Straighthead Disease of Rice (*Oryza sativa* L.) Induced by Arsenic Toxicity

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Abstract

Straighthead disease is a physiological disorder of rice (*Oryza sativa* L.) characterized by sterility of the florates/spikelets leading to reduced grain yield. Though the exact cause of straighthead is unknown, a glass house experiment was conducted with rice (*Oryza sativa* L.) to investigate the effect of inorganic arsenic on straighthead disease. BRRI dhan 29, a popular Bangladeshi rice strain, was grown in soils spiked with arsenic (prepared from sodium arsenate, $Na_2HAsO_4{\cdot}7H_2O$) at the rate of 10, 20, 30, 40, 50, 60, 70, 80 and 90 mg of As kg^{-1} and one control treatment was also run to compare the results. Although there may be some other soil physico-chemical factors involved, arsenic concentration was found to be closely associated with straighthead of rice. With the increase of soil arsenic concentration, the severity of straighthead increased significantly. Up to the 50 mg of As kg^{-1} soil treatments, the severity of straighthead incidences were not prevalent. Straighthead resulted in sterile florets with distorted lemma and palea, reduced plant height, tillering, panicle length and grain yield. Straighthead caused approximately 17-100% sterile florates/spikelets formation and about 16-100% loss of grain yield. Straighthead also causes the reduction of panicle formation and panicle length significantly ($p < 0.01$). In the present study, panicle formation was found to be reduced by 21-95% by straighthead.

Keywords: Arsenic, Straighthead Disease, Spikelet, Rice (*Oryza sativa* L.), BRRI dhan 29, Toxicity.

Introduction

Arsenic contamination in ground water has turned into the gravest natural disaster with spatial extent encompassing Bangladesh (Fazal et al., 2000; Smith et al., 2000; Hopenhayn, 2006), West Bengal (India) (Chowdhury et al., 2000), China, Taiwan, Vietnam, United States of America, Argentina, Chile, Mexico (O'Neill, 1995; Smedley and Kinniburgh, 2002). In Bangladesh, arsenic concentration in ground water has exceeded the safe level (0.05 mg L^{-1} is the Bangladesh standard) in 59 districts out of 64 and about 80 million people are exposed to arsenic poisoning. The natural contamination of shallow tube wells (STWs) in Bangladesh with high level of arsenic has caused widespread human exposure to this toxic element through drinking water (Karim, 2000*)*. However, survey on paddy soils throughout Bangladesh showed that arsenic levels was high in areas where arsenic contaminated groundwater have been used for irrigation and where the shallow tube wells (STWs) have been in operation for longer period of time (Meharg et al., 2003). Onken and Hossner (1995) reported that plants grown in soils treated with arsenic had higher rates of arsenic uptake compared to those plants grown in untreated soils. Many other reports also suggest that higher soil arsenic concentrations increased its accumulation in tissues of paddy crops (Rahman et al., 2004; Abedin et al., 2002; Meharg et al., 2003; Marin et al., 1992).

Bangladesh is one of the major rice growing countries of the world with about 33% of her arable lands under irrigation facilities (BBS, 1996) and a substantial portion of the farmers of Bangladesh are dependent on arsenic contaminated ground water for irrigation. Long term use of shallow tube well water containing high level of arsenic for irrigation may results in elevated arsenic concentration in soils and crops plants (Ullah et al., 1998; Imamul Haq et al., 2003; Rahman et al., 2006; Rahman et al., 2007). Ullah et al. (1998) reported 83 mg kg^{-1} arsenic concentration in rice field soils of Bangladesh. At higher soil arsenic concentration, rice plants show different toxicity symptoms related to physiological and agronomical characteristics such as growth and yield reduction, reduced root and shoot length and biomass production (Rahman et al., 2004; Abedin et al., 2002; Meharg et al., 2003), reduced chlorophyll content, panicle length and panicle number (Rahman et al., 2007).

Straighthead disease is a physiological disorder of rice (*Oryza sativa* L.) characterized by blank florets/spikelets and distorted lemma and palea, and in extreme cases, the panicles or heads do not form at al (Atkins, 1974). As a result, heads remain upright at maturity because of lack of grain development: hence the name “straighthead” (Wengui et al., 2005). The lemma and palea, or both, may be lacking, but if they are present, they are distorted and crescent-shaped forming a characteristics symptom of straighthead called “parrot beak” (Rasamivelona et al., 1995). The straighthead of rice leads to reduced grain yield and in extreme cases, almost a total loss of yield (Dilday et al., 2000; Yan et al., 2005).

