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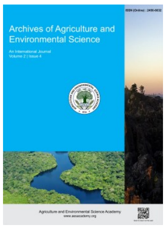

ORIGINAL RESEARCH ARTICLE

Impact of varying water-logging durations at various stages of growth on mustard seed yield

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ABSTRACT

Waterlogging significantly affects agricultural growth and development, making it a severe constraint limiting crop production and quality. This study aims to assess the level of water tolerance of standard mustard cultivars while taking into account the influence of varied water-logging durations on mustard seed output. In this study, a randomized complete block design was used to examine the effects of water-logging on the various phases of various mustard varieties under ambient temperature and sunshine circumstances. Binasarisha-9, Binasarisha-11 and BARI Sarisha-14 were the varieties utilized in the experiment, and water-logging treatments were applied at different times of 0, 24, 48, and 72 hours at 55–60 days after sowing (DAS). Data on plant height, branches plant^{-1}, and siliquae plant^{-1} were taken from 10 randomly selected plants from each plot. The maturity period was counted when 90% of siliquae matured. The seed yield of each plot was recorded after harvest. The result shows that the highest seed yield (1.51t ha^{-1}) was found for Binasarisha-11 under water-logging conditions for 24 hours at 55-60 DAS and almost the same result on seed yield (1.46t ha^{-1}) for Binasarisha-9 was found for the same treatment. Moderate yield at 48 hours water logging was observed whereas there was significant yield reduction for 72 hours water logging. BARI Sarisha-14, Binasarisha-9, and Binasarisha-11 yielded 4.5%, 1.38%, and 11.56% less than non-water-logged situations after 72 hours of water-logging at 55-60 DAS. However, it could be concluded that these results provide valuable insights into the effects of waterlogging on seed yield and can aid in selecting suitable mustard genotypes in flood-prone environments to mitigate the negative effects of climate change

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INTRODUCTION

Water-logging, drought, and salinity are the main unfavorable environmental factors that restrict plant growth. The complete or partial submersion of a plant by water is referred to as "flooding." We refer to flooding of the root system as "waterlogging," and the state in which most or all of the aerial tissue is submerged in water as "submergence." To improve agricultural productivity and profitability, available water and land resources should be utilized (Ogbolumani & Nwulu, 2022). Plants suffer anoxia and the oxygen supply is drastically diminished as a result of an imbalance between slow diffusion and rapid oxygen consumption in the rhizosphere brought on by the decreased gas exchange between plant tissues and the environment as a result of waterlogging. The effects of waterlogging at a specific development stage or for a specific amount of time on seed production rely on pre-and/or post-waterlogging caused by rainfall (Ali, 2018). Flooding is more likely to occur in the future, which might result in far larger losses to agricultural productivity (Cubasch *et al.*, 2001). In the mid-western United States, high soil moisture from intense early spring precipitation events frequently reduced yields of crops and increased nitrogen loss. In 2013 and 2014, the average loss in maize grain production per day due to waterlogging was 0.42 Mg ha^{-1} and 0.72 Mg ha^{-1}, respectively (Kaur *et al.*, 2017). Crop yield and N absorption are frequently restricted by waterlogging stress, which is the result of high soil moisture conditions brought on by either heavy precipitation events or inadequate drainage. This is because soil N losses escalate in waterlogged circumstances (Kumar & Chopra, 2014). In Missouri, Kansas, and Illinois, there are around 4 million hectares of clay pan soils with poor drainage, which can cause waterlogging in the upper soil layers during rainy seasons (Anderson *et al.*, 1990). The deficiency of oxygen in the root zone resulting from anoxic or hypoxic conditions is the reason behind crop damage brought on by soil flooding or waterlogging. In plants impacted by high soil moisture content in the root zone, respiration is the primary metabolic mechanism. In the event of oxygen deprivation, plants will ferment as a survival strategy, although this process only yields 3 ATP molecules as opposed to 39 ATP molecules through hexose respiration (Drew, 1997; Geigenberger, 2003). Conditions of waterlogging can reduce the root's ability to conduct water and nutrients, which can lead to nutritional deficiencies and poor plant development (Bradford & Hsiao, 1982). The yellowing of the leaves is a result of a major fall in plant N content caused by reduced root activity during waterlogging (Ali, 2018). The length of the flooding or waterlogging, the crop's stage of growth at the time of the flooding, and the soil's temperature all affect how damaged the plants get (Ritter & Beer, 1969; Zaidi *et al.*, 2004).

