Herbicide based weed management in aromatic rice of Bangladesh

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Abstract

Selection of appropriate weed management strategy helps reduce rice yield loss due to weeds. Despite some undesirable side-effects, no viable alternative is currently available to shift the chemical weed management in rice. However, time of herbicide application is very important with respect to its efficacy. Keeping in mind the inevitability of herbicidal weed control, the current study was designed to evaluate the response of selected aromatic fine rice varieties of Bangladesh to different herbicides based weed management practices compare to farmers' practices. The experiment was conducted in a randomized complete block design with three replications. The experiment consisted of five aromatic rice varieties; Kalijira, BRRI dhan34, BRRI dhan37, BRRI dhan38 and Binadhan-13, and six different weed management practices comprising no weeding, weed free, mechanical + manual weeding, pre–emergence herbicide + manual weeding, post–emergence herbicide + manual weeding and pre– + post–emergence herbicide. Eleven weed species belonging to five families were observed in the experimental plots. Based on the summed dominance ratio (SDR), grassy weed species *Echinochloa crusgalli* (SDR of 30.7) was the most dominant species, whereas broadleaf weed *Nymphaea nouchali* (SDR of 0.83) was the least one. Among the weed control treatments, application of pre–+ post emergence herbicides offered the highest reduction in weed density and biomass at all sampling dates which resulted in minimum crop-weed competition facilitating improvement in the yield contributing characters and finally resulted in the highest grain yield (2.5 t ha^{-1}) and harvest index (30.7%) next to the weed free treatment. The variety BRRI dhan38 gave the highest grain yield (3.4 t ha^{-1}) due to the highest performance of the yield contributing characters among the varieties. In interaction, BRRI dhan38 with pre–+ post–emergence herbicide application gave the highest yield (3.4 t ha^{-1}) apart from the weed free treatment. Being efficient in weed density and biomass reduction as well as the highest yield producer, sequential application of pre– and post–emergence herbicides may be recommended for effective weed management practices in BRRI dhan38.

Introduction

Bangladesh agriculture is dominated by the rice farming of which aromatic rice has started to get the attention of the consumers. The distinct characteristic of this type of rice is the pleasant aroma while cooked. Aroma is one of the most important qualitative traits of rice grain responsible for the good market value of the produce. The biochemical basis of aroma was identified as 2-acetyl-1-pyrroline (Tanchotikul and Hsieh, 1991). Because of the scented character the production of aromatic rice in Bangladesh is profitable demanding a high price over low price coarse milled rice (Raju and Reddy, 2000; Sikdar *et al.,* 2008). Majority of the aromatic rice cultivars are low yielding but its higher price and low cost of cultivation generate higher profit margins compared to other varieties (Biswas *et al.,* 2016). Besides the genetic constituents of the aromatic rice varieties, other biotic factors and different management practices could be responsible for the low yield of the aromatic rice cultivars. Among the biotic factors, weed is considered as one of the noxious enemies of crop wasting economic inputs worldwide. It is the most acute pest in agriculture with an estimated

annual loss of around 40 billion USD per year worldwide (Monaco *et al.,* 2002). Among the harmful pest, weeds contribute maximum losses in crop production, which may potentially reduce crop production by 34%, followed by animal pests (18%) and pathogens by 16% (Abbas *et al.,* 2018). Weeds also rank first in reducing yields (34%) of major crops world-wide (Jabran *et al.,* 2015). On average 25 and 5% production loss is caused by weeds in developing and developed countries, respectively; despite of any weed control measures (Koch, 1992). Rice yield reduction in Bangladesh is 70–80% (direct seeded Aus rice), 30–40% (transplanted *Aman* rice) and 22–36% (modern *Boro* rice) (Mamun, 1990; BRRI, 2008).

Weeds compete for the natural resources *e.g.,* light, water, space, and nutrient thereby reduce the crop growth, yield and quality (Ashiq and Aslam, 2014). Rao (2000) stated that an increase in one kilogram of weed biomass corresponds to a reduction in one kilogram of crop dry matter. The farmers of Bangladesh mainly practice conventional (manual *i.e.* hand pulling through *niri* or mechanical through rice weeder) methods of

