ARSENIC STRESS TOLERANCE IN FOUR MUSTARD VARIETIES

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CERTIFICATE

*This is to certify that thesis entitled, "**ARSENIC STRESS TOLERANCE IN FOUR MUSTARD VARIETIES**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (MS) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **Most. Ashika Jahan Taishi, Registration no.13-05568** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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DEDICATED TO

MY

BELOVED PARENTS

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ARSENIC STRESS TOLERANCE IN FOUR MUSTARD VARIETIES

ABSTRACT

A pot experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during November, 2019 to February, 2020, to investigate the effect of arsenic stress tolerance of four mustard varieties. The experiment consisted of two factors, and followed Randomized complete block design (RCBD) with five replications. Factor A: Mustard varieties (4) *viz*; V_1=BARI Sarisha-11, V_2=BARI Sarisha-12, V_3=BARI Sarisha-14 and V_4= BARI Sarisha-15 and Factor B: Different arsenic level (3) *viz;* A_0 =No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil. Data on different parameters were collected for assessing results for this experiment and showed significant variation in respect of growth, yield and yield contributing characteristics of mustard due to the effect of different mustard varieties, arsenic level and their combinations. Among the mustard varieties, BARI Sarisha-11 variety recorded the maximum number of siliquae $plant^{-1}$ (86.35), 1000 seeds weight (3.53 g), seed yield $plant^{-1}$ (3.55 g), stover yield $plant^{-1}$ (15.13 g) and harvest index (18.98 %). Among the arsenic levels, 0 ppm arsenic treated plants recorded the maximum number of branches $plant^{-1}$ (4.18), number of siliquaee $plant^{-1}$ (69.97), number of seeds $siliquaee^{-1}$ (17.37), 1000 seeds weight (3.39 g), seed yield $plant^{-1}$ (2.64 g), stover yield $plant^{-1}$ (13.4 g) and harvest index (16.55 %), which were gradually decreased with the increasing arsenic level. In case of combined effect, cultivation of BARI Sarisha-11 alone with different arsenic level gave higher seed yield ranges between (3.82-3.07 g) from 0-100 ppm arsenic level and perform well in case of seed production comparable to other treatment combination and suitable for cultivation of mustard in arsenic prone areas comparable to other varieties.

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ABBREVIATIONS

Full word	Abbreviations	Full word	Abbreviations
Agriculture	Agric.	Milliliter	mL
Agro-Ecological Zone	AEZ	Milliequivalents	Meqs
And others	et al.	Triple super phosphate	TSP
Applied	App.	Milligram(s)	mg
Asian Journal of Biotechnology and Genetic Engineering	AJBGE	Millimeter	mm
Bangladesh Agricultural Research Institute	BARI	Mean sea level	MSL
Bangladesh Bureau of Statistics	BBS	Metric ton	MT
Biology	Biol.	North	N
Biotechnology	Biotechnol.	Nutrition	Nutr.
Botany	Bot.	Pakistan	Pak.
Centimeter	Cm	Negative logarithm of hydrogen ion concentration (-log[H+])	pH
Completely randomized design	CRD	Plant Genetic Resource Centre	PGRC
Cultivar	Cv.	Regulation	Regul.
Degree Celsius	°C	Research and Resource	Res.
Department	Dept.	Review	Rev.
Development	Dev.	Science	Sci.
East	E	Soil plant analysis development	SPAD
Editors	Eds.	Soil Resource Development Institute	SRDI
Emulsifiable concentrate	EC	Technology	Technol.
Environmment	Environ.	Thailand	Thai.
Food and Agriculture Organization	FAO	United Kingdom	U.K.
Gram	g	University	Univ.
Horticulture	Hort.	United States of America	USA
International	Intl.	Wettable powder	WP
Journal	J.	Serial	Sl.
Kilogram	Kg	Percentage	%
Least Significant Difference	LSD	Number	No.
Liter	L	Microgram	µ

CHAPTER-I

INTRODUCTION

Mustard (*Brassica spp*. L.) is a worldwide cultivated thermo and photosensitive oilseed crop. Asia produces 41.50% of mustard seed, which occupies the first position in terms of percentage share of production followed by the USA (FAO, 2018).

Edible oils play vital roles in human nutrition by providing calories and aiding in digestion of several fat soluble vitamins, for example Vitamin A (National Research Council, 1989). The per capita recommended dietary allowance of oil is 6 gm/day for a diet with 2700 Kcal (BNNC, 1984). Oilseeds were cultivated in less than 2.20 % of total arable land under rice-based cultivation system in Bangladesh, where three fourth of total cultivable land was engaged in rice production in 2015-16 (BBS, 2019). Mustard is the major oilseeds in Bangladesh which exhibits an increase in production from 1994 to 2018 except few fluctuations in the case of total production and area under cultivation (FAO, 2018). Mustard occupied more than 69.94 % of the total cultivated area of oilseeds followed by sesame, groundnut, and soybean (BBS, 2019).With the increase in population, the demand for edible oil and oilseeds is in increasing trend (Alam, 2020). Bangladesh has to import a noticeable amount of edible oil and oilseeds to meet up the existing accelerating demand. The value of imported oilseed and edible oil has increased dramatically from USD 544 million in 2002-03 to USD2371 million in 2018-19 which were 4.99 and 4.23 % of the total value of imports respectively (Bangladesh Bank, 2020). Yield of mustard has increased from 0.75 tha^{-1} in 2001 to 1.15 tha^{-1} in 2019 (MoA, 2008; BBS, 2019). Bangladesh was not in an advantageous position in the case of mustard production (Miah and Rashid, 2015). So mustard production must be increasing for cope with the future demand. In Bangladesh mustard production is low due to, lack of high yielding varieties and poor management practices.

Seed yield and other yield contributing characters significantly varied among the varieties of rapeseed and mustard (BARI, 2001). Uddin *et al.* (1987) reported that there was a significant yield difference among the varieties of rapes and mustard with the same species. *Brassica* (genus of mustard) has three species that produce edible oil, they are *B. napus, B. campestris* and *B. juncea*. Of these, *B. napus* and *B. campestris* are of the greatest importance in the world's oil seed trade. In this subcontinent, *B. juncea* is also an important oil seed crop.

Until recently, mustard varieties such as Tori7, Sampad (both *Brassica campestris*) and Doulat (*Brassica juncea*) were mainly grown in this country. Recently several varieties of high yielding potential characteristics has been developed by BARI.

Arsenic (As) has become a global problem due to contamination of ground water, which is the primary source of drinking water and food, pose a serious health risk to the people. High levels of As in ground-water have been detected in many countries, but Bangladesh and West Bengal (India) are the most affected country in the world (Rosen and Liu, 2009). As is an element of interest due to the toxic properties of several As compounds. The major inorganic As species found in the environment are arsenite [As(III)] and arsenate [As(V)] and organic As species are monomethylarsonic acid (MMA), dimethylarsinic acid (DMA), trimethylarsine oxide (TMAO), arsenobetaine, arsenosugars and arsenocholine (Tangahu *et al.,* 2011). The inorganic As species arsenite [As(III)] and arsenate [As(V)] are the main phytoavailable forms of As and predominantly found in soil/water (Meharg and Hartley-Whitaker, 2002). These inorganic forms are interconvertible, depending on the redox condition and may be metabolized by plants from the inorganic to organic form. As (V) is the prevalent As species present in aerobic soils under normal pH conditions (pH 4-8). It is considered as a structural analogue of phosphate, with similar electron configurations, uncouples oxidative phosphorylation, inhibits ATPase, replaces P in DNA and inhibits DNA repair mechanism (Tripathi *et al.,* 2007). As (V) and inorganic phosphate (Pi) compete for uptake through the same transport systems in As hyperaccumulators, As-tolerant non-hyperaccumulators, and As-sensitive non-accumulators (Rai *et al*., 2012., Gupta *et al.,* 2009).

The maximum acceptable concentration of arsenic in agricultural soil is 20 mg kg^{-1} (Kabata-Pendias and Pendias, 1992). At higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity (Marin *et al.,* 1993). When plants are exposed to excess arsenic either in soil or in solution culture, they exhibits toxicity symptoms such as: inhibition of seed germination (Abedin *and Meharg.,* 2002); decrease in plant height (Marin *et al*., 1992; Carbonell-Barrachina *et al*., 1995; Abedin *et al*., 2002b; Jahan *et al*., 2003); depress in tillering (Kang *et al*., 1996; Rahman *et al*., 2004); reduction in root growth (Abedin *et al*., 2002a); decrease in shoot growth (Cox *et al*., 1996); lower fruit and grain yield (Carbonell-Barrachina *et al*., 1995; Abedin *et al*., 2002b; Kang *et al*., 1996); and sometimes, leads to death (Marin *et al*., 1992; Baker *et al*., 1976). The sessile nature of plants needs more protection and this enabled them to evolve unique mechanisms to cope with different stress factors. However, variations do exist in tolerance mechanisms in plants. In the process plants alter their physiology, metabolic mechanisms, gene expressions and developmental activities to cope-up with the stress effects. Several mechanisms to counter As induced stress are reported in various model plants as they vary from species to species depending on their genetic background (Wang *et al*., 2002; Raab *et al.,* 2005; Tripathi *et al.,* 2007 and Gupta *et al*., 2009). Furthermore, many heavy metals including As stimulate the formation of free radicals, reactive oxygen species (ROS) and malondialdehyde (MDA) content (a product of membrane production). The scavenging system controlling ROS includes both enzymatic and non-enzymatic antioxidants such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione, ascorbate and carotenoids (Srivastava *et al.,* 2009; Ahmad *et al.,* 2012; Ahmad and Gupta, 2013; Ali *et al*., 2014a, 2014b). In stress conditions the free radicals may increase, which will enhance the activities of these detoxifying enzymes. Therefore, increased activities of these enzymes may be considered as typical defence components against As toxicity.

Mustard (*Brassica spp*), a fast growing high biomass plant is a good accumulator of heavy metals and is considered as a potential candidate to be a model plant for phytoremediation (Chaturvedi, 2006; Ahmad and Gupta, 2013). Although, lots of work has been done in different varieties of *Brassica* under As stress, still we need to explore more varieties, which will help in the selection of As tolerant variety. It is not possible to block entirely the entry of As species into crop plants because of their shared transport systems with essential and beneficial elements. However, the adverse effect of As can be reduced by selecting different tolerant crop plant species.

By considering the above fact the proposed research work was undertaken to achieve the following objectives;

Objectives:

i. To compare between mustard varieties in terms of different arsenic stress condition.
ii. To study the influence of arsenic treatment on different physiological events of mustard.
iii. To determine the combine effect of variety and arsenic concentration on growth and yield of mustard varieties.

CHAPTER II

REVIEW OF LITERATURE

An attempt was made in this section to collect and study relevant information available regarding to the response of arsenic stress tolerance of four mustard varieties, to gather knowledge helpful in conducting the present piece of work.

2.1 Effect of mustard varieties

Plant height

Das *et al.* (2019) reported that height of a plant is determined by genetical character and under a given set of environment different variety will acquire their height according to their genetical make up.

Tyeb *et al.* (2013) reported that the variation in plant height due to the effect of varietal differences. The variation of plant height is probably due to the genetic make-up of the cultivars.

Rashid *et al.* (2010) conducted a field experiment with different levels of fertilizers three mustard varieties of BARI sharisa-9, BARI sharisa-12 and BARI sharisa-15, to find out the optimum and economically viable fertilizer dose and reported that variety BARI sharisa-15 is of the tall plant type. They reported that others are of intermediate and short stature in plant height. The significant difference in plant height might be associated with the variety characteristics or genetic makeup of the plant.

Sana *et al.* (2003) reported that the final plant height reflected the growth behavior of a crop.

Dry matter accumulation

Helal *et al.* (2016) conducted an experiment of rapeseed-mustard at the Agronomy Research field of Sylhet Agricultural University, Sylhet, during the Rabi season to identify the suitable short durable variety for utilizing the fallow land of Sylhet region that remain fallow after harvest of T. Aman rice. Eight varieties (Improved Tori, TS72, BARI Sarisha-8, BARI Sarisha-9, BARI Sarisha-12, BARI Sarisha-14, BARI Sarisha-15, and Binasarisha-4) and four promising lines (BC-05115 Y, BC-05117 Y, BC-05118 Y and Nap-205) of rapeseed-mustard were evaluated. Results indicated that, dry matter production pattern at different days after sowing showed that different varieties varied their dry matter production pattern.

These variations were noticed from one stage to another stage and none of the variety/line followed the same pattern at different days of sampling. It indicated that each variety/line responded independently from one stage to another stage to the environment in respect of growth of plant, branching and leaf number and ultimately differed in dry matter production.

Rashid *et al.* (2010) noticed significant variation in dry matter (DM) accumulation for different mustard varieties on all days after sowing. This might be due to the different varieties which produced a different type of siliquae, and thus, the DM varied significantly.

Crop growth rate

Toshiyuki *et al.* (2006) reported that the genotypic difference in grain yield was most closely related to that in crop growth rate.

Number of branches

Helal *et al.* (2016) reported that higher number of branches/plant is the result of genetic makeup of the crop and environmental conditions which play a remarkable role towards the final seed yield of the crop.

Mamun *et al.* (2014) carried out a study on the performance of rapeseed and mustard varieties grown under different planting density and observed that BARI Sarisha-13 produced the highest number of branches plant^{-1} (6.14) which was 33.77% higher (4.59) than BARI Sarisha-15.

Sana *et al.* (2003) reported that, higher number of branches/plant is the result of genetic makeup of the crop and environmental conditions which play a remarkable role towards the final seed yield of the crop.

Number of siliquaee plant

Alam *et al.* (2014) A field experiment was conducted at the Central Research Station of BARI, Gazipur for two consecutive years 2010-11 and 2011-12 with 30 varieties/ genotypes of rapeseed-mustard under three dates of sowing viz., 25 November, 5 December, and 15 December to determine changes in crop phenology, growth and yield of mustard genotypes under late sown condition when the crop faced high temperature.

Varieties/genotypes of mustard used in the experiment exerted significant influence on yield and yield attributes and among different varieties maximum number of siliquaee/plant (108 and 90) was recorded in BJDH -05 which differed significantly from other varieties. This has contributed to higher yield. The lowest number of siliquaee/plant (52.0 and 56.3) were found in BARI Sarisha-14.

Mamun *et al.* (2014) found that the number of siliquae plant^{-1} of mustard was significantly affected by different varieties.

Singh *et al.* (2001) conducted an experiment in Jodhpur and observed that number of siliquae/plant recorded higher in cultivar Pusa Bold (257) compared to cultivar TS9 (198).

Yadav *et al.* (1978) suggested that for ensuring high yields in *B. juncea*, the plant type should have more number of siliquaee/plant (100-125).

Number of seeds per siliquae

Rahman *et al*. (2019) carried out an experiment at Sher-e-Bangla Agricultural University Farm, Dhaka- 1207, Bangladesh during Rabi season, November 2017 to February 2018 to find out the effect of different sowing methods and varieties on the yield of (Brassica campestris). The experiment comprised of two factors - the treatment consisted of four sowing methods viz. S_0 = Broadcast method, S_1 = Line to line space 20 cm, S_2 = Line to line space 25 cm and S_3= Line to line space 30 cm and three different varieties viz. V_1 = BARI Sarisha 14, V_2 = BARI Sarisha 15 and V_3 = BARI Sarisha 17. The experiment was laid out in two factors Randomized Complete Block Design (RCBD) with three replications. Result revealed that the maximum number of seeds per silliquae (23.12) was produced in V_2 (BARI Sarisha 15) treatment and the minimum number of seed per silliquae (18.82) was produced in V_1 (BARI Sarisha 14) treatment.

Helal *et al.* (2016) observed significant variations in terms of number of seeds/siliquaee among all the varieties due to reason of difference in the genetic makeup of the variety, which is primarily influenced by heredity.

1000 seeds weight

Mamun *et al.* (2014) carried out a study on the performance of rapeseed and mustard varieties grown under different planting density and observed that BARI Sarisha-13 had the highest 1000 seeds weight (4.00 g) whereas the lowest (2.82 g) - in SAU Sarisha-3.

Mondal and Wahab (2001) described that, weight of 1000 seeds varied from variety to variety and species to species.

Seed yield

Biswas *et al.* (2019) conducted an experiment at Sher-e-Bangla Agricultural University farm to evaluate the performance of five rapeseed and mustard varieties under two different planting techniques. The planting techniques were as conventional sowing and sowing seeds in puddle soil that assigned to the main plot and five varieties *viz*. Improved Tori-7, BARI Sarisha -13, BARI Sarisha -15, BARI Sarisha -16 and SAU SR-3 in the sub-plots. Result revealed that mustard varieties significantly affect seed yield and among different varieties higher seed yield (2.24 t ha^{-1}) was observed in Improved Tori-7 variety which was followed by BARI Sarisha-16 (1.96 t ha^{-1})) and BARI Sarisha-13 (1.57 t ha^{-1}). The lowest seed yield (1.34 t ha^{-1}) was obtained from V_3 (BARI Sarisha-15) which was statistically similar with SAU SR-3 (1.53 t ha^{-1}).