Throughout the life cycle, mustard plants have eight main growth stages: germination, leaf development, stem elongation, inflorescence emergence, flowering, fruit development, ripening, and senescence (Eid *et al.*, 2021). The environmental circumstances of the growth seasons may have an impact on the formation and development of seeds, which in turn may have an impact on the yield, as mustard can be cultivated during the Rabi season (Rashid *et al.*, 2010). During the Rabi season, sometimes rainfall occurs and the mustard crop is damaged due to unexpected water logging. As the weather patterns are constantly changing, we are dying for the need for comparative water-logging tolerant varieties even in the Rabi season. The objective was to study the effect of different durations of water-logging on the seed yield of conventional mustard varieties (Binasarisha-9, Binasarisha-11, and BARI Sarisha-14) at Magura, Dhaka, Bangladesh.

MATERIALS AND METHODS

Experimental site

The field experiment was carried out at the experimental farm of Bangladesh Institute of Nuclear Agriculture (BINA) Sub-Station, Magura covering agro-ecological zone 11 (High Ganges River Floodplain), namely Magura (23°30' N, 89°35' E).

Experimental design and treatments

The test varieties were V_1=Binasarisha-9, V_2=Binasarisha-11, and V_3=BARI Sarisha-14. The experiment was laid out in a randomized complete block design (split-plot) with three replications (Ali, 2018). Seeds were sown on 12 November 2022. Unit plot size was 21 m^2 (7m×3m) with 25cm line-to-line spacing. Although mustard is commonly grown in sandy soils, these sandy soils are gradually turning into sandy loam soils as a result of excessive subsurface water extraction, heavy rainfall, inadequate drainage, over-irrigation from the cultivation of crops that require a lot of water, multiple cropping systems, irrigation canal leaks, and an ill-planned network of canals and they are causing water logging, which is unsuitable for mustard cultivation (Sinha *et al.*, 2011). Therefore, understanding the impacts for water-logging at early flowering stage (55-60 DAS) and the ability to recover from the water-logging, we set three irrigation treatments at 55-60 DAS. The imposed irrigation treatments were: i. no water-logging, ii. water-logging for 24 hours at 55-60 DAS, iii. water-logging for 48 hours at 55-60 DAS, iv. water-logging for 72 hours at 55-60 DAS.

Fertilization and cultural practices

Recommended production packages i.e., application of fertilizers (FRG, 2018), weeding, thinning, irrigation, and application of pesticides were followed to ensure normal plant growth and development. Weeding and insecticide spray were done according to need.

Statistical analysis of the yield data

R-Studio and Microsoft Excel were used for data analysis. Microsoft excel were used for entering and organizing data and appropriate statistical analyses were performed by R 4.2.2 software for the comparison of the means of each character. The mean effect of irrigation treatments on yield and yield-attributing characters of mustard cultivars are summarized in Table 1. All three varieties showed yield reduction than normal practices. Irrigation frequency, total irrigation, and yield in t/ha under different treatments are shown in Table 2.

Table 1. The mean effect of irrigation treatments on yield and yield attributing characters of mustard.

Variety	Treatment	Plant height (cm)	No. of branches/plant	No. of siliquae/plant	Grain yield (t ha^{-1})
V_1	T_1	96.73	2.53	67.07	1.41
$V\text{-}_1$	T_2	99.87	3.27	68.02	1.46
V_1	T_3	96.80	2.47	61.47	1.38
V_1	T_4	99.80	2.67	60.80	1.34
V_2	T_1	110.27	0.00	67.50	1.44
V_2	T_2	109.13	0.00	71.47	1.51
V_2	T_3	108.13	0.00	62.67	1.40
V_2	T_4	115.27	0.00	69.20	1.42
V_3	T_1	112.20	0.00	68.47	1.47
V_3	T_2	109.93	0.00	63.00	1.39
V_3	T_3	109.93	0.00	60.13	1.28
V_3	T_4	111.47	0.00	61.40	1.30
CV (%)		3.85	16.70	21.32	1.57
LSD at 5% level		7.04	1.27	24.34	0.04

N.B. In a column, values for individual/combined means do not differ significantly at the 5% level, NS = Not Significant.

Table 2. Irrigation frequency, irrigation date (DAS), total irrigation and yield under different treatments.