weeding, which are laborious and time consuming. However, these methods are now become difficult because of labour crisis at the peak period, which results in severe yield loss (Hasanuzzaman *et al.,* 2009; Rashid *et al.,* 2007). Therefore, farmers of the country are now going to be solely dependent on herbicidal weed control, which is quick, cost-effective and less laborious. As a result, the use of herbicides in the country has been 37-fold increase in the last three decades (BBS, 2017). However, uninterrupted use of the same herbicides for a long period may cause environmental hazards (Aktar *et al.,* 2009, Islam and Kato-Noguchi, 2014), develop herbicide resistant weed biotypes (Heap, 2018), and cause shifts in weed flora (Holt, 1994). Despite such unwanted after effects, no viable alternative is currently available to shift the chemical dependence for weed management in rice. Herbicidal weed control is now considered as a viable alternative or supplement to conventional weeding (Mahajan *et al.,* 2009; Chauhan and Johnson, 2011; Anwar *et al.*, 2012). However, efficacy of an herbicide mainly depends on its ability to produce a desired effect on the target weeds. In addition, application time of herbicide is also very crucial with respect to its efficacy. Some other researchers stated that integration of more than one weed control methods *i.e.* integrated weed management is the best for efficient weed control due to its less effects on non-target organism, and for sustainable crop production (Singh *et al.,* 2008; Jabran and Chauhan, 2015; Abbas *et al.,* 2018).

Therefore, with a view to enhancing the proper crop growth for getting maximum grain yield by minimizing the crop-weed competition, efficient weed management practices should be practiced. Besides, the selection of appropriate variety is also essential for obtaining a good harvest because different varieties may vary in their canopy structure and growth characteristics and in turn influence the weed-suppressive ability (Mishra and Bhan, 1997; Rahman *et al.,* 2017; Arefin *et al.*, 2018). It has been reported that aromatic rice variety may vary for their yield and quality due to different management aspects (Hossain *et al.,* 2008; Sarkar *et al.,* 2014). But, the information regarding the performance of aromatic rice varieties of Bangladesh to various weed management practices are scarce in the literature. Therefore, this research work was accomplished to evaluate the response of selected aromatic fine rice varieties of Bangladesh to different herbicide based weed management practices compared to farmers' practices.

Material and Methods

Experimental site

The experiment was carried out at the Agronomy Field Laboratory and Weed Management Laboratory, Bangladesh Agricultural University, Mymensingh during the period from July to December 2015. The site belongs to the Old Brahmaputra Floodplain (Agro-ecological Zone 9) of Bangladesh. The experimental soil was characterized by non-calcareous dark gray floodplain soils. The land was well drained, medium high with silty-loam soil in texture (20% sand, 67% silt and 13% clay) and having pH 6.5. The organic matter content of the land is low (1.96%) with bulk density of 1.35 g cm^{-3} (Islam *et al.*, 2017). The site was characterized by high temperature, high humidity and heavy rainfall with occasional gusty wind in April–September (summer) and scanty rainfall associated with moderately low temperature during October–March (winter). Monthly total rainfall, average temperature and humidity of the experimental site during the study period from July to December 2015 are shown in Figure 1.
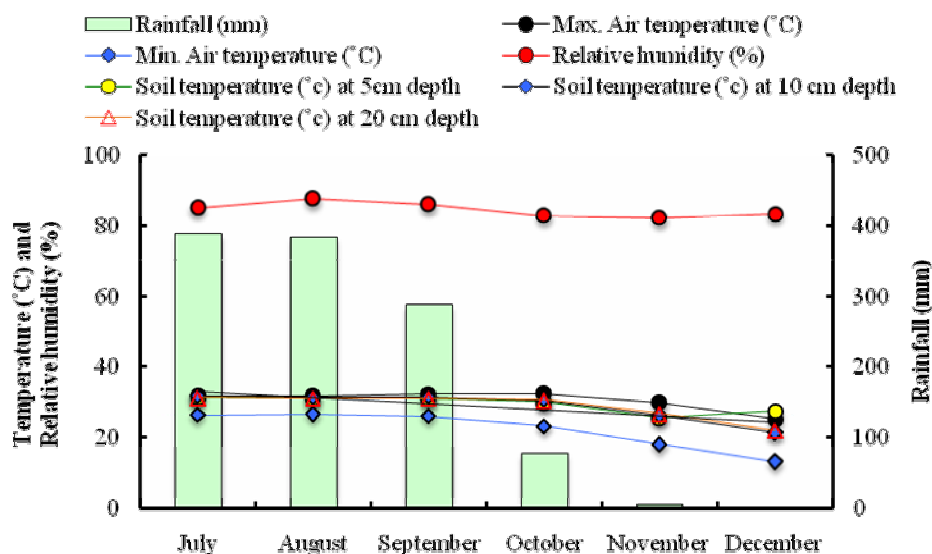

Figure 1. Monthly total rainfall, average temperature and humidity of the experimental site during the study period (July to December 2015)

Treatments and design
The experiment was conducted with five aromatic fine rice varieties *viz.*, Kalijira, BRRI dhan34, BRRI dhan37, BRRI dhan38 and Binadhan-13, and six weed management practices *viz.*, no weeding (season long weedy), weed free (season long weed free), mechanical (by using weeder) + manual weeding (hand pulling), pre–emergence herbicide + manual weeding, post–emergence herbicide + manual weeding and pre–+ post–

emergence herbicide. Here, pre-emergence herbicide (bensulfuran methyl + acetachlor @ 750 g ha^{-1}) was applied to the target plots at 5 days after transplantation (DAT) and post-emergence herbicide (pyrazosulfuron ethyl @ 125–150 g ha^{-1}) was applied to the target plots at 30 DAT. A brief description of the herbicides used in this experiment is presented in Table 1. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