Das *et al*. (2019) carried out a field experiment in the CR Farm of Gayeshpur, BCKV, Nadia, West Bengal, India during *rabi* season of 2015-16 and 2016-17 to find out suitable hybrid variety and optimum spacing for different hybrids. Three hybrid varieties of mustard *viz.* Kesari 5111(V1), Kesari 5222(V2) and Kesari Gold(V3) were taken as treatments in the main plot, whereas, four spacing - 30cm × 10cm (S_1), 30cm × 20cm (S_2), 40cm × 20cm (S_3) and 40cm × 30cm (S4) were imposed as subplot treatment. The experiment was conducted in split plot design with 3 replications and repeated in *rabi* seasons for two consecutive years (2015-16 and 2016-17). The results of the experiment revealed that seed yield significantly differ among varieties and the maximum seed yield was recorded in Kesari Gold (1746 and 2153 kg ha^{-1} respectively in 1st and 2nd year) followed by Kesari 5111.

Helal *et al.* (2016) reported that the production of higher yield by different varieties might be due to the contribution of cumulative favorable effects of the crop characteristics viz., number of branches/plant, *siliquaee*/plant and seeds/siliquae.

Junjariya (2014) reported that seed yield of Indian mustard was influenced significantly with different cultivars. Bio-902 remained at par with RGN-13 and significantly superior as compared to RGN-48 and PBR-357. Bio-902 cultivar produced 8.72 and 23.03 per cent higher yield, respectively, over RGN- 48 and PBR-357. However, RGN13 and RGN-48 were remained at par with each other and significantly superior over PBR-357.

Islam and Mahfuza (2011) conducted an experiment at the research field of Agronomy Division, BARI, Joydebpur, Gazipur during rabi season of 2010- 2011. BARI Sarisha11 produced the highest seed yield (1472 kg ha^{-1}) while BARI Sarisha-14 the lowest (1252 kg ha-1). The highest mean seed yield was recorded at maturity stage (1480 kg ha^{-1}) and decreased towards green siliquae stage.

Zaman *et al.* (1991) who reported that seed yield of mustards were varied with different varieties.

Stover yield

Sultana *et al.* (2009) studied that stover yield for different varieties of rapeseed under study differed significantly. Kollania produced higher stover yield (2159.0 kg ha^{-1}) which was statistically at par with SAU Sarisha-1 (2156.0 kg ha^{-1}) and higher than Improved Tori -7 (1681.0 kg ha^{-1}).

Harvest index

Thakur *et al.* (2021) carried out an investigation on the Agronomic evaluation of Mustard (*Brassica juncea* L.) hybrids under agroclimatic conditions of Prayagraj (U.P.) was carried out during Rabi 2019-2020. The field experiment was laid out in Randomised Block Design, replicated four having 5 different variety as treatments. The finding of the experiment indicated that harvest index significantly influenced by different varieties and maximum harvest index (36.95) was observed in T^2 [45S35]. However, treatment T_1 [BULLET] found to be statistically at par with T_2 [45S35]. As discussed earlier, the different hybrids have different yield potential, which is the reason for yield variation among different varieties.

Lal *et al.* (2020) conducted an experiment was with four mustard varieties (RGN-73, RGN-229, RH-30 and Pusa bold) in two growing environments (open environment and neem shade) to investigate the performance of mustard (*Brassica juncea* L.) varieties under *Azadirachta indica* L. shade and open condition in hot-arid region of Rajasthan and result revealed that The maximum harvest index under RGN-73 (20.8%) was higher but statistical at par with RGN-229 (20.5%), while both varieties were significantly superior than RH-30 (18.9%) and Pusa bold (18.3%). This might be due to genotype characteristics and high yielding potential of the variety.

Uddin *et al.* (2011) reported that the harvest index differed significantly among the varieties due to its genetic variability.

Shah *et al.* (1991) reported that variety had a great influence on harvest index.

2.2 Effect of different arsenic level

Plant height

Chaturvedi (2006) reported that As concentration appearing toxicity was widely varied with plant genotypes. It might be because of varietal differences in As translocation and phytoextraction potential of the plants in Indian mustard varieties. It seems likely that the plant species and even genotypes differ greatly in their ability to take up, transport and accumulate As within the plants.

Stoeva and Bineva (2003) reported that higher arsenic accumulated in the plant tissue stimulates peroxidase synthesis during the early phases of plant development, long before the appearance of visible changes causes degradation of membrane lipids resulting in cell damage and formation of many toxic products impact on plant growth.

Kabata-Pendias and Pendias (1991) reported that arsenic is generally considered phytotoxic and is expected to negatively affect plant growth.

Dry matter accumulation

Chaturvedi (2006) carried out a study on the effects of arsenic concentrations and forms on growth and arsenic uptake and accumulation by indian mustard (Brassica Juncea L.) genotypes and reported that increasing arsenic concentration gradually deceasing dry matter accumulation among different genotype Varuna appeared to have a higher susceptibility to As toxicity than DHR-9504 and this higher sensitivity was associated with corresponding decreases in plant growth. The dry weight of Varuna and DHR9504 were significantly reduced by 54.6 and 33.6% respectively over the control at the 30 mg kg^{-1} of As treated soil.

Gulz *et al.* (2005) reported that As becomes toxic for all plants, causing chlorosis, inhibition of growth by reducing dry matter accumulation and finally death, when soil As concentration is high.

Crop growth rate

Garg and Singla (2011) reported that arsenic is non-essential and generally toxic to plants. Roots are usually the first tissue to be exposed to As, where the metalloid inhibits root extension and proliferation. Upon translocation to the shoot, As can severely inhibit plant growth by slowing or arresting expansion and biomass accumulation result in slow crop growth rate as well as compromising plant reproductive capacity through losses in fertility, yield, and fruit production.

Marin *et al.* (1993) reported that a higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity result in reduced crop growth rate.

Yield contributing characters

Niazi *et al.* (2017) reported that reduction in growth attributes (leaf area, plant height, number of leaves, shoot and root dry biomass), yield attributes (siliquae plant^{-1}, Seed siliquae, 1000 seeds weight) gas exchange attributes (photosynthetic rate, transpiration rate, stomatal conductance), photosynthetic pigments and water use efficiency was higher due to increasing arsenic concentration in the soil or irrigation water.

Shahid *et al.* (2015) reported that arsenic availability in soil can disturb normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity.

De Oliveira *et al.* (2013) reported that the deleterious impacts of As on plant transpiration process are probably the outcome of disturbed nutrient uptake and transport of water which influences the reduction of plant yield.

Imran *et al.* (2013) documented the best performance of *Helianthus annuus* L. seedlings under limited As supply (4 mg/kg soil) but at sufficiently higher concentrations, As hampers critical biochemical and metabolic processes which can result in plant death or reduced productivity.

Mateos-Naranjo *et al.* (2012) reported that As-induced reductions in growth and productivity are consequences of inhibition of photosynthetic activity in plants.

Anjum *et al.* (2011) reported that arsenic inhibit the rate of photosynthesis in plants. As absorption by plants, light harvesting apparatus can be affected with a reduction in chlorophyll concentrations and photosynthetic activity-II or by suppressing few of the key events of above processes. A remarkable reduction in chlorophyll pigment synthesis was reported due to shortage of the adaptive adjustments of photosystems-I and -II as a result of high As levels cause negative impact on plant growth, yield and yield contributing attributes.

Singh *et al.* (2006) reported that different arsenic concentration increasing malondialdehyde (MDA), a membrane lipid peroxidation reaction product, along with electrolyte leakage result in membrane damage of Phaseolus aureus seedlings and it's more severe under increasing As-stress at 50 M.

Srivastava *et al.* (2007) reported that plants exposed to either arsenate or arsenite produce reactive oxygen species ROS.

Singh *et al.* (2006) reported that increasing arsenic concentration cause production of reactive oxygen species (ROS) like hydrogen peroxide and superoxide by plants exposed to environmental stresses causes damage to DNA, proteins and lipids.

VanBreusegem and Dat (2006) reported that higher arsenic exposure is a strong stress which triggers increased ROS production, leading to cellular damages that can cause cell death.

Jahan *et al.* (2003) has confirmed that, when plants were exposed to excess arsenic either in soil or in solution culture, they exhibited toxicity symptoms such as: inhibition of seed germination, decrease in plant height,, lower fruit and grain yield and sometimes, leads to death.

Hughes (2002) reported that both arsenate and arsenite are toxic to plants by disturbing central cellular functions. Arsenate can replace phosphate in aerobic phosphorylation, disturbing the cellular energy flow, and arsenite can disturb protein functioning by binding to sulphydryl groups in the proteins.

Kang *et al.* (1996) noted that increasing the level of arsenic decreased plant height, dry weight of above ground parts and 1000 seeds weight.

Seed yield

Talukdar (2013) reported that existence of As above the threshold limit in soil or in irrigation water interferes with metabolism of crop plants, consequently leading to wilting, curling, necrosis of leaf blades, suppression in the number of leaves and leaf area thereby reducing photosynthesis and biomass accumulation, losses in mineral contents, reduced root elongation, proliferation and nodulation, stunted growth and poor yield.

Montenegro and Mejia (2001) reported the reduction of cereals yield by 10% with the increase of arsenic content in irrigation water.

Stover yield

Delowar *et al.* (2005) reported that increasing arsenic concentration gradually effects on growth and yield of rice plant.

Abedin *et al.* (2002b) noted that increasing in the content of arsenic in irrigation water led to increasing arsenic content in rice plant and consequent decrease in yield.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka to investigate the effect of arsenic stress tolerance ability of four mustard varieties. Materials used and methodologies followed in the present investigation have been described in this chapter.

3.1 Experimental period

The experiment was conducted during the period from November-2019 to February 2020 in Rabi season.

3.2 Description of the experimental site

3.2.1 Geographical location

The experiment was conducted in the Agronomy field of Sher-e-Bangla Agricultural University (SAU). The experimental site is geographically situated at 23°77′ N latitude and 90°33′ E longitude at an altitude of 8.6 meter above sea level (Anon., 2004).

3.2.2 Agro-Ecological Zone

The experimental site belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28 (Anon., 1988 a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1988 b). For better understanding about the experimental site has been shown in the Map of AEZ of Bangladesh in Appendix-I.

3.2.3 Soil

The soil of the experimental field belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon soil series. Soil pH ranges from 5.4–5.6 (Anon., 1989). The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0–15 cm depths were collected from the agronomy field. The soil analyses were done at Soil Resource and Development Institute (SRDI), Dhaka. The physicochemical properties of the soil are presented in Appendix II.

3.2.4 Climate and weather

The climate of the experimental site was subtropical, characterized by the winter season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October . Meteorological data related to the temperature, relative humidity and rainfall during the experiment period of was collected from Bangladesh Meteorological Department (Climate division), Sher-e-Bangla Nagar, Dhaka and has been presented in Appendix-III

3.3 Experimental materials

Four varieties of mustard namely BARI Sarisha-11, BARI Sarisha-12, BARI Sarisha14 and BARI Sarisha-15 were used as planting materials. Seeds of BARI Sarisha-11, BARI Sarisha-12, BARI Sarisha-14 and BARI Sarisha-15 were collected respectively from Oil Seed Research Centre, Bangladesh Agricultural Research Institute, Gazipur.

The important characteristics of these varieties are mentioned below:

BARI Sarisa-11

BARI Sarisa-11 was developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. It is originated from local and exotic germplasm and released, in the year of 2001. Late planting potential, plant height 120-130 cm, 3-5 primary branches are present in each plant, branched is produced from main stem with slight up to soil, leaf light green, leaf with petiole and rough, blooming flower in downward position on axils, flower yellow, number of siliquaee /plant 75-150, two chambers are present in pod, seeds/siliquae 12-15, seed color pink, 1000 seeds weight 3.5-4.0 g, seed weight is greater than another rai sarisa. It is also cultivated as late variety after harvest of aman rice. It's planting in Rabi season from mid October to mid November. Harvesting required 105-110 days from seed sowing and given yield 2-2.5t/ha, yield is 20-25% greater than Daulat variety. Oil content 43-44% and it is also drought and salt tolerant.

BARI Sarisa-12

BARI Sarisa-12 was developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. It is originated from local and exotic germplasm and released, in the year of 2002. Plant height 80-85 cm, 5-6 primary branches are present in each plant, blooming flower in upright position on axils, corolla color of flower is yellow, number of siliquae/plant 70-100, two chambers are present in siliquaee, seed/siliquaee 15-20, seed color pink, 1000 seeds weight 2.6-3.2 g. It's planting in Rabi season from mid October to mid November. Harvesting required 80-85 days from seed sowing given yield 1.45-1.65 t/ha and Oil content 43-44%.

BARI Sarisa-14

BARI Sarisa-14 was developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Developed by crossing between Tori and Sonali Sarisha and released, in the year of 2006. Short duration variety, plant height 75-85 cm, leaf light green, smooth, siliquae/plant 80-102, two chambers are present in siliquaee but as like as four chambers. Seed/siliquaee 22-26, seed color pink, 1000 seeds weight 3.5-3.8 g, crop duration 75-80 days, after harvest aman and before transplant boro It is easily cultivated because of short duration. It's planting in Rabi season from mid October to mid November given yield 1.45-1.60 t/ha having Oil content 44-45%.

BARI Sarisa-15

BARI Sarisa-15 was developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Developed by Selection from local germplasm and released, in the year of 2006. Short durated variety, plant height 90-100 cm, siliquaee/plant 70-80, two chambers are present in pod, seeds/siliquaee 20-22, pod is narrow and taller than BARI sarisa-14, seed color yellow, 1000 seeds weight 3.25-3.50 g, crop duration 80-85 days, after harvest aman and before transplant boro, it is easily cultivated because of short duration. It's planting in Rabi season from mid October to mid November. Yield give 1.45-1.65 t/ha and Oil content 48-52%.

3.4 Collection of fertilizer and manures

Urea, TSP, MOP, Gypsum, ZnSO4, Boric Acid and Cow dung fertilizers were collected from the Farm Office of Sher-e-Bangla Agricultural University (SAU).

3.5 Experimental treatment

There were two factors in the experiment namely mustard variety and different arsenic level as mentioned below:

Factor A: Mustard varieties (4) *viz;*

V_1 = BARI Sarisha-11
V_2= BARI Sarisha-12
V_3 = BARI Sarisha-14
V_4= BARI Sarisha-15

Factor B: Different arsenic (As) level (3) *viz;*

A_0 = No As (Control)
A_1 = 50 mg As kg^{-1} soil
A_2 = 100 mg As kg^{-1} soil

3.6 Experimental design

The experiment was laid out in Randomized complete block design (RCBD) with 2 factor and five replications. Total 60 pots were required for the experiment with 12 treatment combinations.

3.7 Detail of experimental preparation

3.7.1 Selection and preparation of the pot

Earthen pots of having 12 inches diameter, 12 inches height with a hole at the centre of the bottom were used. Silty soil was used in the experiment. The upper edge diameter of the pots was 30 cm (r= 15 cm). While filling with soil, the upper one inch of the pot was kept vacant so that irrigation can be provided using a hose pipe. As such the diameter of the upper soil surface was 15 inch (30 cm) and the area of the upper soil surface was (πr^2 = 3.14x 0.015x 0.015=0.07 m^2). The preparation of the pot was done in 6 November, 2019.

3.7.2 Fertilizer requirement

Fertilizers	Quantity/requirement (kg/ha)	Fertilizer given pot^{-1} (g)
Urea	250	1.75
TSP	170	1.19
MP	85	0.595
Gypsum	150	1.05
Zinc sulphate	5	0.035
Boric Acid	10	0.07
Cow dung	8000	1.75

(Source: (BARI, 2019)

3.7.3 Fertilizer application

Urea, triple superphosphate (TSP), Muriate of potash (Mop), gypsum, zinc sulphate, boric acid and cow dung were used as sources of nitrogen, phosphorus, potassium, zinc, boron and others nutrient, respectively. The soil of the pots was mixed with TSP, MP, gypsum, zinc sulphate, boric acid, cow-dung and one and half amount of urea. The rest amount of urea was applied during flower initiation of mustard (BARI, 2019).

3.7.4 Sowing of seeds in the pot

The seeds of mustard were sown in the pot on 11 November having a depth of 2–3 cm. During seed sowing 0.5 g Bavistin were mixed with seeds. The seed was sowing in 35 seeds $hole^{-1}$.

3.8 Intercultural operations

i) Weeding and Thinning

Weeding followed by thinning were done at15 and 20 days after emergence.

ii) Irrigation

Irrigation was given in the respective pots to ensure proper moisture in soil. First irrigation was given at 15 days after sowing (DAS) and the second irrigation was given at 40 DAS. A little irrigation was given at 60 DAS.

iii) Application of pesticides

In this experiment mustard crops were attacked by aphids (*Lipaphis erysimi*). Malathion 57 EC at the rate of 2 ml/litre of water was applied for controlling aphids attack in the field.

Application of spraying pesticide was done in the afternoon while the pollinating bees were away from the experimental field.

3.9 General observations of the experimental site

Regular observations were made to see the growth stages of the crop. In general, the pot looked nice with normal green plants, which were vigorous and luxuriant.