Though the exact cause of straighthead is yet unknown, studies have shown that the disease increased by consistent flood (Wilson et al., 2001), low soil pH and free iron (Baba and Harada, 1954), rich organic matter in soil (Jones et al., 1938). However, arsenic residue in soil is supposed to be the main factor behind the straighthead of rice (Wells and Gilmour, 1977; Horton et al., 1983). In particular, straighthead has been frequently observed when rice is grown on land where arsenical herbicides such as monosodium methanearsonate (MSMA) were applied previously (Gilmour and Wells, 1980).

MSMA is popular herbicide in cotton (*Gossypium* spp.) production in the USA. Therefore, rice fields with a cotton growing history usually have residual arsenic which has been shown to cause injuries to rice that are similar to straighthead (Gilmour and Wells, 1980). Recently, deposition of inorganic arsenic in soil of rice fields of many arsenic epidemic areas from underground irrigation water raises the possibility of widespread straighthead. Though there are few reports on straighthead of rice caused by residual arsenicals such as MSMA, little is know about the influence of inorganic arsenic in soil on straighthead comes from other sources. The critical soil arsenic concentration for straighthead induction is also unclear form previous study. Thus, an experiment was conducted to investigate the influence of inorganic arsenic concentrations on straighthead disease and the effect of straighthead on rice yield.

Materials and Methods

Soil and Pot Preparation

The experiment was conducted in a glasshouse at Bangladesh Rice Research Institute (BRRI). Initial soil was collected from BRRI farm at a depth of 0-15 cm and sun dried for 7 days. Then the massive aggregates were broken down by gentle crushing with hammer. The unwanted materials such as dry roots, grasses, stones etc. were removed from the bulk soil. Then the soil was crushed into small size, mixed thoroughly, and sieved with 2 mm ware sieve. Sample from this initial soil was collected into a plastic pot to measure physico-chemical properties.

An amount of 5 kg dry soil was taken into 6-L volume plastic pots having no pores. Plastic pot was used to avoid leaching and absorption of water soluble arsenic from the soil. Before taking soil into the pots, all plastic pots were washed by tap water and sun dried. There were altogether 30 pots comprising ten arsenic treatments with three replications for each. The pots were arranged following the factorial Completely Randomized Block Design (RCBD).

Arsenic Treatment

Arsenic concentration in rice fields' soil of arsenic affected areas of Bangladesh has been reported to be between 20 and 90 mg kg^{-1} (Ullah, 1998). Therefore, arsenic was mixed thoroughly with the initial soil at the rate of 10, 20, 30, 40, 50, 60, 70, 80 and 90 mg As kg^{-1}. One control treatment was also run to compare the results. Arsenic was applied to the soil as aqueous solution prepared from sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$). The spiked soil was left for two days without irrigation. After that, about 4.5 L of tap water (having arsenic concentrations of < 0.001 mg l^{-1}) was irrigated to each pot.

Intercultural Operation and Fertilizer Application

The pots were placed on a plane cemented table. The overall temperature in the glasshouse ranged from 22.4 to 33.9 ºC, relative humidity from 59.9 to 83.7%, average evaporation from 3.8 to 6.0 mm, sunshine from 3.4 to 7.8 h/day. BRRI dhan 26, a popular Bangladeshi rice strain, was used as test crop. In each pot, 4 seedlings of 35-days old were transplanted at equal spacing. After transplantation, the rice plants were grown under flooded condition. Pots were irrigated regularly, maintaining a water depth of 3 cm, throughout the post-transplantation period until harvesting. Urea, triple super phosphate (TSP) and muriate of potash (MP) were applied at the rate of 30, 40 and 20 kg per hectare for nitrogen, phosphorous and potassium, respectively in the spiked soil. One-third of the full dose of urea and full dose of other two fertilizers were applied as basal in the individual pot before transplantation. The fertilizers were incorporated with the soil by hand. The second and third splits of urea were applied after 30 (maximum tillering stage) and 60 days (panicle initiation stage) of transplantation.

Physico-chemical Properties of Initial Soil

The physical properties of the soil such as distribution of particle size, textural classes, moisture content were determined and are presented in Table 1. The soil was silty-clay-loam (sand 12.30%, silt 53.00% and clay 34.70%) and blackish in color. The moisture content of the soil was about 16.04%.