Variety	Irrigation Treatment	No. of irrigation applied (nos.)	Irrigation date (days after sowing, DAS)	Total irrigation amount (cm)	Grain Yield (t ha^{-1})
V_1	T_1	--	--	--	1.41
V_{-1}	T_2	1	55	4	1.46
V_1	T_3	2	55, 56	7.5	1.38
V_1	T_4	3	55, 56, 57	10	1.34
V_2	T_1	--	--	--	1.44
V_2	T_2	1	55	4	1.51
V_2	T_3	2	55, 56	7.5	1.40
V_2	T_4	3	55, 56, 57	10	1.42
V_3	T_1	--	--	--	1.47
V_3	T_2	1	55	4	1.39
V_3	T_3	2	55, 56	7.5	1.28
V_3	T_4	3	55, 56, 57	10	1.30

RESULTS AND DISCUSSION

No water-logging condition

BARI Sarisha-14 showed the highest result on seed yield (1.47 t ha^{-1}) under no water-logging condition among other treatments implied on BARI Sarisha-14. Binasarisha-9 and Binasarisha-11 produced seed yields of 1.41 t ha^{-1} and 1.44 t ha^{-1}, respectively with conventional practices. Figure 1 shows the effects on seed yield of selected mustard varieties at Magura under no water-logging conditions.

Response of selected varieties to water-logging for 24 hours at 55-60 DAS

Binasarisha-11 produced the highest seed yield (1.51 t ha^{-1}) under water-logging for 24 hours at 55-60 DAS among the treatments. Binasarisha-9 showed statistically almost the same result on seed yield (1.46 t ha^{-1}) under water-logging for 24 hours at 55-60 DAS. BARI Sarisha-14 produced a moderate yield of 1.39t ha^{-1}. Figure 2 shows the effects on seed yield of selected mustard varieties at Magura under 24 hours of water-logging at 55-60 DAS.

Interaction between cultivars and water-logging

The interaction effects are not statistically different. The results revealed that the selected varieties can produce moderate seed yield under 24 hours of water-logging at 55-60 DAS. Mainly this period of waterlogging creates 2nd irrigation at the inflorescence emergence stage.

Response of selected varieties to water-logging for 48 hours at 55-60 DAS

Water-logging for 48 hours at 55-60 DAS for Binasarisha-11 produced the highest seed yield (1.40 t ha^{-1}) among the selected varieties. But Binasarisha-9 showed statistically almost the same result on seed yield (1.38 t ha^{-1}) under the same condition. BARI Sarisha-14 produced a moderate yield of 1.28 t ha^{-1}. Figure 3 shows the effects on seed yield of mustard varieties at Magura under 48 hours of water-logging at 55-60 DAS.

Interaction between cultivars and water-logging

The results revealed that the selected varieties can produce moderate seed yield under 48 hours of water-logging at 55-60 DAS. BARI Sarisha-14 produced 8.57% and 7.25% lesser yield than Binasarisha-11 and Binasarisha-9, respectively under 48 hours of water-logging at 55-60 DAS. Ali (2018) also observed that cultivars can provide modest seed output up to 36 hours of water-logging at any growth stage, as long as significant rainfall does not occur before or after the water-logging period.