3.10 Crop sampling and data collection

One plant from each pot was randomly selected and marked with sample card. Different non destructive data were recorded from the selected plants at various growth stage.

3.11 Harvesting, threshing and cleaning

Different varieties required different time requirement for maturity. From the experiment crop varieties of mustard were harvested at maturity when 80% of the siliquaee turned into straw yellowish in color. Harvesting was done in the morning to avoid shattering. Prior to harvesting, randomly selected plant from each replication pot were separately harvested for recording yield attributes and other data. The harvested plants were tied into bundless and carried to the threshing floor of the Agronomy Field Laboratory. The crops were sundried by spreading on the threshing floor. The seeds were separated from the siliquaee by beating with bamboo sticks and later were cleaned, well dried and weighed. The weights of the dry stover were also taken.The seeds thus collected were dried in the sun for reducing the moisture in the seed to about 9% level. The stovers were also dried in the sun. Seed and stover yield were recorded. The biological yield was calculated as the sum of the seed yield and stover yield.

3.12 Data collection

The data were recorded on the following parameters

a) Growth parameters

i. Plant height
ii. Total dry matter plant^{-1}
iii. Crop growth rate

b) Yield contributing characters

i. Branches plant^{-1}
ii. Siliquaee plant^{-1}
iii. Seeds siliquae^{-1} iv. 1000 seeds weight

c) Yield characters

i. Seed yield plant^{-1}
ii. Stover yield plant^{-1}
iii. Harvest index

3.13 Relationship and performance

i. Relationship between arsenic level and seed yield of mustard varieties.

ii. Yield performance of mustard varieties at different arsenic levels over control treatment.

iii. Correlation of seed yield plant^{-1} with siliquaee plant^{-1} and 1000 seeds weight of mustard varieties along with different arsenic level.

3.14 Procedure of recording data

i) Plant height (cm)

The height of the selected plant was measured from the ground level to the tip of the plant at 30, 60 DAS and harvest respectively. Mean plant height of mustard plant were calculated and expressed in cm.

ii) Total dry matter accumulation plant^{-1} (g)

Five plants were collected randomly from each plot at 30, 60 DAS and harvest respectively. The sample plants were oven dried for 72 hours at 70°C and then dry matter content plant^{-1} was determined. Mean dry matter plant^{-1} of mustard plant were calculated and expressed in gram (g) for recording data.

iii) Crop growth rate (CGR) (mg cm^{-2} day^{-1})

The average daily increment in plant stand is an important characteristic. The CGR is an increase in dry matter production per unit ground area per unit time. In the present investigation the crop growth rate was worked out between 60 to 90 DAT with the help of following formula given by Watson (1956).

Crop growth rate (CGR) = $\frac{w_2 - w_1}{p(t_2 - t_1)}$ mg cm^{-2} day^{-1}

Where,

P = ground area (cm^2)

W_1 = dry weight per unit area at t_1

W_2 = dry weight per unit area at t_2

t_1 = time of first sampling

t_2 = time of second sampling

iv) No. of branches plant^{-1}

The branches plant^{-1} was counted from five randomly sampled plants. It was done by counting total number of branches of all sampled plants then the average data were recorded. Data were recorded at harvest respectively.

v) Number of siliquaee plant^{-1} (no.)

Siliquae plant^{-1} was counted from the 5 selected plant sample and then the average siliquae number was calculated.

vi) Seeds siliquaee^{-1} (no.)

Seeds siliquae^{-1} was counted from splitting five siliquaee, which were sampled from sample plants and then mean value was determined.

vii) 1000 seeds weight (g)

Thousand seeds were counted which were taken from the seed stock of each pot, then weighed it in an electrical balance and data were recorded.

viii) Seed yield (g plant^{-1})

The mean seed weight was taken by threshing the plants of each sample and then weighed it in an electrical balance and data were recorded on dry weight basis..

ix) Stover yield (g plant^{-1})

The stover weights of mustards were calculated after threshing and separation of the grains from the plant of sample and then weighed it in an electrical balance and data were recorded on dry weight basis.

x) Harvest index (%)

Harvest index was calculated on dry weight basis with the help of following formula.

$$\text{Harvest index (HI \%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Here, Biological yield = Grain yield + Stover yield

3.15 Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program named Statistix 10 Data analysis software and the mean differences were adjusted by Least Significant Difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter with a view to study the arsenic stress tolerance of four mustard varieties. The data are given in different tables and figures. The results have been discussed, and possible interpretations are given under the following headings.

4.1 Plant growth parameters

4.1.1 Plant height (cm)

Effect of variety

Plant height is an important morphological character that acts as a potential indicator of availability of growth resources in its approach. Different mustard variety significantly differed plant height at different days after sowing (Fig 1). Experimental result revealed that BARI Sarisha-11 mustard variety recorded the maximum plant height (22.88, 51.99, and 86.35 cm) at 30, 60 DAS and harvest, respectively. while BARI Sarisha-15 mustard, variety recorded minimum plant height (16.67) at 30 DAS. At 60 DAS and at harvest respectively BARI Sarisha-14 mustard variety recorded minimum plant height (35.93 and 58.31 cm) which was statistically similar with BARI Sarisha-12 mustard variety recorded plant height (57.87 cm) at harvest respectively. The variation in plant height due to the effect of varietal differences. The variation of plant height is probably due to the genetic make-up of the variety. Das *et al.* (2019) and Tyeb *et al.* (2013) found similar result with the present study and reported that height of a plant is determined by genetical character and under a given set of environment different variety will acquire their height according to their genetical make up. Sana *et al.* (2003) reported that, the final plant height reflected the growth behavior of a crop.

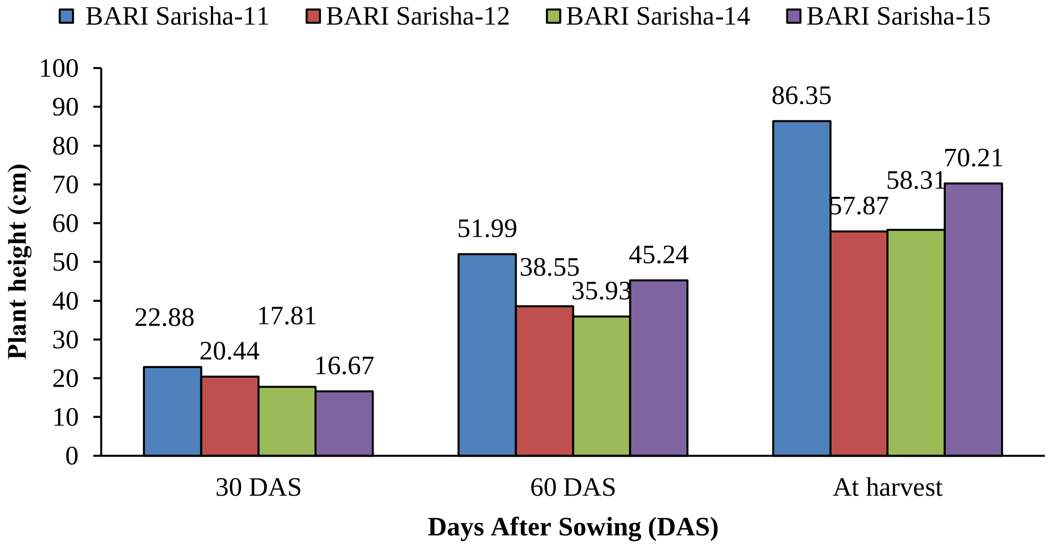
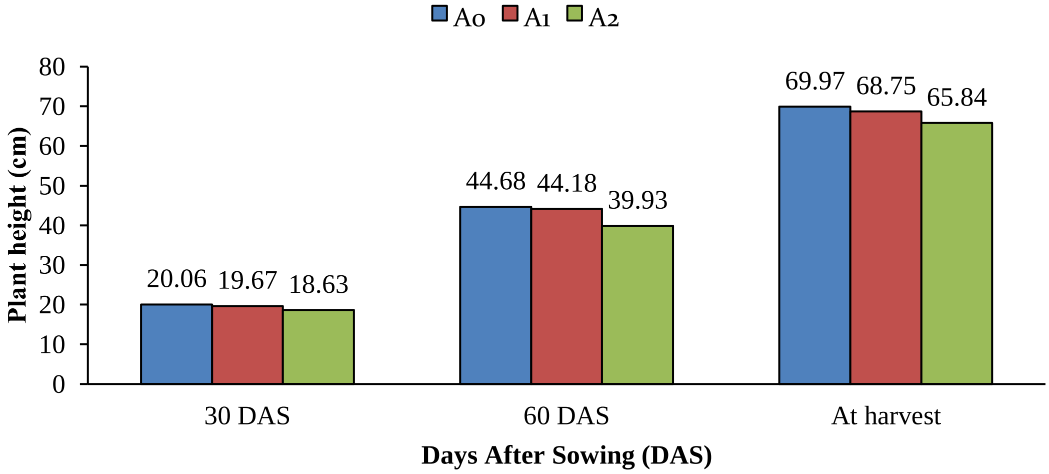


Figure. 1. Effect of variety on plant height of mustard at different DAS (LSD $_{0.05}$ = 0.62, 1.08, 1.68 at 30, 60 DAS and harvest, respectively).

Effect of arsenic level

Different arsenic level significantly differ plant height of mustard at different days after sowing. Experimental result showed that increasing arsenic level gradually decreasing plant height (Fig 2). Due to variation of arsenic level, control treatment or no arsenic treated pot recorded the maximum plant height (20.06, 44.68 and 69.97 cm) at 30, 60 DAS and at harvest respectively which was statistically similar with 50 mg As kg^{-1} soil treated pot and recorded plant height (19.67, 44.18 and 68.75 cm) at 30, 60 DAS and harvest, respectively. Whereas 100 mg As kg^{-1} soil treated pot recorded the minimum plant height (18.63, 39.93 and 65.84) at 30, 60 DAS and at harvest respectively. The variation of plant height might be because of varietal differences in As translocation and phytoextraction potential of the plants in mustard varieties. It seems likely that the plant species and even genotypes differ greatly in their ability to take up, transport and accumulate As within the plants. The result obtained from the present study was similar with the findings of Chaturvedi (2006) who reported that As concentration appearing toxicity was widely varied with plant genotypes. Kabata-Pendias and Pendias (1991) reported that arsenic is generally considered phytotoxic and is expected to negatively affect plant growth.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 2. Effect of arsenic level on plant height of mustard at different DAS (LSD $_{0.05}$ = 0.54, 0.94, 1.45 at 30, 60 DAS and at harvest, respectively).

Combined effect of variety and arsenic level

Different mustard varieties along with arsenic level significantly influenced of plant height of mustard at different days after sowing (Table 1). Experimental result showed that cultivation of BARI Sarisha-11 mustard variety along with no arsenic treated pot recorded the maximum plant height (24.26 cm) at 30 DAS which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded plant height (23.44 cm). At 60 DAS cultivation of BARI Sarisha11 mustard variety along with 50 mg As kg^{-1} soil treated pot recorded the maximum plant height (54.06 cm) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded plant height (5386 cm) and at harvest respectively BARI Sarisha-11 mustard variety along with no arsenic treated pot recorded the maximum plant height (89.02 cm) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded plant height (86.58 cm). Whereas BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum plant height (16.56 and 33.48 cm) at 30 and 60 DAS which was statistically similar with BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded plant height (16.60 cm); with BARI Sarisha-15 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded plant height (16.64 cm); BARI Sarisha-15 mustard variety cultivation along with no arsenic treated pot recorded plant height (16.77 cm) at 30 DAS, and with BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded plant height (35.20 cm) at 60 DAS. At harvest respectively BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum plant height (55.85cm) which was statistically similar with BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded plant height (57.19) cm.

Table 1. Combined effect of variety and arsenic level on plant height of mustard at different DAS

Treatment Combinations	Plant height (cm)		
	30 DAS	60 DAS	At harvest
V_1A_0	24.26 a	53.86 a	89.02 a
V_1A_1	23.44 a	54.06 a	86.58 a
V_1A_2	20.93 b	48.04 b	83.46 b
V_2A_0	20.73 b	40.68 e	58.94 f
V_2A_1	20.18 b	39.78 e	58.83 f
V_2A_2	20.42 b	35.20 gh	55.85 g
V_3A_0	18.46 c	36.50 fg	57.96 fg
V_3A_1	18.40 c	37.82 f	59.79 f
V_3A_2	16.56 d	33.48 h	57.19 fg
V_4A_0	16.77 d	47.66 b	73.97 c
V_4A_1	16.64 d	45.06 c	69.80 d
V_4A_2	16.60 d	43.01 d	66.87 e
$LSD_{(0.05)}$	1.08	1.87	2.91
CV(%)	4.35	3.42	3.35

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

V_1 = BARI Sarisha-11

V_2= BARI Sarisha-12

V_3 = BARI Sarisha-14

V_4= BARI Sarisha-15

A_0 = No As (Control)

A_1 = 50 mg As kg^{-1} soil

A_2 = 100 mg As kg^{-1} soil

4.1.2 Dry matter accumulation plant^{-1} (g)

Effect of variety

The dry matter accumulation (g plant^{-1}) were differed among different varieties due to reason that individual variety have individual growth stage, and resources utilization its surrounded which influences the dry matter accumulation (g plant^{-1}). In this Experimental result showed that different rice varieties significantly influenced dry matter accumulation (g plant^{-1}) of mustard at different DAS (Figure 3). Among different mustard varieties BARI Sarisha-11 mustard variety recorded the maximum dry matter accumulation (4.14, 8.97 and 18.71 g plant^{-1}) at 30, 60 DAS and at harvest respectively. Whereas cultivation of BARI Sarisha-15 mustard variety recorded the minimum dry matter accumulation (2.83 g plant^{-1}) at 30 DAS. At 60 DAS cultivation of BARI Sarisha-14 mustard variety recorded the minimum dry matter accumulation (5.54 g plant^{-1}). At harvest respectively cultivation of BARI Sarisha-12 mustard variety recorded the minimum dry matter accumulation (12.82 g plant^{-1}) which was statistically similar with BARI Sarisha-14 mustard variety recorded dry matter accumulation (12.93 g plant^{-1}). Resources utilization ability had greater in high yielding varieties which influences the dry matter accumulation. The result obtained from the present study was similar with the findings of Helal *et al.* (2016) who reported that each variety/line responded independently from one stage to another stage to the environment in respect of growth of plant, branching and leaf number and ultimately differed in dry matter production. Rashid *et al.* (2010) reported that the different varieties which produced a different type of siliquae, and thus, the DM (Dry matter) varied significantly.

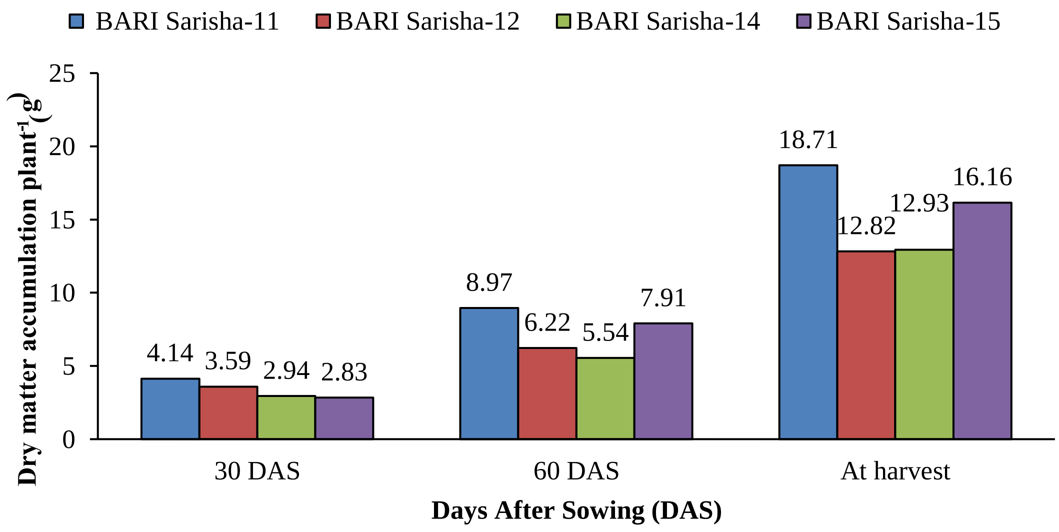
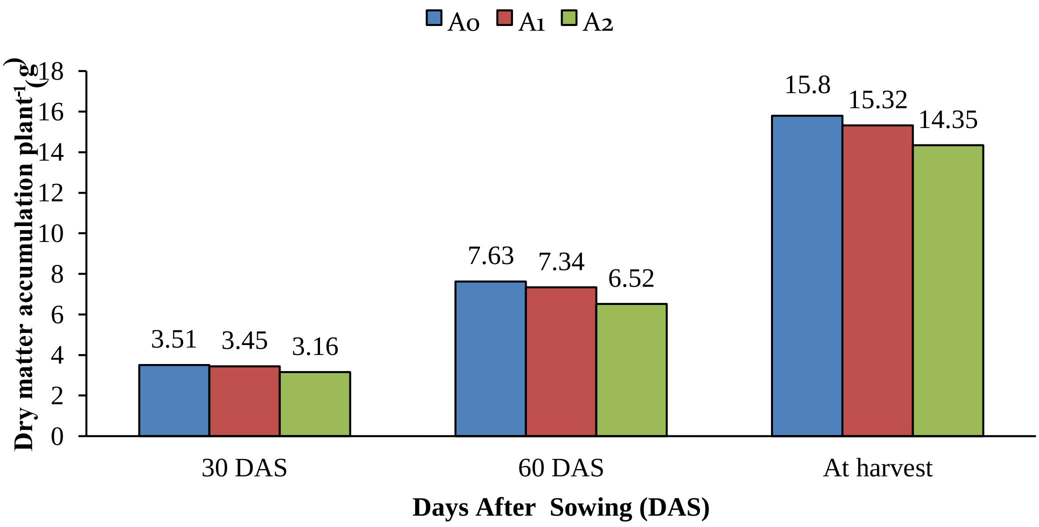


Figure. 3. Effect of variety on dry matter accumulation plant^{-1} of mustard at different DAS (LSD $_{0.05}$ = 0.10, 0.19 and 0.30 at 30, 60 DAS and at harvest, respectively).

