Mohabir (79.22 cm WF, 71.11 cm weedy) demonstrated moderate plant heights. PacD22 recorded the lowest plant height under both weed-free (74.45 cm) and weedy conditions (61.94 cm). At harvest, Khoibhutta showed the highest plant height at harvest under weed-free conditions, while BARI Hybrid Bhutta 9 recorded the highest under weedy conditions. In weed-free conditions, maize plants can access resources like light, water, and nutrients without competition, leading to better growth and higher plant height. Conversely, in weedy conditions, competition from weeds can reduce the availability of these resources, resulting in lower plant height and growth.

3.6. Above-ground plant biomass

Above ground plant biomass was significantly influenced by varieties (Table 4). At 30 DAS, under weed-free conditions, BARI Hybrid Bhutta 9 recorded the highest plant biomass, closely followed by BARI Hybrid Bhutta 7. Under weedy conditions, Don 112 had the highest plant biomass, followed by Khoibhutta. Varieties like BARI Hybrid Bhutta 12 and Samit showed moderate biomass under weed-free conditions. In weedy conditions, Samit and Uttaran exhibited moderate performance. PacD22 (0.0106 g) and Khoibhutta recorded the lowest biomass under weed-free conditions. Under weedy conditions, BARI Hybrid Bhutta 12 had the lowest biomass, followed by Hiramon (26.0 g).

At 60 DAS in weed-free conditions, Samit and Uttaran both recorded the highest plant biomass, followed closely by BARI Hybrid Bhutta 9 and Don 112, respectively. Under weedy conditions, Don 112 again recorded the highest biomass, followed by PacD22 at 47.33 g. Varieties such as BARI Hybrid Bhutta 7 and Mohabir showed moderate performance in weed-free conditions.

In weedy conditions, Uttaran and Hiramon demonstrated moderate biomass accumulation. Khoibhutta recorded the lowest biomass in weed-free conditions, while BARI Hybrid Bhutta 13 and Mohabir had the lowest biomass under weedy conditions. BARI Hybrid Bhutta 9 and Don 112 stand out as the best-performing varieties in terms of plant biomass, particularly under weedy conditions, where they showed robust growth. In contrast, varieties like Khoibhutta and BARI Hybrid Bhutta 13 were less competitive under weed pressure, with lower biomass accumulation. These results highlight the importance of variety selection for optimal biomass production in environments with varying levels of weed pressure.

3.7. Relative chlorophyll content (SPAD Value)

Relative chlorophyll content was significantly influenced by variety (Table 4). AT 30 DAS, under weed-free conditions, BARI Hybrid Bhutta 9 showed the highest SPAD value, followed by Uttaran. In weedy conditions, Uttaran had the highest SPAD value, followed by BARI Hybrid Bhutta 7. The lowest SPAD values were recorded for BARI Hybrid Bhutta 13 under weed-free conditions and for PacD22 under weedy conditions. At 45 DAS, under weed-free conditions, Don 112 recorded the highest SPAD value, followed by Uttaran. In weedy conditions, BARI Hybrid Bhutta 13 had the highest SPAD value, followed by Uttaran. The lowest SPAD values were recorded for BARI Hybrid Bhutta 14 under weedy conditions and for BARI Hybrid Bhutta 7 under weed-free conditions. At 60 DAS, under weed-free conditions, BARI Hybrid Bhutta 9 showed the highest SPAD value, followed closely by BARI Hybrid Bhutta 14. Under weedy conditions, Khoibhutta showed the highest SPAD value, followed by Uttaran with 46.00. The lowest SPAD values at 60 DAS were recorded for PacD22 under weed-free conditions and for BARI Hybrid Bhutta 7 under weedy conditions. BARI Hybrid Bhutta 9 and Uttaran consistently recorded the highest SPAD values across different growth stages under both weed-free and weedy conditions, indicating strong chlorophyll content and photosynthetic activity. PacD22 and BARI Hybrid Bhutta 14 generally had the lowest SPAD values, suggesting weaker growth performance in terms of leaf chlorophyll content. These results highlight the variations in chlorophyll content (SPAD value) among different maize varieties, providing insights into their growth performance under both weed-free and weedy conditions.