Table 1. A brief description of the herbicides used in this experiment

Trade name	Generic name	Mode of action	Selectivity	Time of application	Marketed by	Manufactured by
Clean Master 18 wp	Bensulfuran methyl + Acetachlor	Systemic	Selective for grass and sedge of rice	Pre–emergence	Haychem Bangladesh Ltd.	Jhijiyang E–Tong Chemical Co. Ltd., China
Tiraz 10 wp	Pyrazosulfuron ethyl	Systemic	Selective for weeds of rice	Early post– emergence	Sweet Agrovet Ltd.	Reful Holding Co. Ltd., China

Crop husbandry
Seeds of Kalijira were collected from the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. Seeds of BRRI dhan34, BRRI dhan37 and BRRI dhan38 were collected from Bangladesh Rice Research Institute (BRRI) Gazipur, whereas seeds of Binadhan-13 were collected from Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. Sprouted seeds of all the varieties were sown in five different wet nursery beds. Proper care was taken to raise the seedling in the nurseries. Transplanting of 30-day old seedlings was done in puddled soil on July 29, 2015. Rice varieties were fertilized with 150, 97, 70, 60 and 12 kg ha^{-1} urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively. All the fertilizers except urea were applied in the unit plots at the time of final land preparation. Urea was top-dressed in three equal splits at 30, 50 and 70 days after transplanting (DAT), Seedlings were transplanted in the plots according to the layout at the rate of three seedlings hill^{-1} maintaining 25 cm × 15 cm spacing. Rice was grown as rainfed crop since rainfall was sufficient. Intercultural operations *e.g.,* gap filling, and drainage were done as per requirement. Plants were slightly infested with green leafhoppers, which were successfully controlled by spraying Karate 2.5 EC (Lamda Cyhalothrin@1 mLL^{-1}) once at 20 DAT.

Data recording and statistical analyses
Weed species grown in the experimental field were identified and the summed dominance ratio (SDR) was calculated as per Hia *et al.* (2017):

$$SDR = \frac{\text{Relative density (RD)} + \text{Relative dry weight (RDW)}}{2} \times 100 \ \ldots\ldots\ldots (i)$$

Where,

$$RD = \frac{\text{Density of a given weed species}}{\text{Density of all weed species}} \times 100 \ \ldots\ldots\ldots\ldots (ii)$$

$$RDW = \frac{\text{Dry weight of a given weed species}}{\text{Dry weight of all weed species}} \times 100 \ \ldots\ldots (iii)$$

The percent reduction of weed density (RWD) and reduction of weed biomass (RWB) were calculated as per the following formula:

$$\% RWD = 1 - \frac{\text{Number of weeds m}^{-2}\ in\ treated\ plots}{\text{Number of weeds m}^{-2}\ \text{in weedy plots}} \times 100 \ \ldots\ldots\ldots\ldots\ldots (iv)$$

$$\% RWB = 1 - \frac{\text{Number of weeds biomass m}^{-2}\ \text{in treated plots}}{\text{Number of weeds biomass m}^{-2}\ \text{in weedy plots}} \times 100 \ \ldots\ldots\ldots\ldots\ldots (v)$$

Five hills (excluding border hills) were randomly selected in each plot and uprooted before harvesting for recording the yield contributing data as per Ray *et al.,* (2015). The crops of central one square meter area from each plot were harvested and threshed by pedal thresher. The grains were sun dried and cleaned. Final grain weight was adjusted to 14% moisture content using the following formula:

$$\% \text{Moisture} = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight}} \times 100 \ \ldots\ldots (vi)$$

Adjusted yield at 14% moisture content (MC)

$$= \frac{\text{Fresh weight} \times (100 - \% \text{MC})}{(100 - 14)} \ \ldots\ldots\ldots\ldots (vii)$$

Analysis of variance was done with the help of computer package MSTAT-C. The mean differences among the treatments were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984).

Results and Discussion

Weed composition

The experimental field was infested with the naturally occurring weed community including grass, broad leaved and sedge weeds. The weed composition of the weedy plots is presented in Table 2. Ten weed species belonging to five families (five grasses, three broadleaves and two sedges) were found growing in the experimental field. Based on the summed dominance ratio (SDR) values, grass weed species *Echinochloa crusgalli* (SDR of 30.7) was the most dominant species in the weedy plot followed by the broadleaf weed

Monochoria vaginalis (SDR of 25.1). On the other hand, the least dominant weed species was broadleaf weed *Nymphaea nouchali* (SDR of 0.83) followed by broadleaf weed species *Marsilea crenata* (SDR of 0.95) (Figure 2). *Echinochloa crusgalli* and *Monochoria vaginalis* dominated weed community in rice were also reported by Islam *et al.* (2017) and Popy *et al.* (2017) in the rice field at the same experimental site. In fact, weed community of a field is mostly determined by the soil seed bank, weed management in previous crops and the cropping pattern followed.