Effect of arsenic level

Different arsenic level significantly influenced dry matter accumulation (g plant^{-1}) of mustard at different days after sowing (Fig 4). Experimental result sowed that maximum dry matter accumulation (3.51, 7.63 and 15.80 g plant^{-1}) at 30, 60 DAS and at harvest, respectively was recorded in control or no arsenic treated pot which was statistically similar with 50 mg As kg^{-1} soil treated pot recorded dry matter accumulation (3.45 g plant^{-1}) at 30 DAS and with increasing arsenic level dry matter accumulation g plant^{-1} gradually decreasing and 100 mg As kg^{-1} soil treated pot recorded the minimum dry matter accumulation (3.16, 6.52 and 14.35 g plant^{-1}) at 30, 60 DAS and harvest, respectively. The differences of dry matter accumulation at different arsenic level was due to reason that increasing arsenic concentration becomes toxic for all plants, causing chlorosis, inhibition of growth by reducing dry matter accumulation and finally death. Chaturvedi (2006) and Gulz *et al.* (2005) found similar result, which supported the present finding and reported that increasing arsenic concentration gradually deceasing dry matter accumulation of the plant.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 4. Effect of arsenic level on dry matter accumulation $plant^{-1}$ of mustard at different DAS (LSD $_{0.05}$ = 0.08, 0.17 and 0.26at 30, 60 DAS and at harvest, respectively).

Combined effect of variety and arsenic level

Combined effect of variety and arsenic level showed significantly influenced dry matter accumulation (g $plant^{-1}$) of mustard at different days after sowing (Table 2). Experimental result showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum dry matter accumulation (4.35, 9.25 and 19.20 g $plant^{-1}$) at 30, 60 DAS and at harvest, respectively which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded dry matter accumulation (4.25, 9.12 and 18.80 g $plant^{-1}$) at different days after sowing. While BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum dry matter accumulation (2.62 and 4.78 g $plant^{-1}$) at 30 and 60 DAS. At harvest, respectively BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum dry matter accumulation (12.00 g $plant^{-1}$), which was statistically similar with BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded dry matter accumulation (12.10 g $plant^{-1}$).

Table 2. Combined effect of variety and arsenic level on dry matter accumulation plant^{-1} of mustard at different DAS

Treatment Combinations	Dry matter accumulation plant^{-1} (g)		
	30 DAS	60 DAS	At harvest
V_1A_0	4.35 a	9.25 a	19.20 a
V_1A_1	4.25 a	9.12 a	18.80 a
V_1A_2	3.81 b	8.55 b	18.14 b
V_2A_0	3.75 bc	6.79 e	13.47 f
V_2A_1	3.61 c	6.39 f	13.00 f
V_2A_2	3.40 d	5.48 h	12.00 g
V_3A_0	3.09 e	5.90 g	13.32 f
V_3A_1	3.10 e	5.95 g	13.38 f
V_3A_2	2.62 g	4.78 i	12.10 g
V_4A_0	2.86 f	8.59 b	17.22 c
V_4A_1	2.84 f	7.90 c	16.12 d
V_4A_2	2.79 f	7.25 d	15.15 e
$LSD_{(0.05)}$	0.16	0.34	0.52
CV(%)	3.83	3.68	2.70

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

V_1 = BARI Sarisha-11

V_2= BARI Sarisha-12

V_3 = BARI Sarisha-14

V_4= BARI Sarisha-15

A_0 = No As (Control)

A_1 = 50 mg As kg^{-1} soil

A_2 = 100 mg As kg^{-1} soil

4.1.3 Crop growth rate (mg cm^{-2} day^{-1})

Effect of variety

Different mustard varieties significantly influenced crop growth rate at different DAS (Fig 5). Experimental result revealed that BARI Sarisha-15 mustard variety cultivation recorded the maximum crop growth rate (0.24 mg cm^{-2} day^{-1}) at 30-60 DAS. During 60 DAS-harvest respectively BARI Sarisha-11 recorded maximum crop growth rate (0.29 mg cm^{-2} day^{-1}). Whereas BARI Sarisha-12 mustard variety cultivation recorded the minimum crop growth rate (0.12 and 0.22 mg cm^{-2} day^{-1}) at 30-60 DAS and 60 DAS-harvest respectively which was statistically similar with BARI Sarisha-14 mustard variety cultivation recorded crop growth rate (0.12 mg cm^{-2} day^{-1}). In this experiment it was observed that high yielding varieties give better response to nutrients utilization and thus, their production rate increases substantially comparatively to others. Toshiyuki *et al.* (2006) also found similar result, which supported the present finding and reported that the genotypic difference in grain yield was most closely related to that in crop growth rate.

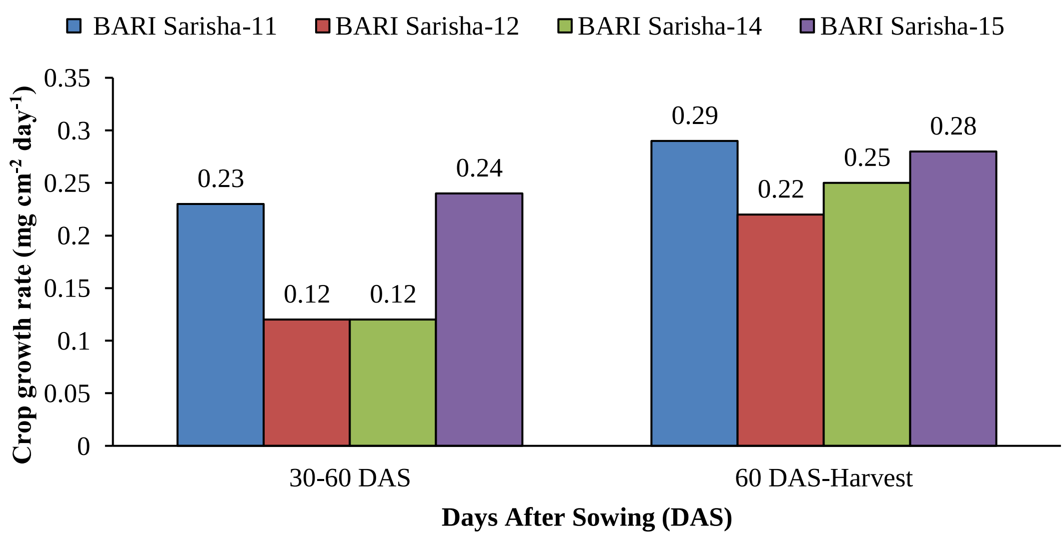
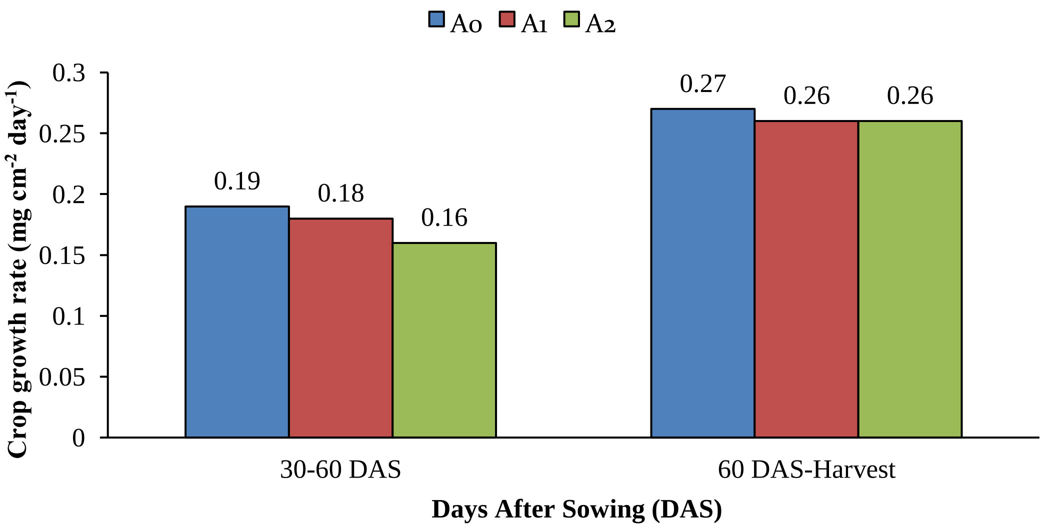


Figure. 5. Effect of variety on crop growth rate of mustard at different DAS (LSD $_{0.05}$ = 0.008 and 0.005 at 30-60 DAS and 60 DAS-harvest, respectively).

Effect of arsenic level

Crop growth is less than potential when the uptake of water, oxygen, or nutrients is less than the demand of the crop**.** Less nutrients occurred due to increasing arsenic concentration in the crop field. Different arsenic levels significantly influenced crop growth rate at different days after sowing (Fig 6). Experimental results showed that no arsenic treated pot recorded the maximum crop growth rate (0.19 and 0.27 mg cm^2 day^{-1}) at 30-60 DAS and 60 DAS-harvest, respectively. While increasing arsenic level gradually decreased crop growth rate and higher arsenic level *viz,* 100 mg As kg^{-1} soil treated pot recorded the minimum crop growth rate (0.16 and 0.26 g cm^{-2} day^{-1}) at 3060 DAS and 60 DAS-harvest, respectively. The differences of crop growth rate at different arsenic levels was due to reason that arsenic is non-essential and generally toxic to plants. The results obtained from the present study was similar to the findings of Garg and Singla (2011) Who reported that arsenic causes toxicity to plant and among different parts of the plant roots are usually the first tissue to be exposed to As, where the metalloid inhibits root extension and proliferation. Upon translocation to the shoot, As can severely inhibit plant growth by slowing or arresting expansion and biomass accumulation result in slow crop growth rate as well as compromising plant reproductive capacity through losses in fertility, yield, and fruit production. Marin *et al.* (1993) also reported that at higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity result in reduced crop growth rate.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 6. Effect of arsenic level on crop growth rate of mustard at different DAS ($LSD_{0.05}$ = 0.007 and 0.004 at 30-60 DAS and 60 DAS-harvest, respectively).

Combined effect of variety and arsenic level

Different mustard varieties along with different arsenic levels significantly influenced crop growth rate at different days after sowing (Table 3). Experimental result showed that among different treatment combination BARI Sarisha-15 mustard variety cultivation along with no arsenic treated pot recorded the maximum crop growth rate (0.27 mg cm^{-2} day^{-1}) at 30-60 DAS. At 60-harvest respectively BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum crop growth rate (0.29 mg cm^{-2} day^{-1}) which was statistically similar with BARI Sarisha-15 mustard variety cultivation along with no arsenic treated pot recorded crop growth rate (0.29 mg cm^{-2} day^{-1}).Whereas BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum crop growth rate (0.09 and 0.22 mg cm^{-2} day^{-1}) at 30-60 DAS and 60 DAS-harvest respectively which was statistically similar with BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded crop growth rate (0.10 mg cm^{-2} day^{-1}) at 30-60 DAS and with BARI Sarisha-12 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded crop growth rate (0.22 mg cm^{-2} day^{-1}) at 60 DAS harvest respectively.

Table 3. Combined effect of variety and arsenic level crop growth rate of mustard at different DAS

Treatment Combinations	Crop growth rate (mg cm^{-2} day^{-1})	
	30-60 DAS	60 DAS-Harvest
V_1A_0	0.23 bc	0.29 a
V_1A_1	0.23 bc	0.29 a
V_1A_2	0.22 cd	0.28 b
V_2A_0	0.14 e	0.23 e
V_2A_1	0.13 e	0.22 f
V_2A_2	0.09 f	0.22 f
V_3A_0	0.13 e	0.25 d
V_3A_1	0.13 e	0.25 d
V_3A_2	0.10 f	0.25 d
V_4A_0	0.27 a	0.29 a
V_4A_1	0.24 b	0.28 b
V_4A_2	0.21 d	0.27 c
$LSD_{(0.05)}$	0.01	0.008
CV(%)	6.43	2.48

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

V_1 = BARI Sarisha-11

V_2= BARI Sarisha-12

V_3 = BARI Sarisha-14

V_4= BARI Sarisha-15

A_0 = No As (Control)

A_1 = 50 mg As kg^{-1} soil

A_2 = 100 mg As kg^{-1} soil

4.2 Yield contributing characters

4.2.1 Number of branches plant^{-1}

Effect of variety

Different variety significantly influenced number of branches plant^{-1} of mustard (Fig 7). Experimental results revealed that BARI Sarisha-12 mustard variety cultivation recorded the maximum number of branches plant^{-1} (5.17) while BARI Sarisha-15 mustard variety cultivation recorded the minimum number of branches plant^{-1} (2.84). The reason of difference in number of branches plant^{-1} is the genetic makeup of the variety, which is primarily influenced by heredity. Helal *et al.* (2016) also found similar results which supported the present finding and reported that that higher number of branches/plant is the result of genetic makeup of the crop and environmental conditions which play a remarkable role towards the final seed yield of the crop. Mamun *et al.* (2014) reported that BARI Sarisha-13 produced the highest number of branches plant^{-1} (6.14) which was 33.77% higher (4.59) than BARI Sarisha15. Sana *et al.* (2003) also reported that, higher number of branches/plant is the result of genetic makeup of the crop and environmental conditions which play a remarkable role towards the final seed yield of the crop.

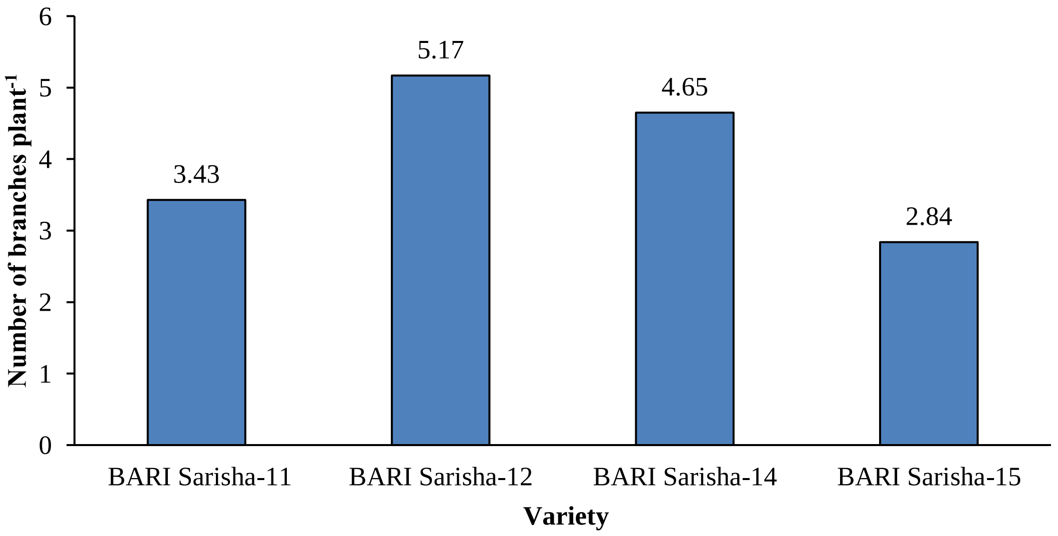
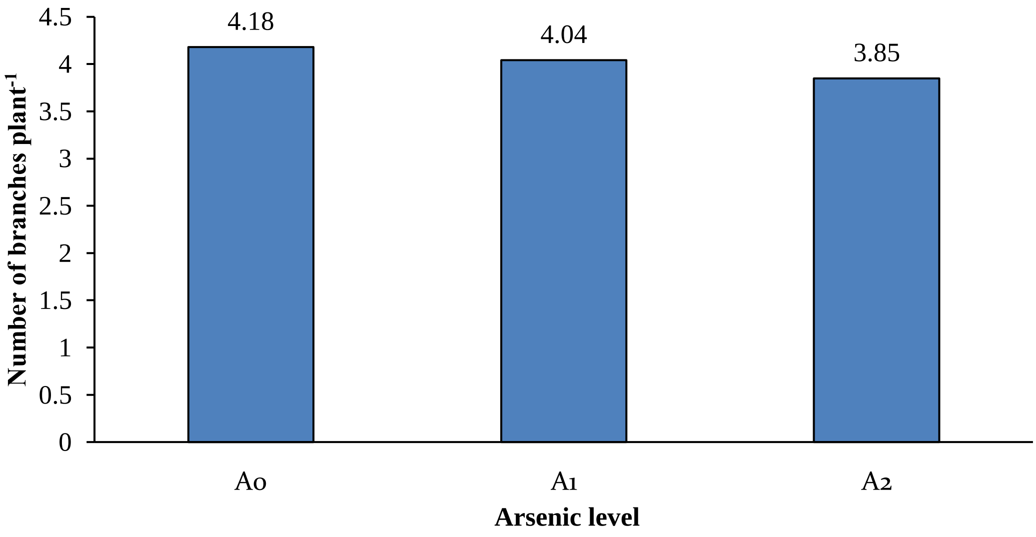


Figure. 7. Effect of variety on number of branches plant^{-1}of mustard (LSD $_{0.05}$ = 0.07).