The chemical properties of the soil such as pH, organic carbon, organic matter, total nitrogen, total phosphorus, total potassium, total iron, total arsenic, available phosphorus and available iron were determined and the results are presented in Table 2. The initial soil was acidic (pH

5.27) in nature. The background arsenic of the experimental soil was 3.25 mg kg^{-1}. The soil was rich in iron with available iron of 48.02 mg kg^{-1}. Organic carbon and organic matter was about 0.77 and 1.32%, respectively. Total nutrients such as nitrogen, phosphorus and potassium in soils were not sufficient (0.25, 0.02 and 0.12%, respectively). Fertilizers of these nutrients elements were applied to reduce their deficiency. Available phosphorus was about 6.15% in the soil.

Determination of Arsenic Induced Straighthead of Rice

As the straighthead disease of rice is characterized by sterility of the florets leading to reduced grain yield, the disease incidence was determined by rating on a 0-6 scale calculated from sterile florets and the total number of grain per pot. The effect of straighthead on rice yield in terms of penicle number, penicle length, total spikelets, filled and unfilled spikelets was also investigated. Penicle number was counted after harvest and length of panicle was measured from basal node of the rachis to the apex. Rice spikelets were collected from the penicles by hand. Empty spikelets were separated from the filled spikelets and the number of filled spikelets in each pot was counted. The weight of filled spikelets per pot (grain yield) was measured after drying at 50 ºC for 48 hours.

Statistical Analysis

The experimental data were statistically analyzed for mean separation of treatments according to the least significant difference (LSD) at 5% level by IRRI-STAT 4.0 for windows (developed by the biometrics unit, IRRI, Philippines).

Results and Discussions

Straighthead disease induced by arsenic toxicity

Straighthead disease is especially characterized by sterile florates with distorted lemma and palea and thus, heads remain upright at maturity because of lack of grain development. In present experiment, the straighthead disease was rated on a 1-6 scale on the basis of the number of sterile or unfilled rice grain in relation to the total number of grain per panicle. It is evident from Figure 1 that straighthead remains normal and almost consistent up to 50 mg of As kg^{-1} soil treatment. The straighthead disease becomes prevalent from 60 mg of As kg^{-1} soil treatment. With the increase of soil arsenic concentrations from 60 mg kg^{-1}, the straighthead increased gradually. At 90 mg of As kg^{-1} soil treatment, the BRRI dhan 29 was found to be highly susceptible to straighthead with 6 rating (Fig. 1). At this soil arsenic concentration, panicles were completely sterile and upright. In another study (unpublished), we also found that the severe straighthead occurred at 60 mg kg^{-1} soil arsenic concentration with completely sterile and upright panicle.

Wengui et al. (2005) observed that rice (*Oryza sativa* L.) was highly susceptible to straighthead with ratings from 7.2-8.0 of a 1-9 scale when the rice was tested at 6.7 kg ha^{-1} arsenical herbicide (MSMA). Wengui et al. (2005) found most grains to become parrot beaked, a characteristic symptom of straighthead (Rasamivelona et al., 1995), many panicles to fail to emerge, and plants to become stubby, resulting in no seed set. In the present study, the symptoms of straighthead (Fig. 2 and 4) were also seemed to be similar to those of Wengui et al. (2005) experiment. The results indicate that the inorganic arsenic in soil also produces straighthead symptoms as the residual arsenic of arsenical herbicide (MSMA) produced. The results of the present study also suggest that 60 mg of As kg^{-1} soil might be the critical concentration of arsenate to induce straighthead disease.

In the present study, it was also observed that with the increase of soil arsenic concentration, number of filled spikelet/panicle decreased though the total number of spikelet/panicle remained statistically consistent (Fig. 3). The decrease in filled spikelet production was due to straighthead resulted from arsenic toxicity.

Effect of Straighthead disease on rice yield

Straighthead disease delayed heading date, shortened plant height and drastically reduced rice yield (Fig. 4). In the present experiment, the number of panicle per pot was found to be decreased significantly ($p < 0.01$) with the increase of soil arsenic concentrations (Fig. 5A) and the average length of penicle was not affected up to the 60 mg of As kg^{-1} soil treatment (Fig. 5B). However, rice yield (g/pot) was reduced significantly ($p < 0.01$) by augmentation of straighthead disease caused by increasing soil arsenic concentrations (Fig. 5C). The average grain yield was reduced about 16-100% by arsenic induced straighthead of BRRI dhan 29. Yan et al., (2005) reported 24 to 96% reduction of rice yield depending on rice strains/varieties due to straighthead disease. When MSMA was applied to the soil at the rate of 6.7 kg ha^{-1}, Wengui et al. (2005) found a severe reduction of grain yield from 80% for Bengal strain to 96% for Mars, as compared with their corresponding untreated MSMA treatment. The results indicate that the increasing soil arsenic concentrations in rice field of arsenic epidemic areas like Bangladesh and West Bengal (India) from irrigation water may cause severe straighthead disease which may results a great loss of yield.