Table 2. Weed composition found in untreated weedy plots of the experimental field

| Sl. No.	Scientific name	Family	Morphological type
1	*Echinochloa crusgalli* (L.) Beauv.	Poaceae	Annual grass
2	*Cyperus difformis* L.	Poaceae	Annual grass
4	*Digitaria sanguinalis* L.	Poaceae	Annual grass
5	*Paspalum scrobiculatum* L.	Poaceae	Perennial grass
6	*Leersia hexandra* Sw.	Poaceae	Perennial grass
7	Eleocharis *atropurpurea* (Retz.) J. & K. Presl	Cyperaceae	Annual sedge
8	*Cyperus iria* L.	Cyperaceae	Annual sedge
9	*Marsilea crenata* C. Presl.	Marsileaceae	Annual broad leaf
10	*Nymphaea nouchali* Burm. f.	Nymphaeaceae	Annual broad leaf
11	*Monochoria vaginalis* (Burm. F.) C. Presl.	Pontederiaceae	Perennial broad leaf
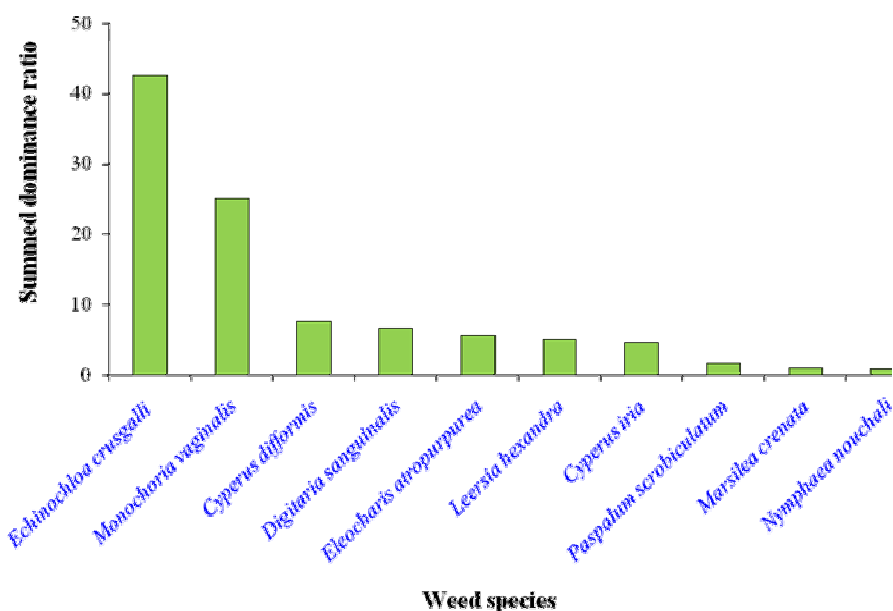
Figure 2. Summed dominance ratio (SDR) of the major weeds found in weedy plots

Percent reduction in weed density and biomass

Variation in weed density and biomass reduction over control was observed among the weed management practices at different days after transplanting (DAT) (Table 3). At all sampling dates, weed free treatments gave the complete reduction in weed density and biomass (100%) over control (weedy) because no weed was allowed to grow in weed free plots. As expected, the lowest percentage of weed density and biomass reduction (0%) was noted in plots where weeds were

allowed to compete with rice plants without adopting any weed management practices *i.e.*, weedy plots. Apart from the weed free and weedy plots, the highest percentage of weed density (76.5%) and biomass (92.0%) reduction were observed in pre– + post–emergence herbicide application, and the lowest was in post–emergence herbicide + manual weeding at 45 DAT (Table 3). At 65 DAT, the highest percentage of reduction in weed density (17.8%) and biomass (50.7%) were observed in pre– + post–emergence herbicide

application and the lowest weed density (7.3%) was in post–emergence herbicide + manual weeding, and the lowest biomass (33.1%) in pre–emergence herbicide + manual weeding. On the other hand, at 85 DAT, pre– + post–emergence herbicide application reduced highest percentage of weed density and biomass (43.2 and 48.6%, respectively), while post–emergence herbicide + manual weeding reduced the lowest weed density (22.5%) and mechanical weeding + manual weeding reduced the lowest weed biomass (1%) (Table 3). Hia *et al.* (2017) also observed that pre– + post–emergence herbicide treatment had the highest weed control efficiency at all observations. Weed density and biomass at earlier stage of crop growth were more critical than later stage (Bedmar *et al.,* 1999; Popy *et al.,* 2017). Several researchers established the importance of time of emergence of the weeds (Ciuberkis *et al.,* 2007; Singh *et al.,* 2017). It has been reported that the weeds, which emerge simultaneously or shortly after the crop emergence cause severe yield losses at very low densities (Popy *et al.,* 2017). Therefore, the treatment consisting of pre– + post–emergence herbicide can control weed more effectively at earlier stages of crop growth and hence can be considered as the most effective weed management practice.