Effect of arsenic level

Arsenic levels had significant impact on number of branches plant^{-1} of mustard (Figure 8). Experimental results showed that increasing arsenic level gradually decreased number of branches plant^{-1} of mustard. Among different arsenic level no treat the maximum number of branches plant^{-1} (4.18) and 100 mg As kg^{-1} soil recorded the minimum branches plant^{-1} (3.85). Arsenic is not essential element to the plant and higher concentration in the soil result in root damage and malfunction of the plant which ultimately cause reduction of growth, yield or some time death of the plant.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 8. Effect of arsenic level on number of branches $plant^{-1}$ of mustard ($LSD_{0.05}$ = 0.06).

Combined effect of variety and arsenic level

Different varieties along with different arsenic levels had significant impact on number of branches $plant^{-1}$ of mustard (Table 4). Experimental results showed that BARI Sarisha-12 mustard variety cultivation along with no arsenic treated pot recorded the maximum number of branches $plant^{-1}$ (5.24) which was statistically similar with BARI Sarisha-12 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded branches $plant^{-1}$ (5.18) while BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum number of branches $plant^{-1}$ (2.58).

4.2.2 Number of siliquaee $plant^{-1}$

Effect of variety

Different variety significantly influenced number of siliquaee $plant^{-1}$ of mustard (Fig 9). Experimental results revealed that BARI Sarisha-11 mustard variety cultivation recorded the maximum number of siliquae $plant^{-1}$ (86.35) while BARI Sarisha-12 mustard variety cultivation recorded the minimum number of siliquaee $plant^{-1}$ (57.87), which was statistically similar with BARI Sarisha-14 variety cultivation recorded number of siliquaee $plant^{-1}$ (58.31). Different mustard varieties have different number of siliquaee $plant^{-1}$ was due to the genetic makeup of the variety and higher number of siliquaee plant^{-1} is obtained from high yielding varieties comparable to low yielding mustard varieties. The result obtained from the present study was similar with the findings of Alam *et al.* (2014) who reported that varieties of mustard significantly influence on yield and yield attributes and among different varieties maximum number of siliquaee/plant (108 and 90) was recorded in BJDH -05 which differed significantly from other varieties. Mamun *et al.* (2014) also found similar result with the present study and reported that the number of siliquaee plant^{-1} of mustard was significantly affected by different varieties.

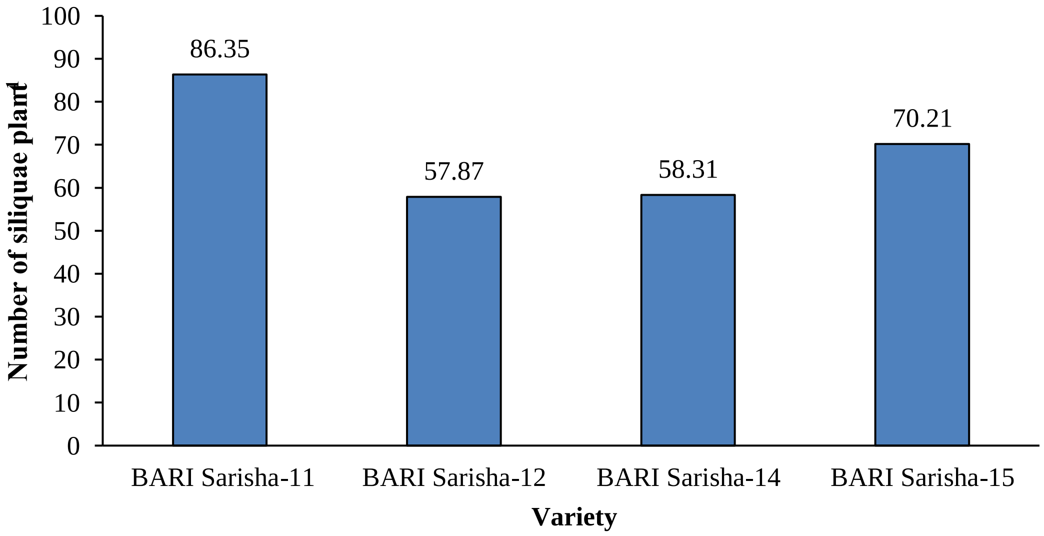
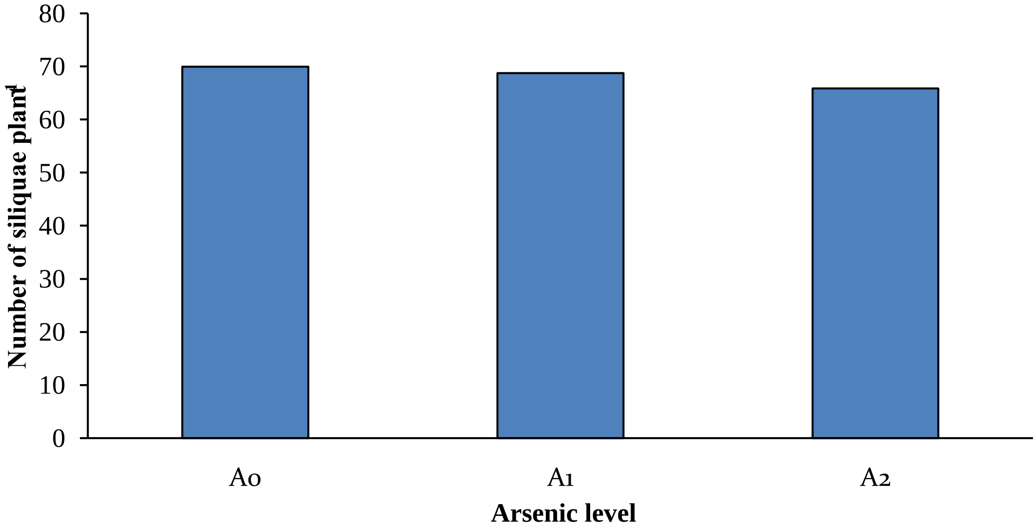


Figure. 9. Effect of variety on number of siliquaee plant^{-1} of mustard (LSD $_{0.05}$ = 1.68).

Effect of arsenic level

Number of siliquaee plant^{-1} of mustard was significantly influenced by different arsenic levels (Figure 10). Experimental results showed that no arsenic treated pot recorded the maximum number of siliquaee plant^{-1} (69.97), which was statistically similar with 50 mg As kg^{-1} soil treated pot recorded siliquaee plant^{-1} (68.75). While 100 mg As kg^{-1} soil treated pot recorded the minimum number of siliquaee plant^{-1} (65.84). The differences of siliquaee plant^{-1} at difefrent arsenic level was due to reason that higher arsenic accumulated in the plant tissue stimulates peroxidase synthesis during the early phases of plant development, long before the appearance of visible changes causes degradation of membrane lipids resulting in cell damage and formation of many toxic products impact on plant growth and ultimately reduced yield characters. Similar result also found by Imran *et al.* (2013) who reported that at sufficiently higher concentrations, As hampers critical biochemical and metabolic processes which can result in plant death or reduced productivity.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 10. Effect of arsenic level on number of siliquaee plant^{-1} of mustard (LSD $_{0.05}$ = 1.45).

Combined effect of variety and arsenic level

Different varieties along with different arsenic level significantly impact on number of siliquaee plant^{-1} of mustard. Experimental results showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum number of siliquaee plant^{-1} (89.02) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded siliquaee plant^{-1} (86.58) while BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum number of siliquaee plant^{-1} (55.85) which was statistically similar with BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded siliquaee plant^{-1} (57.19) and with BARI Sarisha-14 mustard variety cultivation along with no arsenic treated pot recorded siliquaee plant^{-1} (57.97).

4.2.3 Number of seeds siliquaee^{-1}

Effect of variety

Mustard varieties significantly influenced number of seeds siliquae^{-1} (Figure 11). Experimental results revealed that BARI Sarisha-14 mustard variety cultivation recorded the maximum number of seeds siliquae^{-1} (20.29) while BARI Sarisha-11 mustard variety cultivation recorded the minimum number of seeds siliquae^{-1} (14.43). The differences of number of seeds siliquae^{-1} was due to the genetic makeup of the varieties. Similar result observed by Helal *et al.* (2016) and reported that, variations in terms of number of seeds/siliquae among all the varieties due to reason of difference in the genetic makeup of the variety, which is primarily influenced by heredity.

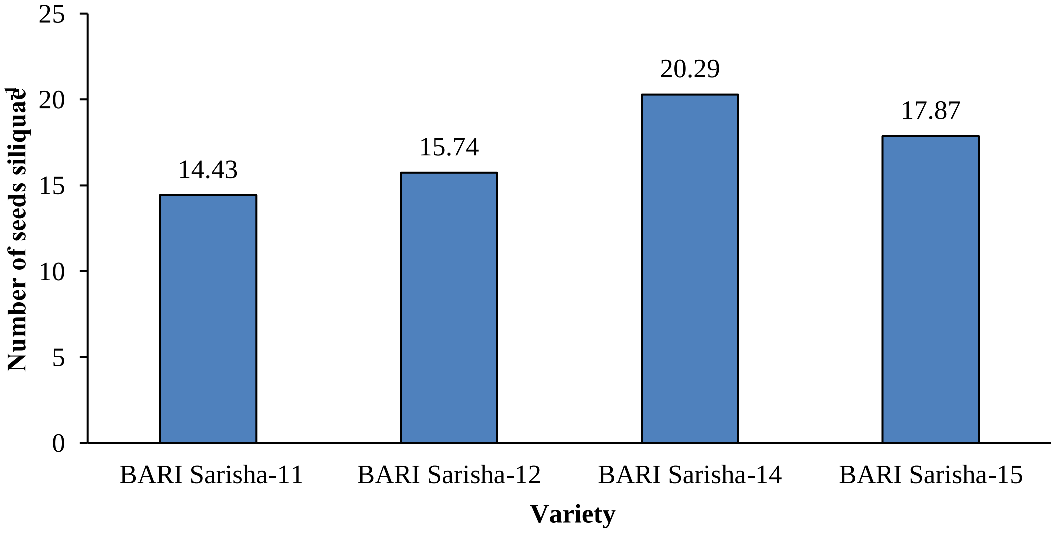
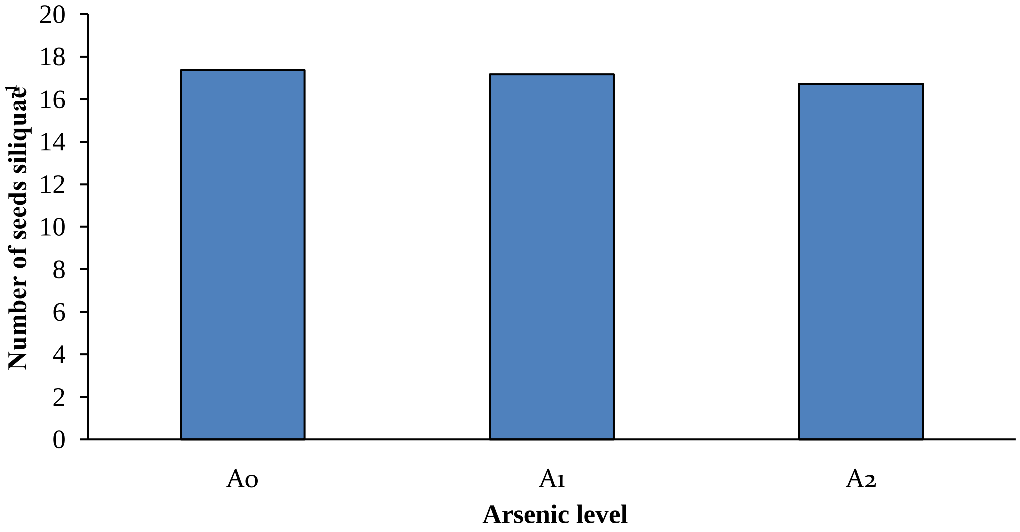


Figure. 11. Effect of variety on number of seed siliquae^{-1} of mustard (LSD $_{0.05}$ = 0.25).

Effect of arsenic level

Number of seeds siliquae^{-1} of mustard significantly influenced due to the effect of different arsenic level (Fig 12). Experimental results showed that no arsenic treated pot recorded the maximum number of seeds siliquae^{-1} (17.37) which was statistically similar with 50 mg As kg^{-1} soil treated pot recorded seeds siliquae^{-1} (17.17). While 100 mg As kg^{-1} soil treated pot recorded the minimum number of seeds siliquae^{-1} (16.72). The result obtained from the present study was similar with the findings of Niazi *et al.* (2017) who reported that reduction in yield attributes (siliquae plant^{-1}, Seed siliquae, 1000 seeds weight) was higher due to increasing arsenic concentration in the soil or irrigation water. Jahan *et al.* (2003) who reported that, when plants were exposed to excess arsenic either in soil or in solution culture, they exhibited toxicity symptoms such as: inhibition of seed germination, decrease in plant height, lower fruit and grain yield and sometimes, leads to death.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 12. Effect of arsenic level on number of seed siliquae^{-1} of mustard

(LSD $_{0.05}$ = 0.21).

Combined effect of variety and arsenic level

Different varieties along with different arsenic level significantly impact on number of seeds siliquae^{-1} of mustard (Table 4). Experimental results showed that BARI Sarisha14 mustard variety cultivation along with no arsenic treated pot recorded the maximum number of siliquae plant^{-1} (20.36) which was statistically similar with BARI Sarisha-14 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded seeds siliquae^{-1} (20.30) and with BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded seeds siliquae^{-1} (20.22) while BARI Sarisha-11 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum number of seeds siliquae^{-1} (13.74).

4.2.4 Weight of 1000 seeds (g)

Effect of variety

Different varieties significantly influenced 1000 seeds weight of mustard. (Figure 13). Experimental results revealed that BARI Sarisha-11 mustard variety cultivation recorded the maximum 1000 seeds weight (3.53 g) while BARI Sarisha-12 mustard variety cultivation recorded the minimum 1000 seeds weight (2.90 g). The differences of the 1000 seeds weight among different mustard varieties may be attributes to the varietal performance and genetic makeup of the varieties. Similar result observed by Mamun *et al.* (2014) who reported that among different varieties BARI Sarisha-13 had the highest 1000 seeds weight (4.00 g) whereas the lowest (2.82 g) - in SAU Sarisha-3. Mondal and Wahab (2001) described that, weight of 1000 seeds varied from variety to variety and species to species.