Conclusion

Reduction in rice grain yield from straighthead disease has been well reported though the factors involved with this disease are not conspicuous at all. In some previous field investigations, straighthead has been frequently observed when rice was grown in field with a cotton growing history, where arsenical herbicide such as MSMA was applied. The present study reveals that the inorganic arsenic in soil also results in the straighthead though there may be some other soil factors involved. According to the present study, it might also be conclude that 60 mg As kg^{-1} is the critical concentration of arsenate to induce straighthead disease. However, more investigation is necessary to determine the critical concentration of arsenic for straighthead.

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Table 1: Physical properties of soils

Physical properties of initial soil	Glasshouse soil
% Sand (2 – 0.05 mm)	12.30
% Silt (0.05 – 0.002 mm)	53.00
% Clay (< 0.002 mm)	34.70
Textural Class	Silty-clay-loam
Moisture (%)	16.04

Table 2: Chemical properties of soil

Chemical properties of initial soil	Glasshouse soil
pH (Soil : Water = 1 : 2.50)	5.27
Organic Carbon (%)	0.77
Organic Matter (%)	1.32
Total Nitrogen (%)	0.25
Total Phosphorus (%)	0.02
Total Potassium (%)	0.12
Total Iron (%)	2.01
Total Arsenic (mg kg^{-1})	3.25 (+10)*
Available Phosphorus (mg kg^{-1})	6.15 (+3.12)**
Total Manganese (mg kg^{-1})	-

* 10 mg As kg^{-1} soil was spiked to the initial soils of glasshouse experiment.

** After the rice harvest, available phosphate in the soil was 9.27 mg kg^{-1}.

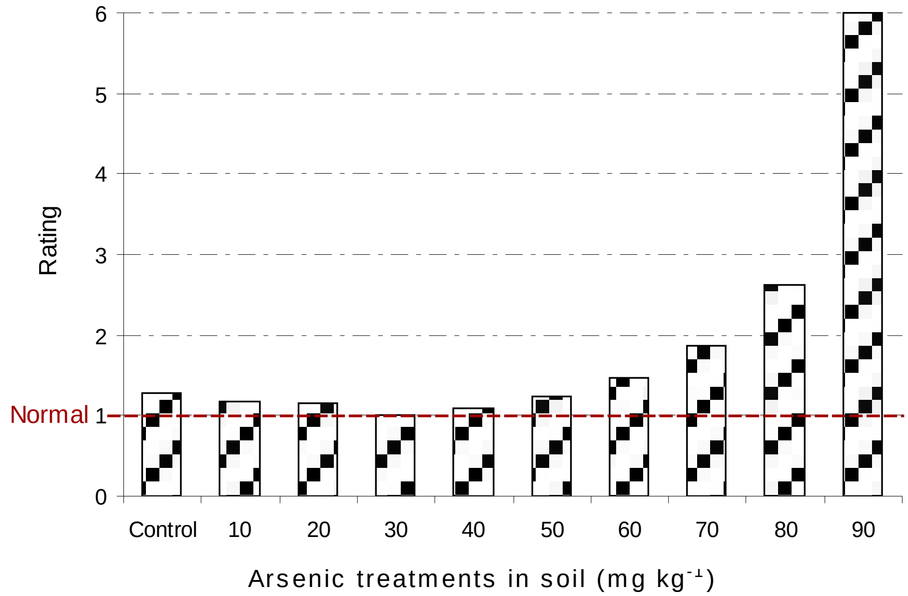

Figure 1: Straighthead ratings on a 1-6 scale, where 1 is normal and 6 is the worst straighthead caused from arsenic toxicity.