Yield contributing characters
Number of effective tillers hill^{-1} was significantly affected by rice variety, different weed management and their interaction (Table 4, 5 and 6). Number of grains panicle^{-1}, weight of 1000-grain were significantly affected by rice variety and different weed management and not in their interaction, whereas panicle length was significantly influenced only by rice variety (Table 4, 5 and 6). The highest number of effective tiller hill^{-1} (9.06) was found in BRRI dhan38, which was statistically identical with Binadhan-13 (8.72). The lowest number of effective tiller hill^{-1} (6.44) was found in Kalijira (Table 4). Significant variations in number of effective tillers hill^{-1} among the varieties were also reported by Ferdous *et al.*(2016). The highest number of effective tillers hill^{-1}(9.80) was found in weed free treatment followed by pre–+post–emergence herbicide application. The lowest number of effective tiller hill^{-1} (5.27) was found in weedy plot (Table 5). The lowest number of effective tiller hill^{-1} was observed due to the severe crop-weed competition in the weedy treatment whereas, the highest number was found in weed free treatment because of no crop-weed competition. Weeding reduced inter species competition between crop and weed thus facilitated efficient utilization of resources *viz.,* sunlight, nutrient and moisture to produce effective tillers. The highest number of effective tillers hill^{-1} (11.67) was produced by BRRI dhan38 and BINAdhan-13 in weed free treatment which was statistically identical with (10.33) Binadhan-13 in pre–+ post–emergence herbicide application. The lowest number of effective tillers hill^{-1} (3.67) was produced by BRRI dhan34 and BRRI dhan37 in weedy treatment (Table 6).

Table 3. Percent reduction in weed density and biomass over control due to different weed management practices

Weed management	Weed density			Weed biomass		
	45 DAT	65 DAT	85 DAT	45 DAT	65 DAT	85 DAT
No weeding	0	0	0	0	0	0
Weed free	100	100	100	100	100	100
Mechanical + manual weeding	52.9	11.3	27.9	89.3	37.5	1.0
Pre–emergence herbicide + manual weeding	72.3	11.9	37.0	90.9	33.1	27.4
Post–emergence herbicide + manual weeding	43.7	7.3	22.5	89.2	44.3	6.0
Pre– + post–emergence herbicide	76.5	17.8	43.2	92.0	50.7	48.6

Table 4. Effect of variety on yield contributing characters of aromatic rice

Variety	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	Panicle length (cm)	Weight of 1000-grains (g)	Harvest index (%)
Kalijira	6.4c	144.8c	23.4bc	14.4d	25.8c
BRRI dhan34	7.6b	158.3b	25.6a	12.4e	29.6b
BRRI dhan37	7.5b	149.6bc	22.7c	18.7b	29.3b
BRRI dhan38	9.1a	193.1a	23.9b	20.1a	33.9a
Binadhan-13	8.7a	145.2c	23.1bc	17.5c	33.2a
CV (%)	23.98	8.14	5.32	5.47	24.64
Level of significance	**	**	**	**	*

In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. **=Significant at 1% level of probability, * =Significant at 5% level of probability.

Table 5. Effect of weed management on yield contributing characters of aromatic rice

Weed Management	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	Panicle length (cm)	Weight of 1000-grain(g)	Harvest index (%)
No weeding	5.3d	135.3d	23.8	15.7c	24.7c
Weed free	9.8a	172.5a	23.9	17.5a	31.8a
Mechanical + Manual weeding	7.9c	155.1c	23.8	16.6b	27.5b
Pre–emergence herbicide + Manual weeding	7.4c	160.3bc	23.4	16.4b	25.3b
Post–emergence herbicide + Manual weeding	8.1bc	158.3bc	23.6	16.8b	26.8b
Pre– + Post–emergence herbicide	8.8b	167.7ab	23.8	16.6b	30.7a
CV (%)	13.25	8.14	5.69	5.41	8.42
Level of significance	**	**	NS	**	**

In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. **=Significant at 1% level of probability, NS= non-significant.