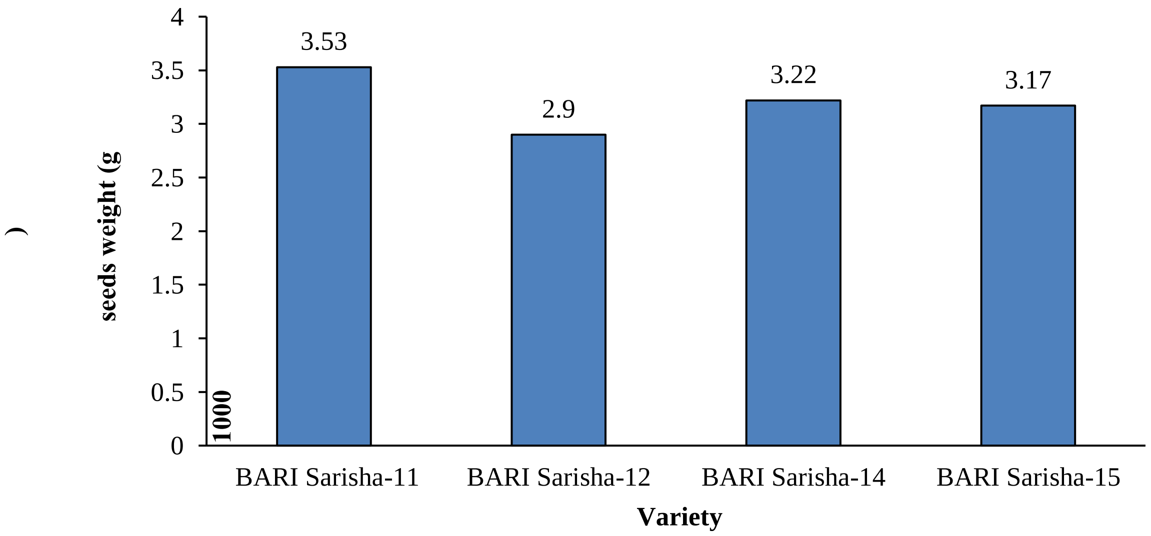
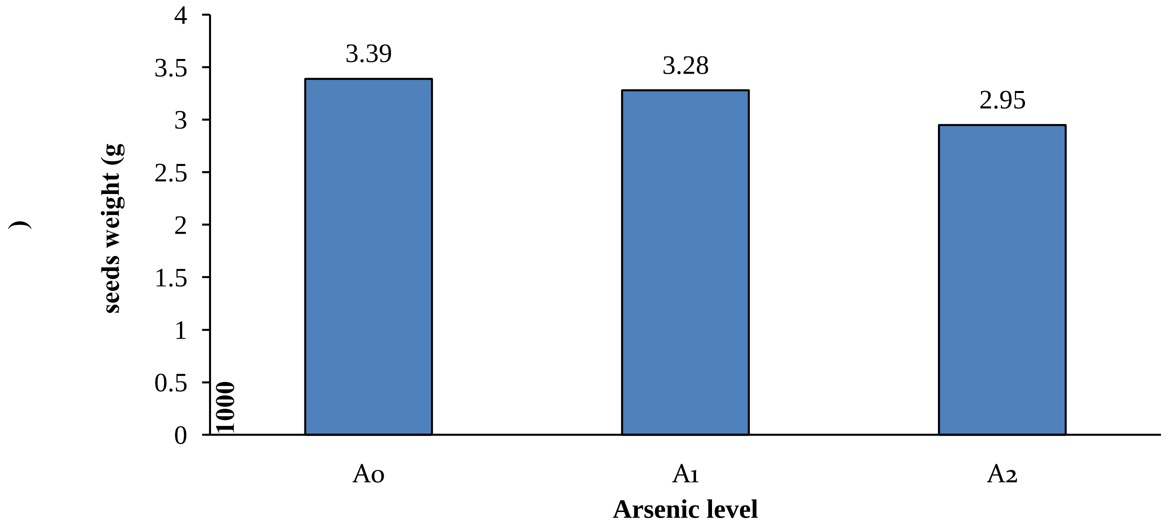


Figure. 13. Effect of variety on 1000 seeds weight of mustard (LSD $_{0.05}$ = 0.14).

Effect of arsenic level

Different arsenic levels significantly influenced on 1000 seeds weight of mustard (Fig 14). Experimental results showed that no arsenic treated pot recorded the maximum 1000 seeds weight (3.39 g) which was statistically similar with 50 mg As kg^{1} soil treated pot recorded 1000 seeds weight (3.28 g). While 100 mg As kg^{-1} soil treated pot recorded the minimum 1000 seeds weight (2.95 g). Arsenic is non-essential and toxic to plant and with increasing arsenic concentration disturbed nutrient uptake and transport of water which influences the reduction of plant yield. Niazi *et al.* (2017) reported that reduction in yield attributes (siliquae plant^{-1}, Seed siliquae, 1000 seeds weight) was higher due to increasing arsenic concentration in the soil or irrigation water. Shahid *et al.* (2015) also found similar result which supported the present finding and reported that arsenic availability in soil can disturb normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity. Anjum *et al.* (2011) also reported that high As levels cause negative impact on plant growth, yield and yield contributing attributes. Kang *et al.* (1996) reported that increasing the level of arsenic decreased plant height, dry weight of above ground parts and 1000 seeds weight.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure.14. Effect of arsenic level on 1000 seeds weight of mustard ($LSD_{0.05}$= 0.13).

Combined effect of variety and arsenic level

Combined effect of variety and arsenic level significantly impact on 1000 seeds weight of mustard. Experimental results showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum 1000 seeds weight (3.76 g) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded 1000 seeds weight (3.74 g). While BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum 1000 seeds weight (2.80 g) which was statistically similar with BARI Sarisha-12 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded 1000 seeds weight (288 g); with BARI Sarisha-12 mustard variety cultivation along with no arsenic treated pot recorded 1000 seeds weight (3.04 g). and with BARI Sarisha-11 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded 1000 seeds weight (3.07 g).

Table 4. Combined effect of variety and arsenic level on number of branches plant^{-1}, siliquae plant^{-1}, seeds siliquae^{-1} and 1000 seeds weight of mustard

Treatment Combinations	Number of branches plant^{-1}	Number of siliquae plant^{-1}	Number of seeds siliquae^{-1}	1000 seeds weight (g)
V_1A_0	3.60 f	89.02 a	14.76 f	3.76 a
V_1A_1	3.44 g	86.58 a	14.78 f	3.74 a
V_1A_2	3.24 h	83.46 b	13.74 g	3.07 c-f
V_2A_0	5.24 a	58.94 f	16.26 d	3.04 d-f
V_2A_1	5.18 ab	58.83 f	15.66 e	2.88 ef
V_2A_2	5.08 b	55.85 g	15.30 e	2.80 f
V_3A_0	4.82 c	57.96 fg	20.36 a	3.33 bc
V_3A_1	4.64 d	59.79 f	20.30 a	3.23 b-d
V_3A_2	4.50 e	57.19 fg	20.22 a	3.11 c-e
V_4A_0	3.04 i	73.97 c	18.08 b	3.45 b
V_4A_1	2.90 j	69.80 d	17.92 bc	3.27 b-d
V_4A_2	2.58 k	66.87 e	17.60 c	2.80 f
$LSD_{(0.05)}$	0.11	2.91	0.43	0.27
CV(%)	2.24	3.35	1.96	6.56

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

V_1 = BARI Sarisha-11

V_2= BARI Sarisha-12

V_3 = BARI Sarisha-14

V_4= BARI Sarisha-15

A_0 = No As (Control)

A_1 = 50 mg As kg^{-1} soil

A_2 = 100 mg As kg^{-1} soil

4.3 Yield characters

4.3.1 Seed yield plant^{-1} (g)

Effect of variety

Mustard varieties significantly influenced seed yield plant^{-1} (Fig 15). Experimental results revealed that BARI Sarisha-11 mustard variety cultivation recorded the maximum seed yield plant^{-1} (3.55 g) while BARI Sarisha-12 mustard variety cultivation recorded the minimum seed yield plant^{-1} (1.89). Different mustard variety have individual genetic makeup which influenced the growth and yield among different varieties. Biswas *et al.* (2019) also found similar result which supported the present finding and reported that seed yield differed among different varieties of mustard. Junjariya (2014) reported that seed yield of Indian mustard was influenced significantly with different cultivars. Zaman *et al.* (1991) who reported that seed yield of mustards were varied with different varieties.

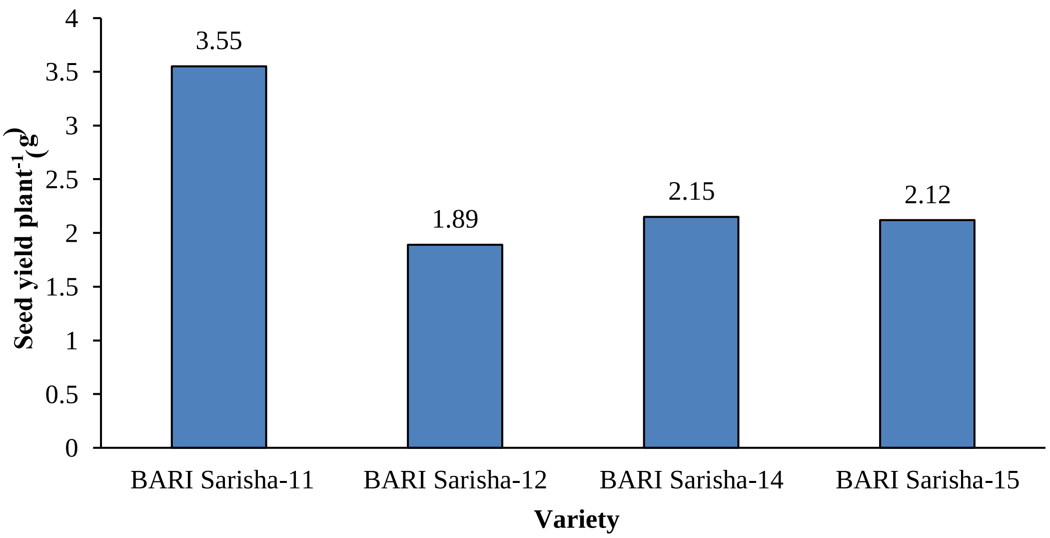
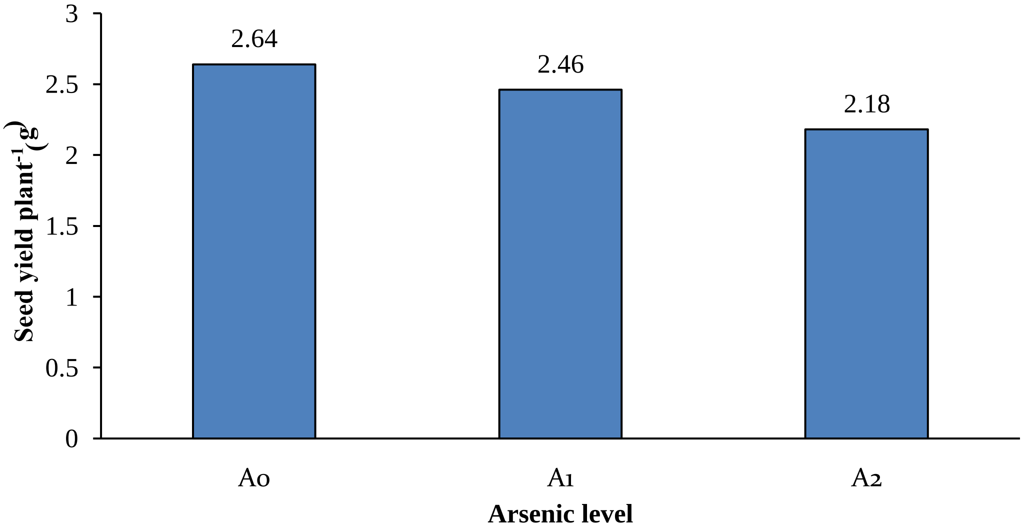


Figure. 15. Effect of variety on seed yield plant^{-1} of mustard (LSD $_{0.05}$ = 0.14).

Effect of arsenic level

Seed yield plant^{-1} of mustard was differed significantly due to the effect of different arsenic levels (Fig 16). Experimental results revealed that no arsenic treated pot recorded the maximum seed yield plant^{-1} (2.64 g) while 100 mg As kg^{-1} soil treated pot recorded the minimum seed yield plant^{-1} (2.18 g). The reduction of seed yield in increasing arsenic concentration due to reason that arsenic inhibit the rate of photosynthesis in plants which ultimately impact on plant growth, yield and yield contributing attributes. Talukdar (2013) also found similar result, which supported the present finding and reported that existence of

As above the threshold limit in soil or in irrigation water interferes with metabolism of crop plants, consequently leading to wilting, curling, necrosis of leaf blades, suppression in the number of leaves and leaf area thereby reducing photosynthesis and biomass accumulation, losses in mineral contents, reduced root elongation, proliferation and nodulation, stunted growth and poor yield.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 16. Effect of arsenic level on seed yield plant^{-1} of mustard (L000SD $_{0.05}$ = 0.12).

Combined effect of variety and arsenic level

Combined effect of variety and arsenic level had significant influenced seed yield plant^{1} of mustard (Table 5). Experimental results showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum seed yield plant^{-1} (3.82 g) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded seed yield plant^{-1} (3.76 g). While BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum seed yield plant^{-1} (1.76 g) which was statistically similar with BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded seed yield plant^{-1} (1.80 g) and with BARI Sarisha-12 mustard variety cultivation along with 50 mg As kg^{-1} soil arsenic treated pot recorded seed yield plant^{-1} (1.88 g).

4.3.2 Stover yield plant^{-1} (g)

Effect of variety

Different mustard varieties significantly influenced stover yield plant^{-1} (Figure 17). Experimental results revealed that BARI Sarisha-11 mustard variety cultivation recorded the maximum stover yield plant^{-1} (15.13 g) while BARI Sarisha-14 mustard variety cultivation recorded the minimum stover yield plant^{-1} (10.78), which was statistically similar with BARI Sarisha-12 mustard variety cultivation recorded stover yield plant^{-1} (10.94). Sultana *et al.* (2009) also found similar result with present study and reported that stover yield of mustards were varied with different varieties.

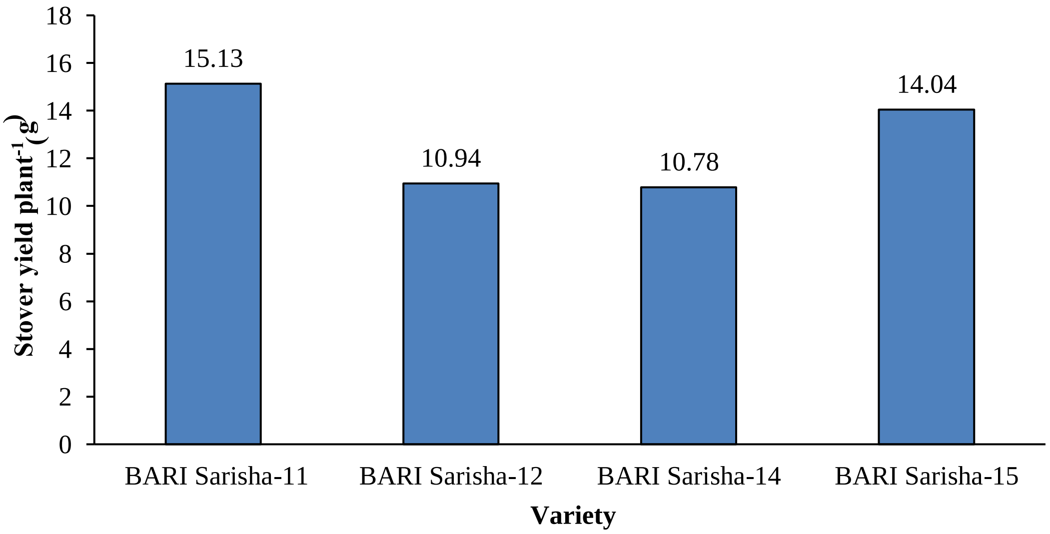
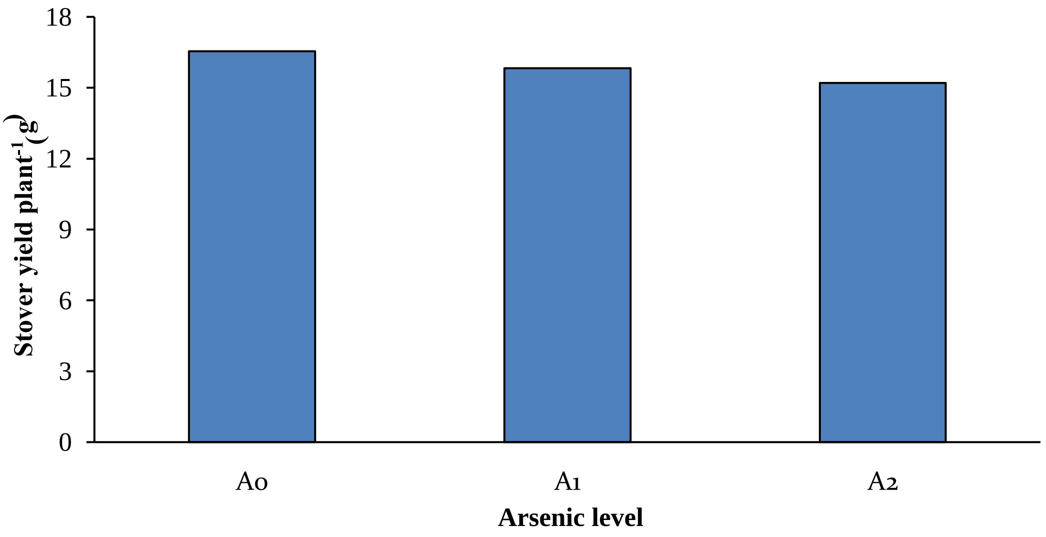


Figure. 17. Effect of variety on stover yield plant^{-1} of mustard (LSD $_{0.05}$ = 0.33).

Effect of arsenic level

Stover yield plant^{-1} of mustard differ significantly due to the effect of different arsenic levels (Fig 18). Experimental results revealed that no arsenic treated pot recorded the maximum stover yield plant^{-1} (13.4 g) which was statistically similar with 50 mg As kg^{-1} soil treated pot recorded stover yield plant^{-1} (12.86 g) while 100 mg As kg^{-1} soil treated pot recorded the minimum stover yield plant^{-1} (12.17 g). Arsenic in toxic to plant and its availability in soil can disturb normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity. The result obtained from the present study was similar with the findings of Delowar *et al.* (2005) who reported that increasing arsenic concentration gradually effects on growth and yield of plant. Abedin *et al.* (2002b) also reported that increasing in the content of arsenic in irrigation water led to increasing arsenic content in plant and consequent decrease in yield.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 18. Effect of arsenic level on stover yield plant^{-1} of mustard (LSD $_{0.05}$ = 0.28).