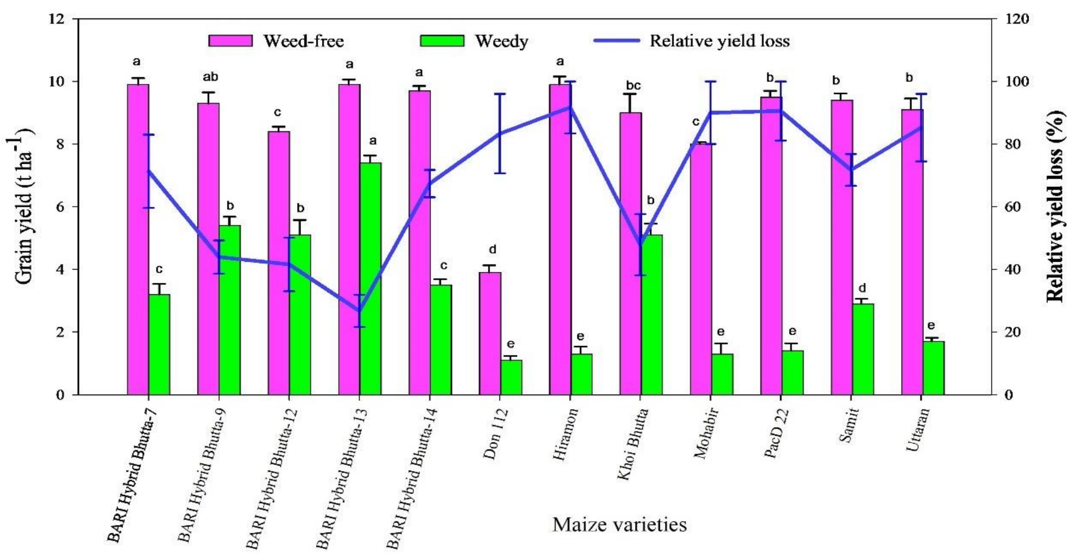

Figure 3. Interaction effect of variety and weeding regime of grain yield and relative yield loss in maize. Vertical bars indicate the standard errors of the mean. The different lowercase letters indicate significant differences at a 5% probability level

Table 3. Plant height of different maize varieties under weedy and weed-free conditions

Variety	30 DAT		45 DAT		60 DAT		At harvest	
	Weed free	Weedy	Weed free	Weedy	Weed free	Weedy	Weed free	Weedy
BHB 7	25.78ab	22.78a	45.22bc	39.22ab	75.78ab	66.55abc	149.46ab	124.23abc
BHB 9	28.66a	22.56a	55.22a	44.44a	87.66a	71.00abc	149.90ab	138.90a
BHB 12	19.56c	22.22a	44.78bc	39.44ab	81.78ab	67.38abc	148.13abc	115.96b-e
BHB 13	23.11bc	23.44a	47.00abc	41.66ab	76.44ab	66.78abc	128.73de	101.56def
BHB 14	24.8 ab	22.67a	41.89bc	34.78b	78.37ab	69.44abc	120.86e	108.7b-f
Khoibhutta	22.0bc	24.55a	49.89ab	40.60ab	79.00ab	74.72ab	151.53a	88.60f
Mohabir	24.67abc	22.89a	50.56ab	41.11ab	79.22ab	71.11abc	149.23abc	104.27c-f
Hiramon	22.33bc	24.44a	46.78abc	41.0ab	75.55ab	64.09bc	131.56cde	112.80b-e
PacD22	21.78bc	23.86a	39.55c	35.00b	74.45ab	61.94c	114.96e	99.40ef
Samit	22.56bc	21.22b	42.0bc	38.89ab	75.78ab	66.49abc	147.23abc	122.53a-d
Don 112	23.44abc	24.73a	43.78bc	38.78ab	77.11ab	73.33abc	132.23b-e	127.50ab
Uttaran	25.44ab	22.89a	41.78bc	42.89ab	66.89b	76.55a	142.3abd	129.76ab
Sig. level	**	*	**	*	*	*	**	**
CV (%)	7.21	7.66	6.44	8.21	5.44	5.47	7.53	7.65
LSD	5.3	5.75	9.62	8.91	17.61	12.25	17.7	22.59

* = Significant at 5% level of probability, ** = Significant at 1% level of probability. The different lowercase letters indicate significant differences at a 5% probability level; BHB = BARI Hybrid Bhutta