Table 6. Effect of variety and weed management interaction on yield contributing characters and yield of aromatic rice

Variety	Weed Management	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	Panicle length (cm)	Weight of 1000-grain (g)	Grain Yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Kalijira	No weeding	5.7h	132.7	23.8	13.9	1.0klm	3.0	25.3
	Weed free	7.7c-g	170.7	22.9	14.8	2.4f-j	5.6	29.7
	Mechanical + Manual weeding	6.0gh	159.0	23.3	14.4	1.1jkl	3.6	23.6
	Pre–emergence herbicide + Manual weeding	6.0gh	163.7	23.4	14.3	1.3i-l	3.9	24.2
	Post–emergence herbicide + Manual weeding	6.3fgh	156.0	23.6	14.4	1.3i-l	4.8	20.9
	Pre– + Post–emergence herbicide	7.0d-h	167.7	23.5	14.3	1.8h-k	4.4	29.1
BRRI dhan34	No weeding	3.7i	163.0	23.9	11.9	0.7m	2.6	20.8
	Weed free	9.0bcd	215.7	26.2	12.9	3.2c-g	6.1	33.9
	Mechanical + Manual weeding	8.0c-f	182.7	25.8	12.4	2.1hij	5.2	29.1
	Pre–emergence herbicide + Manual weeding	8.0c-f	192.3	25.0	12.3	2.3g-j	5.4	29.5
	Post–emergence herbicide + Manual weeding	8.3cde	201.0	26.2	12.3	2.7e-i	6.0	31.1
	Pre– + Post–emergence herbicide	8.7bcd	203.7	26.1	12.4	2.9d-h	5.8	33.6
BRRI dhan37	No weeding	3.7i	133.0	23.4	17.4	2.0l	6.7	23.2
	Weed free	9.0bcd	163.7	23.1	19.1	2.7cd	5.6	32.2
	Mechanical + Manual weeding	7.7c-g	156.0	23.4	18.7	2.2d-h	5.5	28.9
	Pre–emergence herbicide + Manual weeding	8.3cde	145.7	21.9	18.7	2.3d-h	5.1	30.9
	Post–emergence herbicide + Manual weeding	8.0c-f	141.0	21.5	18.9	2.4e-h	5.8	29.7
	Pre– + Post–emergence herbicide	8.3cde	158.0	22.90	19.3	2.3efg	5.1	31.3
BRRI dhan38	No weeding	7.7c-g	130.0	24.9	18.8	2.2g-j	5.4	29.1
	Weed free	11.7a	156.3	23.9	22.0	3.7a	6.4	36.7
	Mechanical + Manual weeding	9.3bc	135.0	24.1	20.4	3.0c-f	6.8	30.6
	Pre–emergence herbicide + Manual weeding	8.0c-f	146.7	23.5	19.9	3.3c-h	6.7	32.8
	Post–emergence herbicide + Manual weeding	8.0c-f	150.0	23.5	19.5	3.2c-h	7.6	29.7
	Pre– + Post–emergence herbicide	9.7bc	153.3	23.4	20.0	3.4bc	6.2	35.7
Binadhan-13	No weeding	5.7h	117.7	22.9	16.3	1.1klm	4.0	20.7
	Weed free	11.7a	156.0	23.3	18.8	3.6ab	5.7	38.7
	Mechanical + Manual weeding	8.3cde	143.0	22.5	17.2	2.4f-i	5.6	29.7
	Pre–emergence herbicide + Manual weeding	6.7e-h	153.3	23.5	16.7	1.9h-k	5.1	26.8
	Post–emergence herbicide + Manual weeding	9.7bc	143.3	23.2	18.9	2.2c-f	5.7	28.1
	Pre– + Post–emergence herbicide	10.3ab	155.7	23.3	17.1	2.5cde	5.2	32.7
	CV (%)	13.9	13.9	5.5	10.0	5.5	6.9	5.7
	Level of significance	*	NS	NS	NS	*	NS	NS

In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. * =Significant at 5% level of probability, NS= non-significant

The highest number of grains panicle^{-1} (193.1) was found in BRRI dhan38. The lowest number of grains panicle^{-1} (144.8) was found in Kalijira, which was statistically identical with Bina dhan-13 (145.2) and BRRI dhan37 (Table 4). Variable number of grains panicle^{-1} among the varieties was also observed by Sarkar *et al.* (2014). Varietal variation regarding the number of grains panicle^{-1} might be due to their variation in genetic constitution. The highest number of grains panicle^{-1} (172.5) was found in weed free

condition which was statistically identical with (167.7) pre– + post–emergence herbicide application. The lowest number of grains panicle^{-1} (135.3) was found in weedy plots (Table 5). Similar results were also reported by Paul *et al.* (2015) and Khan *et al.* (2017). They reported that the highest number of grains panicle^{-1} was produced in the weed free condition in rice. Number of grains panicle^{-1} was not significantly affected by interaction between variety and weed management (Table 6).