Combined effect of variety and arsenic level

Different varieties along with different arsenic level significantly influenced stover yield plant^{-1} of mustard (Table 5). Experimental results showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum stover yield plant^{-1} (15.28 g), which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded stover yield plant^{-1} (15.07 g); with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded stover yield plant^{-1} (15.04 g) and with BARI Sarisha-15 mustard variety cultivation along with no arsenic treated pot recorded stover yield plant^{-1} (14.72 g). While BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum stover yield plant^{-1} (10.02 g), which was statistically similar with BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded stover yield plant^{-1} (10.24 g).

4.3.3 Harvest index (%)

Effect of variety

Mustard varieties significantly influenced harvest index (Fig 19). Experimental results revealed that BARI Sarisha-11 mustard variety cultivation recorded the maximum harvest index (18.98 %) while BARI Sarisha-15 mustard variety cultivation recorded the minimum harvest index (13.06 %). The harvest index differed significantly among the varieties due to its genetic variability. Thakur *et al.* (2021) also found similar result, which supported the present finding and reported that the different varieties have different yield potential, which is the reason for yield variation among different varieties which ultimately impact on harvest index. Uddin *et al.* (2011) reported that the harvest index differed significantly among the varieties due to its genetic variability. Shah *et al.* (1991) also reported that variety had a great influence on harvest index.

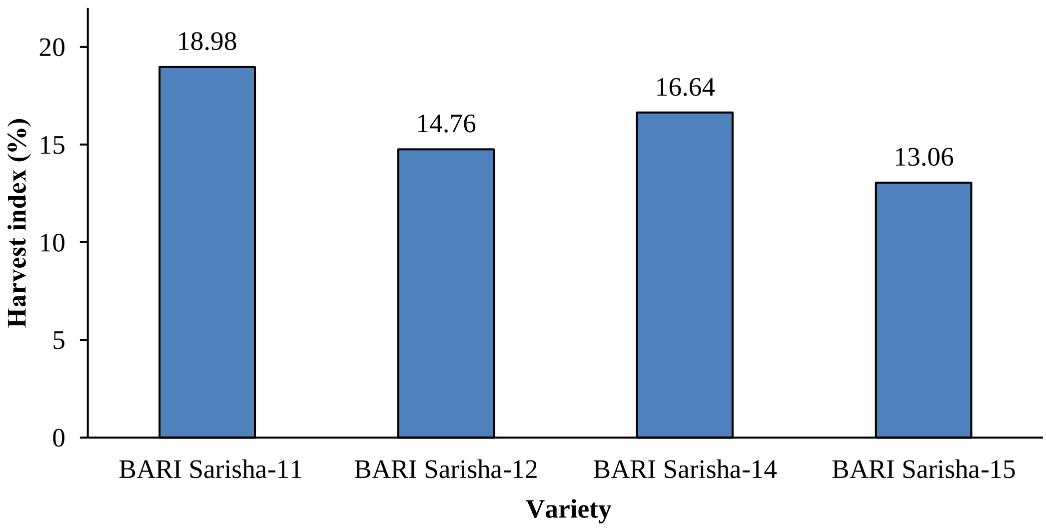
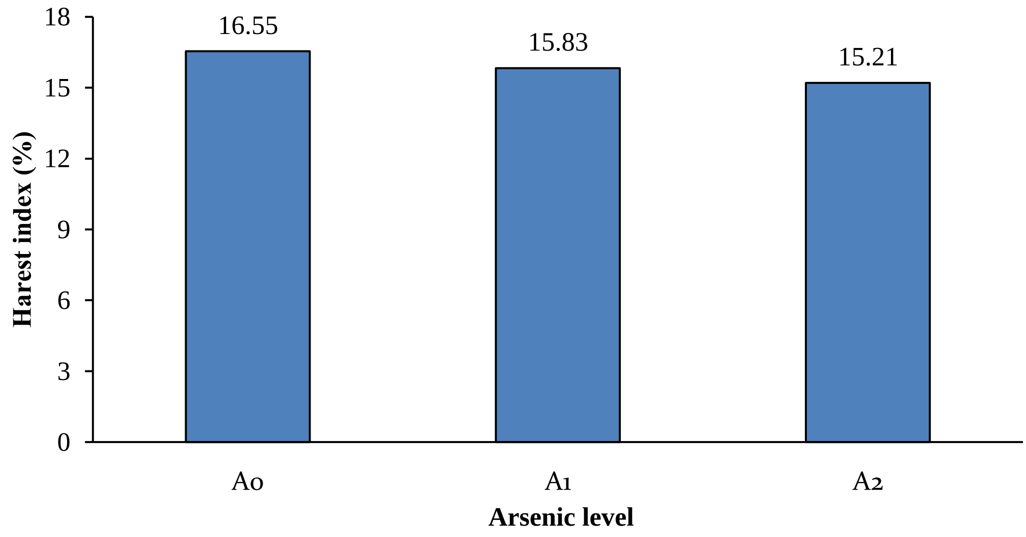


Figure. 19. Effect of variety on harvest index of mustard (LSD $_{0.05}$ = 0.80).

Effect of arsenic level

Harvest index of mustard differ significantly due to the effect of different arsenic levels. Experimental results revealed that no arsenic treated pot recorded the maximum harvest index (16.55 %) while 100 mg As kg^{-1} soil treated pot recorded the minimum harvest index (15.21) which was statistically similar with 50 mg As kg^{-1} soil treated pot recorded harvest index (15.83). The differences of harvest index at different arsenic level due to reason that increasing the level of arsenic decreased yield contributing characters of plant which ultimately impact on harvest index.



Here, A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 20. Effect of arsenic level on harvest index of mustard (LSD $_{0.05}$ = 0.70).

Combined effect of variety and arsenic level

Different varieties along with different arsenic level significantly influenced harvest index of mustard (Table 5). Experimental results showed that BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum harvest index (20.00 %) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded harvest index (20.00 %). While BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum harvest index (11.88 %) which was statistically similar with BARI Sarisha-15 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot recorded harvest index (12.78 %).

Table 5. Combined effect of variety and arsenic level on seed yield plant^{-1}, stover yield plant^{-1}and harvest index of mustard

Treatment Combinations	Seed yield plant^{-1} (g)	Stover yield plant^{-1} (g)	Harvest index (%)
V_1A_0	3.82 a	15.28 a	20.00 a
V_1A_1	3.76 a	15.04 a	20.00 a
V_1A_2	3.07 b	15.07 a	16.92 b
V_2A_0	2.02 d-f	11.45 d	14.99 cd
V_2A_1	1.88 e-g	11.12 d	14.46 d
V_2A_2	1.76 g	10.24 e	14.83 cd
V_3A_0	2.22 d	11.10 d	16.67 b
V_3A_1	2.15 d	11.23 d	16.07 bc
V_3A_2	2.08 de	10.02 e	17.20 b
V_4A_0	2.50 c	14.72 a	14.52 d
V_4A_1	2.06 de	14.06 b	12.78 e
V_4A_2	1.80 fg	13.35 c	11.88 e
$LSD_{(0.05)}$	0.24	0.57	1.39
CV(%)	7.74	3.49	6.89

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Notes *viz:*

V_1 = BARI Sarisha-11

V_2= BARI Sarisha-12

V_3 = BARI Sarisha-14

V_4= BARI Sarisha-15

A_0 = No As (Control)

A_1 = 50 mg As kg^{-1} soil

A_2 = 100 mg As kg^{-1} soil

4.4 Relationship between arsenic level and seed yield of mustard varieties

A negative linear relationship was observed between different arsenic level and seed yield plant^{-1} of mustard varieties. It was evident from the Fig 21 that the regression equation y = -0.004x + 2.656 gave a good fit to the data, and the co-efficient of determination (R^2 = 0.984), indicating that 98.4 % of the variation in the data is determined by the regression line. From this regression analysis, it was evident that there was a strongly negative relationship between different arsenic level and seed yield plant^{-1} of mustard varieties. Seed yield plant^{-1} of mustard varieties dependent on various yield contributing characters such as number of siliquae plant^{-1},1000 seeds weight etc. In this present experiment the yield contributing character were significantly varied due to the increasing of arsenic level which ultimately influenced on seed yield plant^{-1} and impact on the relationship between different arsenic level and seed yield plant^{-1} of mustard varieties.

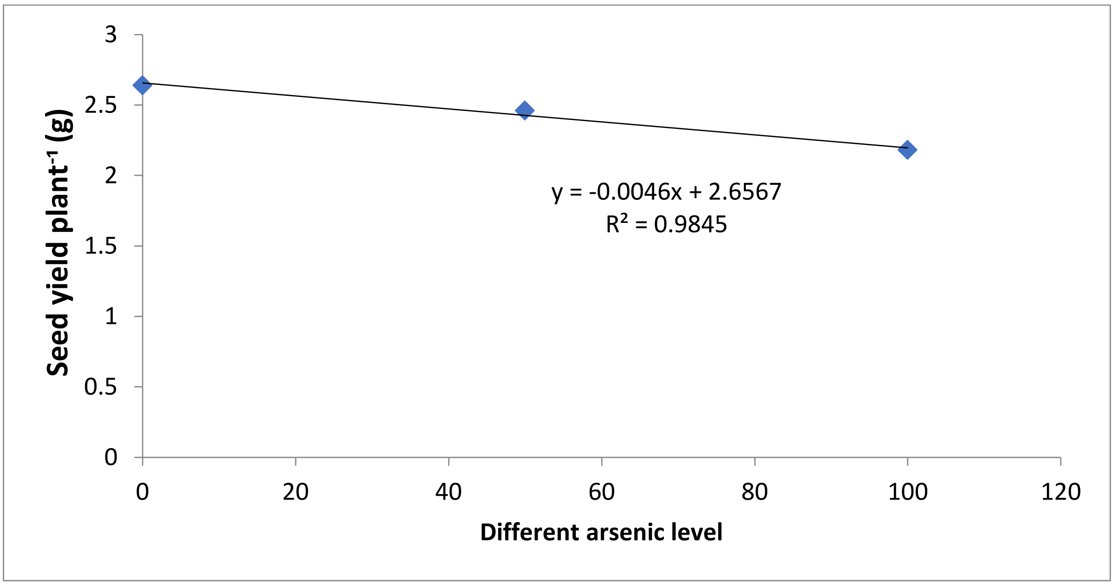
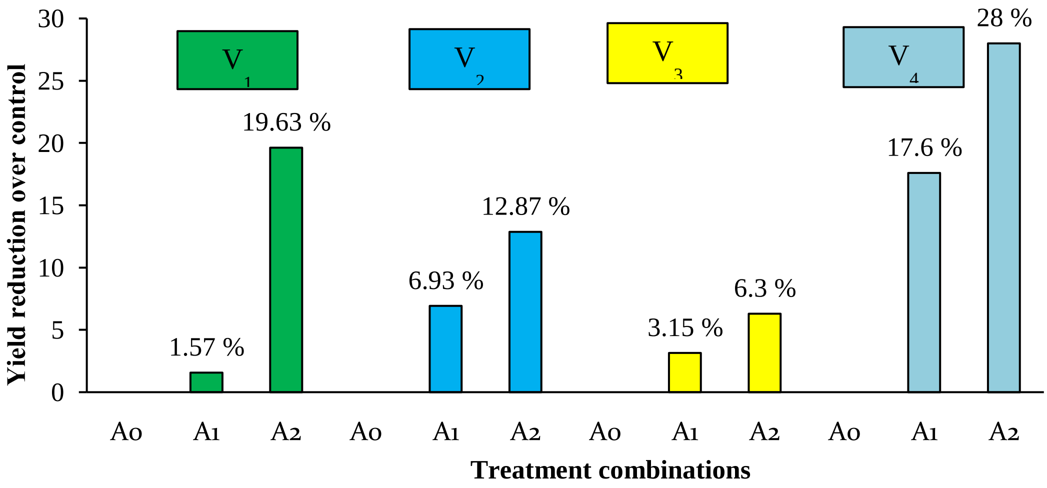


Figure. 21. Functional relationship between different arsenic level and seed yield plant^{-1} of mustard

4.5. Percent yield reduction of mustard varieties at different arsenic levels over control treatment

From the experiment, results revealed that different arsenic levels decreasing yield of mustard varieties and its reduction of yield depends on its varietal performance. From the Figure 22 it was notices that among different mustard varieties, BARI Sarisha-11 mustard variety cultivation alone with 50 mg As kg^{-1} soil treated pot recorded the minimum yield reduction percentage (1.57 %) over control treatment comparable to other varieties, While cultivation of mustard varieties along with 100 mg As kg^{-1} soil level, the minimum yield reduction (6.3 %) was recorded in BARI Sarisha-14 mustard variety comparable to others varieties. Among different varieties, cultivation of BARI Sarisha-11 alone with different arsenic level gave higher seed yield ranges between (3.82-3.07 g) from 0-100 ppm arsenic level and perform well in case of seed production comparable to other varieties.



V_1 = BARI Sarisha-11, V_2= BARI Sarisha-12, V_3 = BARI Sarisha-14, V_4= BARI Sarisha-15, A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil.

Figure. 22. Percent yield reduction of mustard varieties at different arsenic levels over control treatment

4.6 Correlation of seed yield plant^{-1} with siliquae plant^{-1} and 1000 seeds weight of mustard varieties along with different arsenic level

From the Figure 23 and 24 it was noticed that seed yield plant^{-1} was positively correlated with siliquae plant^{-1} (R^2=0.825) and 1000-seeds weight (R^2=0.691). From the correlation study, it appears that seed yield plant^{-1} increase with increasing siliquae plant^{1} and 1000-seeds weight. In this experiment maximum seed yield plant^{-1} was recorded under BARI Sarisha-11 mustard variety cultivation along with control arsenic treatment(no arsenic) which was statistically similar with BARI Sarisha-11 mustard variety cultivation along with 50 mg As kg^{-1} soil treated pot due to reason that BARI Sarisha-11 mustard variety can produce higher number of siliquae plant^{-1}, increased 1000-seeds weight and also withstand some degree of arsenic stress condition in comparable to others varieties in different level of stress condition.

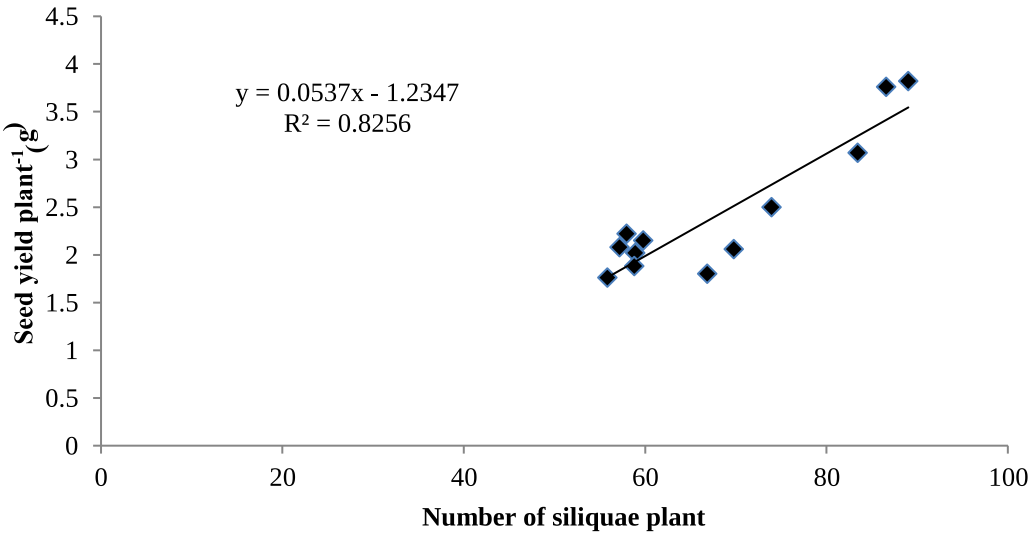


Figure. 23. Functional relationship between siliquae plant^{-1} and seed yield plant^{-1} of mustard.

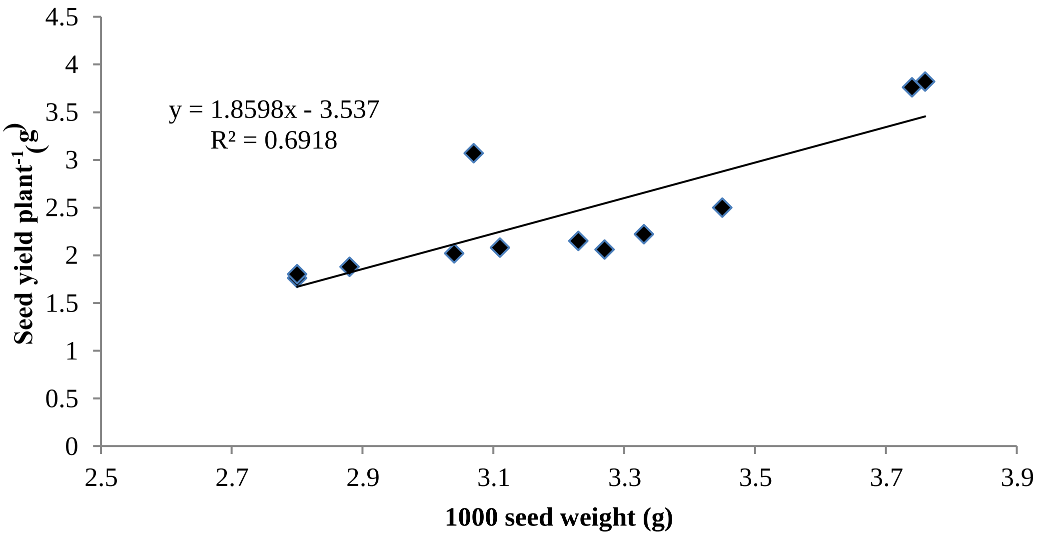


Figure. 24. Functional relationship between 1000 seeds weight and seed yield plant^{-1} of mustard.