3.8. Correlation coefficient of different plant traits with yield and Weed Competitive Index (WCI)

The correlation of coefficient analysis among various agronomic traits, including plant height (HT), dry weight (DW), SPAD values (chlorophyll content), grain yield (GY), and weed competitiveness index (WCI), highlights several key relationships that influence crop performance, particularly in terms of yield and weed suppression (Table 5). Plant height at 30 DAS (HT30) has a moderately significant positive correlation with plant height at 45 DAS (HT45) (r = 0.44, p < 0.05), indicating that early-stage plant height influences the mid-stage height. Plant height at 45 DAS is also significantly correlated with plant height at 60 DAS (HT60) (r = 0.37, p < 0.05), showing consistency in plant height across the growth stages. This suggests that plants that are taller at 45 days tend to maintain their height advantage at 60 days. HT60 does not show any significant correlation with HT30, indicating that early height growth is less predictive of final plant height. DW30 (dry weight at 30 DAS) shows a significant positive correlation with HT60 (r = 0.39, p < 0.05), indicating that plants with greater early biomass accumulation tend to have better height at 60 days. DW60 (dry weight at 60 DAS) is significantly correlated with HT30 (r = 0.43, p < 0.05) and HT60 (r = 0.53, p < 0.05), showing that early plant height positively impacts dry weight at later stages. This suggests that taller plants tend to accumulate more biomass by 60 days. Additionally, DW30 is positively correlated with DW60 (r = 0.25, p < 0.05), reinforcing that early biomass accumulation contributes to greater dry weight later in the season. Spad30 (SPAD value at 30 DAS) has weak correlations with plant height and dry weight at different stages, showing no significant impact on these traits. However, it has a moderate but non-significant correlation with DW60 (r = 0.30). Spad45 (SPAD value at 45 DAS) has a moderate correlation with HT45 (r = 0.31) and HT60 (r = 0.30), indicating that mid-stage chlorophyll content may be slightly related to plant height, although these correlations are not statistically significant.

Table 4. Above-ground biomass and SPAD value of different maize varieties under weedy and weed-free conditions

Variety	Above-ground plant biomass (g)				SPAD value					
	30 DAS		60 DAS		30 DAS		45 DAS		60 DAS	
	Weed Free	Weedy	Weed Free	Weedy	Weed Free	Weedy	Weed Free	Weedy	Weed Free	Weedy
BHB 7	0.022ab	43.66ab	0.0143a	33.00ab	31.10ab	33.13ab	38.23b	26.23a	43.40bc	33.66b
BHB 9	0.023a	40.66ab	0.022a	31.00b	36.03a	30.10a-d	38.90b	29.43a	55.23a	35.06b
BHB 12	0.0216ab	23.33b	0.016a	46.00ab	29.50ab	29.10a-d	37.13b	28.63a	51.63a	39.36ab
BHB 13	0.0133ab	29.33ab	0.012a	27.33b	28.70b	29.10ad	39.33b	31.26a	43.20c	40.10ab
BHB 14	0.0133ab	28.33ab	0.0196a	37.66ab	29.83ab	29.73a-d	43.93ab	25.80b	55.033a	33.16b
Khoibhutta	0.0110b	48.66ab	0.009a	48.0ab	32.20ab	30.03a-d	40.90ab	28.9a	43.16c	52.76a
Mohabir	0.0126ab	28.0ab	0.017a	29.33b	30.83ab	27.46cd	41.63ab	27.60a	43.01c	43.16ab
Hiramon	0.0153ab	26.0ab	0.020a	37.33ab	33.93ab	32.96ab	43.53ab	27.70a	41.73c	35.76b
PacD22	0.0106b	41.66ab	0.0113a	47.33ab	29.83ab	26.70d	42.26ab	26.23b	40.46c	38.41ab
Samit	0.0193ab	32.33ab	0.024a	30.33b	32.53ab	28.50bcd	39.86ab	30.63a	44.9ab	39.60ab
Don 112	0.0156ab	52.66a	0.019a	69.66a	33.96ab	32.86abc	47.73a	31.03a	48.23ab	39.43ab
Uttaran	0.0173ab	34.33ab	0.024a	39.0ab	35.73a	34.20a	43.76ab	31.63a	48.56b	46.00ab
Sig. level	*	*	NS	*	*	*	*	*	*	*
CV (%)	6.13	8.13	54.96	6.19	7.18	7.69	6.46	8.68	6.82	7.06
LSD	0.011	26.71	0.016	37.74	6.6	5.49	8.04	5.31	21.14	14.83

* = Significant at 5% level of probability, NS=non-significant, the different lowercase letters indicate significant differences at a 5% probability level; BHB = BARI Hybrid Bhutta