The longest panicle (25.6 cm) was produced by BRRI dhan34, whereas the shortest one (22.7 cm) by BRRI dhan37 (Table 4). Sarkar *et al.,* (2014) also found the higher panicle length in BRRI dhan34 than the BRRI dhan37 and BRRI dhan38. Panicle length was not significantly affected by weed management and its interaction with varieties (Table 5 and 6). The variation of panicle length is due to the genetic makeup of the varieties (Ifftikhar *et al.,* 2009).

The highest 1000-grain weight (20.1 g) was produced by BRRI dhan38. The lowest weight of 1000-grain (12.35 g) was produced by BRRI dhan34 followed by Kalijira (14.4 g) (Table 4). The variations in the weight of 1000-grain could be due the differences in the grain size among the varieties. Baloch *et al.* (2002) and Saha *et al.* (2015) also found the variations in the weight of 1000-grain within varieties. The highest weight of 1000-grain (17.5 g) was found in weed free condition. The lowest weight of 1000-grain (15.7 g) was found in weedy plot (Table 5). The result was similar to the findings of Ganeshwor and Gadadhar (2000). Khan and Tarique (2011) and Popy *et al.* (2017) also obtained heavier grains from weed free plots, this is because 1000-grain weight is negatively related to weed density (Karim and Ferdous, 2010). Khan *et al.* (2017) found that no weeding reduced 1000-grain weight significantly. Weight of 1000-grains was not significantly affected by interaction of variety and weed management (Table 6).

Yield
Yield of aromatic rice was significantly affected by rice variety, different weed management and in their interaction except straw yield in case of their interaction (Figure 3, 4 and Table 6). The highest grain yield (3.4 t ha^{-1}) was produced by BRRI dhan38. The lowest grain yield (1.5 t ha^{-1}) was produced by Kalijira (Figure 3). Similar results were found elsewhere (Islam *et al.,* 2012; Tyeb *et al.,* 2013), who reported that variety exerted variable effect on yield contributing characters and yield of rice. Differences in grain yield due to varieties were also reported by Yoshida (1994) and Siddeque *et al.* (2002). The highest grain yield (3.2 t ha^{-1}) was found in

weed free treatment followed by pre– + post–emergence herbicide application (2.5 t ha^{-1}). The lowest grain yield (1.4 t ha^{-1}) was found in no weeding treatment (Figure 4). The highest grain yield (3.7 t ha^{-1}) was found in BRRI dhan38 in weed free treatment, which was statistically identical with Binadhan-13 (3.6 t ha^{-1}) in the same treatment. The lowest grain yield (0.7 t ha^{-1}) was produced by BRRI dhan34 in weedy plot, which was statistically identical with Binadhan-13 (1.1 t ha^{-1}) and Kalijira (1.02 t ha^{-1}) in the same condition (Table 6). Other than the weedy and weed free treatments, the highest grain yield (3.4 t ha^{-1}) was obtained from BRRI dhan38 with pre– + post–emergence herbicide application. The highest yield in this treatment could be due to the higher number of effective tillers hill^{-1}. Mahajan and Chauhan (2015) stated that the time window for the application of pre–emergence herbicide is very narrow and sometimes, farmers miss the optimum time application. Therefore, sequential applications of pre– + post–emergence herbicides provided better control of early and late flushes of weeds than the sole application (Mahajan and Chauhan, 2013).

The highest straw yield (6.5 t ha^{-1}) was produced by BRRI dhan38, which was statistically identical with Binadhan-13 (5.9 t ha^{-1}). The lowest straw yield (4.2 t ha^{-1}) was produced by Kalijira, which was statistically identical with BRRI dhan34 (5.2 t ha^{-1}) (Figure 3). The highest straw yield (6.9 t ha^{-1}) was found in weed free treatment which was statistically identical with post–emergence herbicide + manual weeding (6.5 t ha^{-1}), pre–emergence herbicide + manual weeding (6.1 t ha^{-1}), mechanical + manual weeding (5.8 t ha^{-1}) and pre–+ post–emergence herbicides (5.7 t ha^{-1}) (Figure 4). The lowest straw yield (4.2 t ha^{-1}) was found in no weeding treatment (Figure 4). Straw yield was not significantly affected by the interaction of variety and weed management (Table 6).