CHAPTER V

SUMMARY AND CONCLUSION

A pot experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during November-2019 to February-2020, to investigate the effect of arsenic stress tolerance ability of four mustard varieties. The experiment consisted of two factors, and followed Randomized complete block design (RCBD) with five replications. Factor A: Mustard varieties (4) *viz*; V_1 = BARI Sarisha-11, V_2= BARI Sarisha-12, V_3 = BARI Sarisha-14 and V_4= BARI Sarisha-15 and Factor B: Different arsenic level (3) *viz;* A_0 = No As (Control), A_1 = 50 mg As kg^{-1} soil and A_2 = 100 mg As kg^{-1} soil. Data on different parameters were collected for assessing results for this experiment and showed significant variation in respect of growth, yield and yield contributing characteristics of mustard due to the effect of different mustard varieties, arsenic level and their combinations.

In case of mustard varieties, BARI Sarisha-11 mustard variety recorded the maximum plant height (22.88, 51.99, and 86.35 cm) at 30, 60 DAS and at harvest respectively, dry matter accumulation plant^{-1} (4.14, 8.97 and 18.71 g) at 30, 60 DAS and at harvest respectively. BARI Sarisha-15 mustard variety cultivation recorded the maximum crop growth rate (0.24 mg cm^{-2} day^{-1}) at 30-60 DAS. During 60 DAS-harvest respectively BARI Sarisha-11 recorded maximum crop growth rate (0.29 mg cm^{-2} day^{-1}). BARI Sarisha-12 mustard variety cultivation recorded the maximum number of branches plant^{-1} (5.17). BARI Sarisha-11 mustard variety cultivation recorded the maximum number of siliquae plant^{-1} (86.35). BARI Sarisha-14 mustard variety cultivation recorded the maximum number of seeds siliquae^{-1} (20.29), BARI Sarisha-11 mustard variety cultivation recorded the maximum 1000 seeds weight (3.53 g), seed yield plant^{-1} (3.55 g), stover yield plant^{-1} (15.13 g), harvest index (18.98 %). Whereas BARI Sarisha-15 mustard variety recorded the minimum plant height (16.67) at 30 DAS. At 60 DAS and at harvest respectively BARI Sarisha-14 mustard variety recorded minimum plant height (35.93 and 58.31 cm). BARI Sarisha-15 mustard variety recorded the minimum dry matter accumulation (2.83 g plant^{-1}) at 30 DAS. At 60 DAS cultivation of BARI Sarisha-14 mustard variety recorded the minimum dry matter accumulation (5.54 g plant^{-1}). At harvest respectively cultivation of BARI Sarisha-12 mustard variety recorded the minimum dry matter accumulation (12.82 g plant^{-1}). BARI Sarisha-12 mustard variety cultivation recorded the minimum crop growth rate (0.12 and 0.22 mg cm^{-2} day^{-1}) at 30-60 DAS and 60 DAS-harvest respectively. BARI Sarisha-15 mustard variety cultivation recorded the minimum number of branches plant^{-1} (2.84). BARI Sarisha-12 mustard variety cultivation recorded the minimum number of siliquae plant^{1} (57.87). BARI Sarisha-11 mustard variety cultivation recorded the minimum number of seeds siliquae^{-1} (14.43). BARI Sarisha-12 mustard variety cultivation recorded the minimum 1000 seeds weight (2.90), seed yield plant^{-1} (1.89) and stover yield plant^{-1} (10.94). BARI Sarisha-15 mustard variety cultivation recorded the minimum harvest index (13.06 %).

In case of different arsenic level, no arsenic treated pot recorded the maximum plant height (20.06, 44.68 and 69.97 cm) at 30, 60 DAS and at harvest respectively, dry matter accumulation plant^{-1} (3.51, 7.63 and 15.80 g) at 30, 60 DAS and at harvest respectively, crop growth rate (0.19 and 0.27 mg cm^{-2} day^{-1}) at 30-60 DAS and 60 DASharvest respectively, number of branches plant^{-1} (4.18), number of siliquae plant^{-1} (69.97), number of seeds siliquae^{-1} (17.37), 1000 seeds weight (3.39 g), seed yield plant^{1} (2.64 g), stover yield plant^{-1} (13.4 g), harvest index (16.55 %). Whereas 100 mg As kg^{-1} soil treated pot recorded the minimum plant height (18.63, 39.93 and 65.84) at 30, 60 DAS and at harvest respectively, dry matter accumulation (3.16, 6.52 and 14.35 g plant^{-1}) at 30, 60 DAS and at harvest respectively, crop growth rate (0.16 and 0.26 g cm^{-2} day^{-1}) at 30-60 DAS and 60 DAS-harvest respectively, branches plant^{-1} (3.85), number of siliquae plant^{-1} (65.84), number of seeds siliquae^{-1} (16.72), 1000 seeds weight (2.95 g), seed yield plant^{-1} (2.18 g), stover yield plant^{-1} (12.17 g) and harvest index (15.21).

In case of combination effect, cultivation of BARI Sarisha-11 mustard variety along with no arsenic treated pot recorded the maximum plant height (24.26 cm) at 30 DAS. At 60 DAS cultivation of BARI Sarisha-11 mustard variety along with 50 mg As kg^{-1} soil treated pot recorded the maximum plant height (54.06 cm) and at harvest respectively BARI Sarisha-11 mustard variety along with no arsenic treated pot recorded the maximum plant height (89.02 cm). BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum dry matter accumulation (4.35, 9.25 and 19.20 g plant^{-1}) at 30, 60 DAS and at harvest respectively. BARI Sarisha-15 mustard variety cultivation along with no arsenic treated pot recorded the maximum crop growth rate (0.27 mg cm^{-2} day^{-1}) at 30-60 DAS. At 60-harvest respectively BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum crop growth rate(0.29 mg cm^{-2} day^{-1}).BARI Sarisha-12 mustard variety cultivation along with no arsenic treated pot recorded the maximum number of branches plant^{-1} (5.24). BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum number of siliquae plant^{-1} (89.02).

BARI Sarisha-14 mustard variety cultivation along with 0 ppm arsenic treated pot recorded the maximum number of siliquae plant^{-1} (20.36). BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum 1000 seeds weight (3.76 g), seed yield plant^{-1} (3.82 g), stover yield plant^{-1} (15.28 g), harvest index (20.00 %). Whereas BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum plant height (16.56 and 33.48 cm) at 30 and 60 DAS. At harvest respectively BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum plant height (55.85cm). BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum dry matter accumulation (2.62 and 4.78 g plant^{-1}) at 30 and 60 DAS. At harvest respectively BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum dry matter accumulation (12.00 g plant^{-1}). BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum crop growth rate (0.09 and 0.22 mg cm^{-2} day^{-1}) at 30-60 DAS and 60 DAS-harvest respectively. BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum number of branches plant^{-1} (2.58). BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum number of siliquae plant^{-1} (55.85). BARI Sarisha-11 mustard variety cultivation along with 100 mg As kg^{-1} soil arsenic treated pot recorded the minimum number of seeds siliquae^{-1} (13.74). BARI Sarisha-12 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum 1000 seeds weight (2.80 g) and seed yield plant^{-1} (1.76 g). BARI Sarisha-14 mustard variety cultivation along with 100 mg As kg^{1} soil treated pot recorded the minimum stover yield plant^{-1} (10.02 g). BARI Sarisha-15 mustard variety cultivation along with 100 mg As kg^{-1} soil treated pot recorded the minimum harvest index (11.88 %).

In case of relationships, increasing arsenic level showed strongly negative relationship ($y = -0.004x + 2.656$) between arsenic concentration and seed yield plant^{-1} of mustard varieties. And in cultivation of different mustard varieties along with different arsenic level showed positive correlation due to mustard varieties withstand some degree of arsenic tolerance and among them cultivation of BARI Sarisha-11 alone with different arsenic level gave higher seed yield ranges between (3.82-3.07 g) from 0-100 mg As kg-1 soil arsenic level and perform well in case of seed production comparable to other varieties.

Conclusion

Based on the above results of the present study, the following conclusions may be drawn

i. Among different mustard varieties, BARI Sarisha-11 mustard variety cultivation recorded the maximum number of siliquae plant^{-1} (86.35), 1000 seeds weight (3.53 g), seed yield plant^{-1} (3.55 g), stover yield plant^{-1} (15.13 g), harvest index (18.98 %) comparable to other varieties.

ii. In case of different arsenic level, no arsenic treated pot recorded the maximum number of branches plant^{-1} (4.18), number of siliquae plant^{-1} (69.97), number of seeds siliquae^{-1} (17.37), 1000 seeds weight (3.39 g), seed yield plant^{-1} (2.64 g), stover yield plant^{-1} (13.4 g), harvest index (16.55 %) which was gradually decreasing due to increasing arsenic level.

iii. In case of combination, BARI Sarisha-11 mustard variety cultivation along with no arsenic treated pot recorded the maximum 1000 seeds weight (3.76 g), seed yield plant^{-1} (3.82 g), stover yield plant^{-1} (15.28 g), harvest index (20.00 %) when yield per plant was at per with 50mg As kg soil. iv. Among different mustard varieties, cultivation of BARI Sarisha-11 alone with different arsenic level gave higher seed yield ranges between (3.82-3.07 g) from 0-100 ppm arsenic level and perform well in case of seed production comparable to other varieties.

Thus for cultivation of mustard in arsenic prone areas, BARI Sarisha-11 mustard variety is suitable due to its higher seed yield and with stands tolerance ability comparable to others varieties of mustard.

Recommendations

- Studies of similar nature could be carried out of different Agro Ecological Zones (AEZ) in Bangladesh for the evaluation of zonal adaptability.

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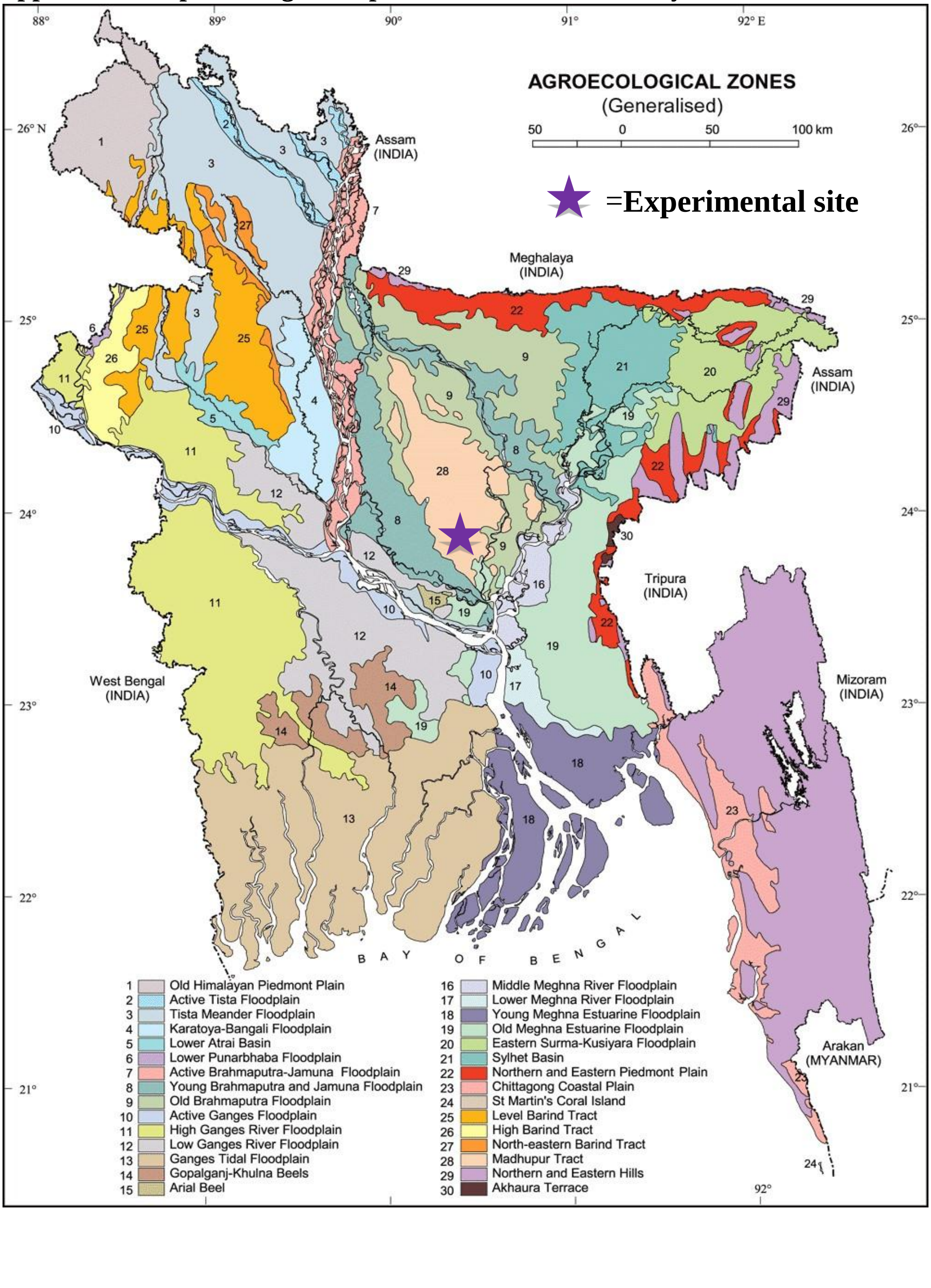
APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Characteristics of soil of experimental pot

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics

Constituents	Percent
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical characteristics

Soil characteristics	Value
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

Appendix III. Monthly meteorological information during the period from November, 2019 to February 2020.

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2019	November	29.6	19.8	53	00
	December	28.8	19.1	47	00
2020	January	25.5	13.1	41	00
	February	25.9	14	34	7.7

(Source: Meteorological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Analysis of variance of the data on plant height of mustard at different DAS

Source	DF	Mean square of plant height at		
		30 DAS	60 DAS	At harvest
Replication (R)	4	0.746	0.79	3.75
Variety (V)	3	115.77**	777.42**	2689.91**
Arsenic Level (A)	2	10.89**	135.93**	90.02**
V×A	6	3.48**	5.87*	12.25*
Error	44	0.72	2.155	5.20
Total	59			

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data on dry matter accumulation plant^{-1} of mustard at different DAS

Source	DF	Mean square of dry matter accumulation plant^{-1} at		
		30 DAS	60 DAS	At harvest
Replication (R)	4	0.02	0.19	0.23
Variety (V)	3	5.57**	36.76**	120.25**
Arsenic Level (A)	2	0.73**	6.72**	11.00**
V×A	6	0.07**	0.22*	0.41*
Error	44	0.02	0.07	0.17
Total	59			

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data on crop growth rate of mustard at different DAS

Source	DF	Mean square value of crop growth rate at	
		30-60 DAS	60 DAS -harvest
Replication (R)	4	0.00013	0.00004
Variety (V)	3	0.06467**	0.01278**
Arsenic Level (A)	2	0.00754**	0.00050**
V×A	6	0.00071**	0.00011*
Error	44	0.00013	0.00004
Total	59		

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VII. Analysis of variance of the data on number of branches plant^{-1}, siliquae plant^{-1}, seeds siliquae^{-1} and 1000 seeds weight of mustard

Source	DF	Mean square of			
		Number of branches plant^{-1}	Number of siliquae plant^{-1}	Number of seeds siliquae^{-1}	1000 seeds weight
Replication (R)	4	0.01	3.75	0.53	0.034
Variety (V)	3	17.30**	2689.91**	98.90**	0.98**
Arsenic Level (A)	2	0.53**	90.02**	2.22**	1.08**
V×A	6	0.02*	12.25*	0.35*	0.13*
Error	44	0.008	5.20	0.11	0.044
Total	59				

**: Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VIII. Analysis of variance of the data on number on seed yield plant^{-1}, stover yield plant^{-1}and harvest index of mustard

Source	DF	Mean square of		
		Seed yield plant^{-1}	Stover yield plant^{-1}	Harvest index
Replication (R)	4	0.04	0.33	1.83
Variety (V)	3	8.62**	72.45**	96.79**
Arsenic Level (A)	2	1.09**	4.97**	8.96**
V×A	6	0.17**	0.54*	5.92**
Error	44	0.04	0.19	1.19
Total	59			

**: Significant at 0.01 level of probability

*: Significant at 0.05 level of probability