Table 5. Correlation coefficient of various agronomic traits, including plant height (HT), dry weight (DW), SPAD values (chlorophyll content), grain yield (GY), and weed competitiveness index (WCI)

	HT30	HT45	HT60	DW30	DW60	Spad30	Spad45	Spad60	GY	WCI
HT30	1									
HT45	0.44*	1								
HT60	0.05	0.37*	1							
DW30	0.09	0.11	0.39*	1						
DW60	0.43*	0.13	0.53*	0.25*	1					
Spad30	0.07	0.05	0.28	0.20	0.30	1				
Spad45	0.12	0.31	0.30	0.11	0.28	0.33	1			
Spad60	0.01	0.02	-0.15	-0.02	-0.09	0.25	0.55	1		
GY	0.04	0.44*	0.38*	0.18*	0.23*	0.06	0.21	0.11	1	
WCI	0.20	0.45*	0.36*	0.12	0.21*	0.06	0.14	0.09	0.72*	1

Spad60 (SPAD value at 60 DAS) shows a weak correlation with most traits and is even negatively correlated with HT60 (r = -0.15). This suggests that chlorophyll content at 60 days is independent of plant height and other key traits. Grain Yield (GY) is significantly correlated with HT45 (r = 0.44, p < 0.05) and HT60 (r = 0.38, p < 0.05), showing that taller plants at mid and late stages tend to produce higher yields. DW30 (r = 0.18, p < 0.05) and DW60 (r = 0.23, p < 0.05) also show a significant positive correlation with grain yield, indicating that early and late-stage dry weight accumulation is positively associated with better yields. There is no significant

correlation between SPAD values (chlorophyll content) and grain yield, suggesting that higher chlorophyll content at any stage does not directly impact yield performance. WCI shows a strong positive correlation with HT45 ($r = 0.45$, $p < 0.05$) and HT60 ($r = 0.36$, $p < 0.05$), indicating that taller plants at mid and late-growth stages have better weed competitiveness. This is likely because taller plants shade out weeds and compete more effectively for light. DW60 is positively correlated with WCI ($r = 0.21$, $p < 0.05$), suggesting that higher dry weight at 60 days contributes to improved weed competitiveness. Crops with more biomasses are better at suppressing weeds due to enhanced resource capture. GY has a strong positive correlation with WCI ($r = 0.72$, $p < 0.05$), showing that maize varieties with higher weed competitiveness tend to produce higher yields. This reinforces the importance of selecting crops that can effectively compete with weeds to maximize yield.

Weed competitiveness is defined as the ability of a crop to suppress or tolerate weeds and is associated with plant height, plant biomass, leaf area index, specific leaf area, specific stem length, canopy ground cover and early vigor (Caton et al. 2003). The competitiveness of maize cultivars against weeds is a crucial aspect of sustainable weed management. Developing such cultivars could significantly reduce the reliance on herbicides in agroecosystems. While herbicides are essential tools for managing weeds today, they can have negative impacts on the environment and public health (Ahmed et al. 2021; Chauhan et al. 2015). Moreover, the overuse and repetitive application of the same herbicidal mode of action can lead to the development of herbicide-resistant weeds, which is a growing concern in chemical weed management. Therefore, it is important to explore strategies that minimize the environmental risks associated with excessive herbicide use and help combat herbicide-resistant weeds (Heap, 2021). Simply growing more competitive maize cultivars will not fully address the challenges posed by difficult weed control conditions; therefore, integrated approaches are needed.

4. Conclusion

The key findings of this study demonstrates that the maize varieties of Bangladesh tested varied widely among themselves in their weed suppressive ability and yield performance. The fast early growth rate was the most desirable trait for weed competitiveness in maize varieties. Results of the current experiment also showed that weed inflicted yield loss of the maize can be minimized by selecting cultivar with strong weed suppressive ability. Based on the findings it might be conclude that strong weed suppressive maize variety could be adopted as an integral part of sustainable weed management package aimed at reducing dependence on herbicides. But strong weed suppressive ability does not ensure high yields with varieties having low yield potential. Hence, high and stable yields along with strong weed competitiveness are a priority as selection criteria for the cereal varieties of Bangladesh. Therefore, breeder should consider the weed competitive traits of the crops during high yielding crop variety development. In addition, the current results are from a one-year trial of a single location; as a result, to corroborate the present study's conclusions more research with different maize varieties should be done in various agro-climatic situations before drawing a final recommendation.

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Conflict of Interests

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

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