Harvest index (%)
Similar to some other yield contributing characters harvest index was significantly affected by rice variety and different weed management but not by their interaction (Table 4, 5 and 6). The highest harvest index (33.9%) was obtained in BRRI dhan38 which was statistically identical with Binadhan-13 (33.2%). The lowest harvest index (25.8%) was observed in Kalijira (Table 4). Pre– + post–emergence herbicide application gave the highest harvest index (31.8%), which was statistically identical with weed free treatment (30.7%). The lowest harvest index (24.7%) was observed in weedy plot (Table 5). Harvest index was not significantly affected by interaction between variety and weed management (Table 6).
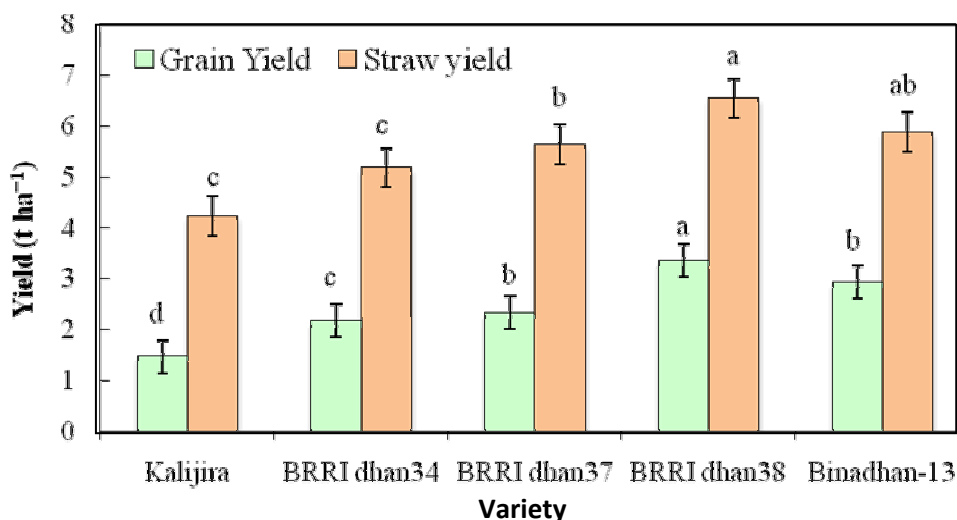
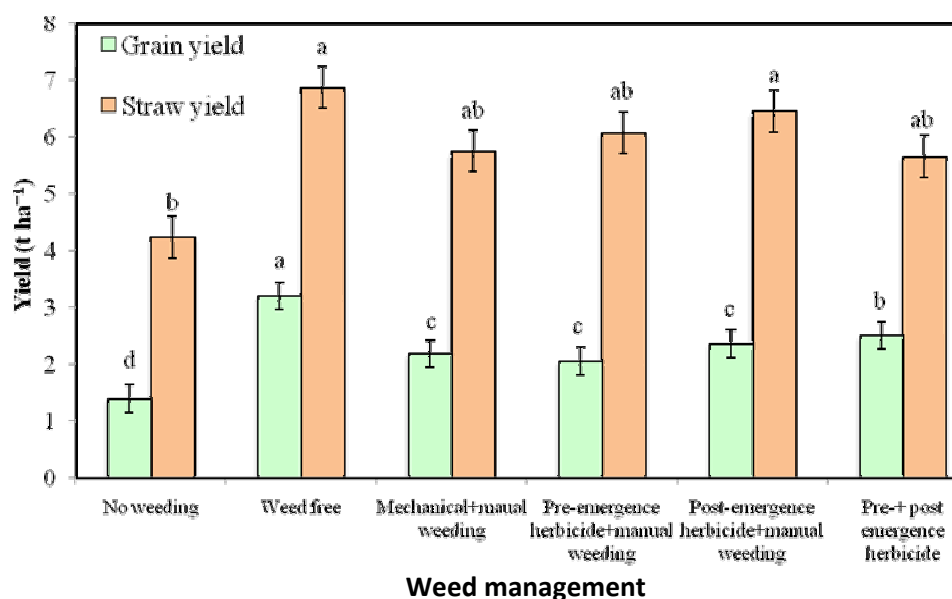Figure 3. Grain and straw yield of aromatic rice as influenced by variety

Figure 4. Grain and straw yields of aromatic rice as influenced by weed management

Conclusion

Weed management is challenging task in agriculture to maintain crop yield and productivity. This fact is also true for aromatic fine rice, as it is one of the factors responsible for lowering the grain yield. However, very little research has been conducted in aromatic fine rice of Bangladesh as well as their weed management. Farmers mainly practiced either conventional (manual or mechanical) or chemical means of weed control. In the current research it was observed the recent released varieties performed very well in respect of yield than the old variety Kalijira. Among the tested herbicides, pre– + post–emergence herbicide performed very well in controlling weeds compared to other methods of weed control. However, this experiment was conducted only in one location and one year. Multi-location trials for several years should be conducted before recommending the package to the farmers. Moreover, environmental issues related to herbicide use should be brought under consideration. Because, farmers sometimes ignore the instructions and do not use the correct volume of spray, dose and spray nozzle, which lead to poor weed suppression. In that case farmers may integrate pre– or post–emergence herbicide with a manual weeding considering both the environmental and labour cost issues.

Conflict of Interest

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

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