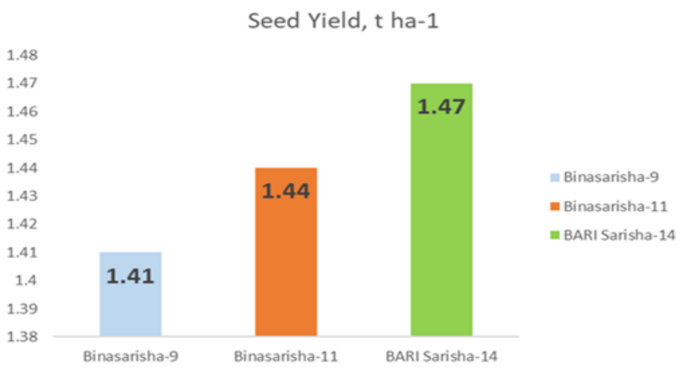

Figure 1. *Seed yield under no water-logging condition.*

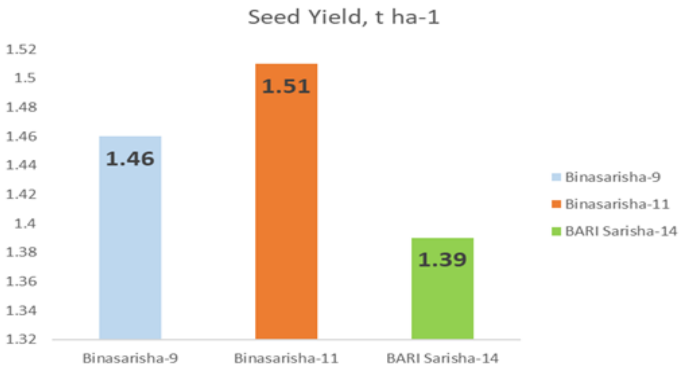

Figure 2. *Seed yield under 24 hours water-logging at 55-60 DAS.*

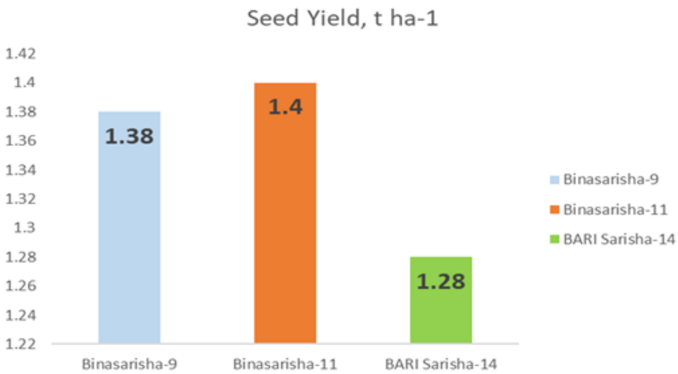

Figure 3. *Seed yield under 48 hours of water-logging at 55-60 DAS.*

Response of selected varieties to water-logging for 72 hours at 55-60 DAS

Binasarisha-11 produced the highest seed yield (1.42 t ha^{-1}) under water-logging for 72 hours at 55-60 DAS among the selected varieties. But Binasarisha-9 and BARI Sarisha-14 showed statistically almost the same result on seed yield (1.34 t ha^{-1} and 1.30 t ha^{-1}, respectively). Figure 4 shows the effects on seed yield of mustard varieties at Magura under 72 hours of water-logging at 55-60 DAS. The other researchers also identified the greatest influence of waterlogging during the reproductive (R2) development stage on the other crops like cowpea with an average decrease in leaf area of 65%, chlorophyll content of 39%, stomatal conductance (gs) of 93%, and photochemical efficiency of 32% when compared to plants that were not waterlogged (Olorunwa *et al.*, 2023).

Interaction between cultivars and water-logging

Twenty rapeseed types were utilized in a field experiment in China to assess the impact of waterlogging during the early flowering stage on yield and seed quality. It was discovered that waterlogging stress impacted rapeseed development and resulted in yield loss (Ashraf & Mehmood, 1990). Here, the results revealed that the selected varieties can produce moderate seed yield under 72 hours of water-logging at 55-60 DAS. But BARI Sarisha-14, Binasarisha-9, and Binasarisha-11 showed 4.5%, 1.38%, and 11.56% lesser yield, respectively under 72 hours of water-logging at 55-60 DAS than no water-logging conditions. A significant quantity of foreign currency is spent on oil imports to meet the national demand (Ali, 2018). To increase mustard yield, focus should be placed on growing high-yielding cultivars using various modern farming techniques, taking particular attention to issues like water-logging (Wang *et al.*, 2016). Long-term water logging can threaten mustard production in Bangladesh and elsewhere.

Conclusion

From the present study, the following conclusions can be drawn:

- The effects of waterlogging on mustard production at a specific development stage or for a specific amount of time rely on pre-and/or post-waterlogging from rainfall.
- Binasarisha-11 produced the highest seed yield (1.51 t ha^{-1}) with water-logging for 24 hours at 55-60 DAS (mainly 2^{nd} irrigation at inflorescence emergence stage) among the treatments. BARI Sarisha-14 showed the highest result on seed yield (1.47 t ha^{-1}) under no water-logging among other treatments implied on BARI Sarisha-14.

DECLARATIONS

Author's contribution statement

Conceptualization, methodology: S.T.A. and M.R.S.; Software, validation: S.T.A. and F.A.J.; Investigation: S.T.A. and M.R.S.; Data curation: S.T.A.; Writing -original draft preparation: F.A.J. and S.T.A..; Writing-review and editing: F.A.J..; Supervision: S.T.A., M.R.S. and F.A.J. All authors have read and agreed to the published version of the manuscript.

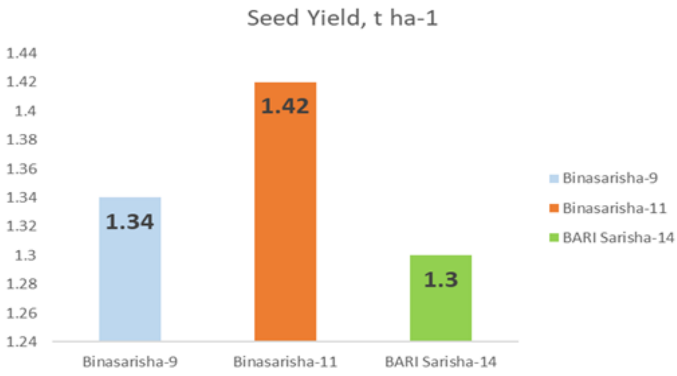

Figure 4. *Seed yield under 72 hours of water-logging at 55-60 DAS.*

Conflicts of interest: The authors declare no conflict of interest.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

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