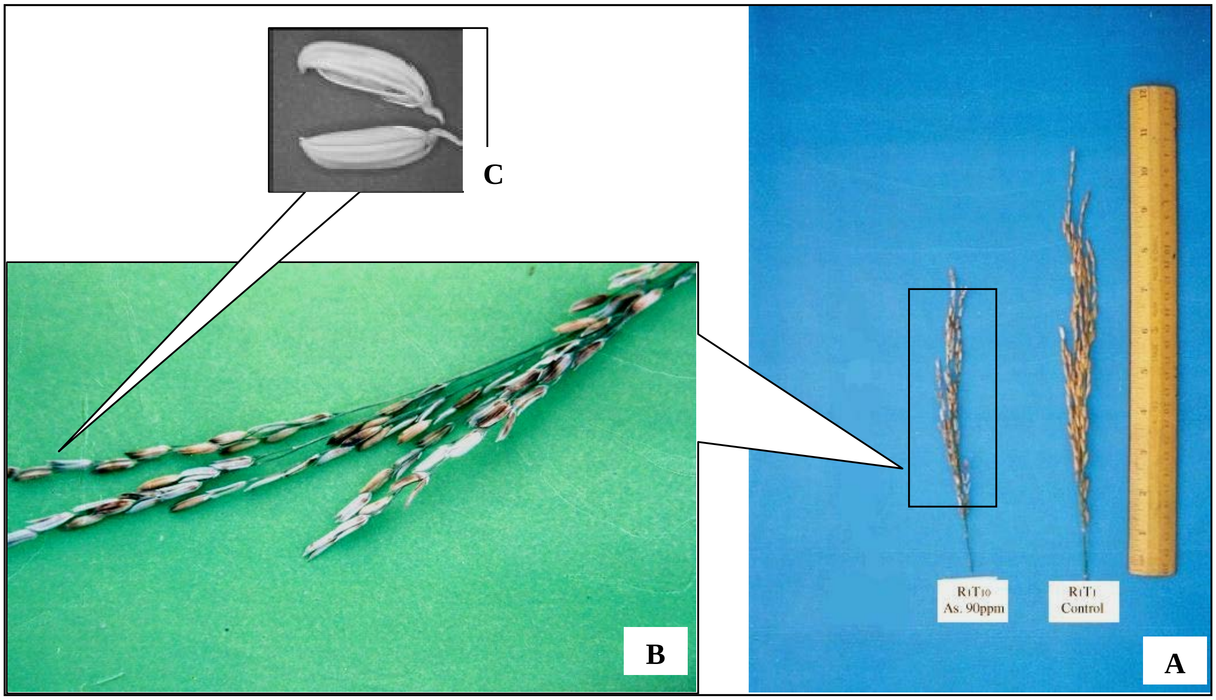

Figure 2: Straighthead disease of rice characterized by sterile florets with distorted lemma and palea forming a characterized symptom called “parrot beak” resulted from arsenic toxicity. (A) Panicle from control and 90 mg As kg^{-1} soil treatments. (B) Close view of panicle of 90 mg As kg^{-1} soil treatments. (C) Characteristic symptom of straighthead called “carrot beak”.

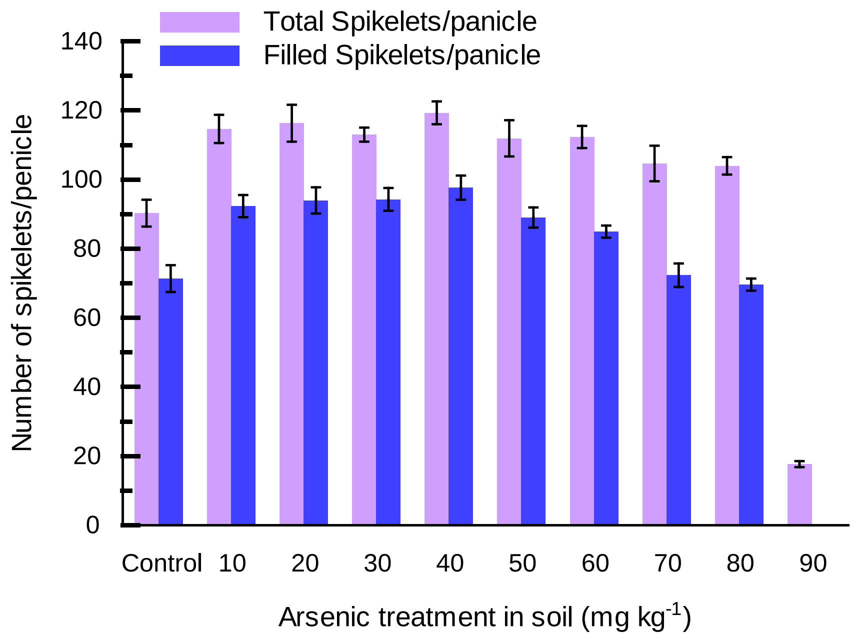

Figure 3: Empty spikelet formation due to straighthead resulted from arsenic toxicity. Error bars represent mean ± S.E.M. (*n* = 3).

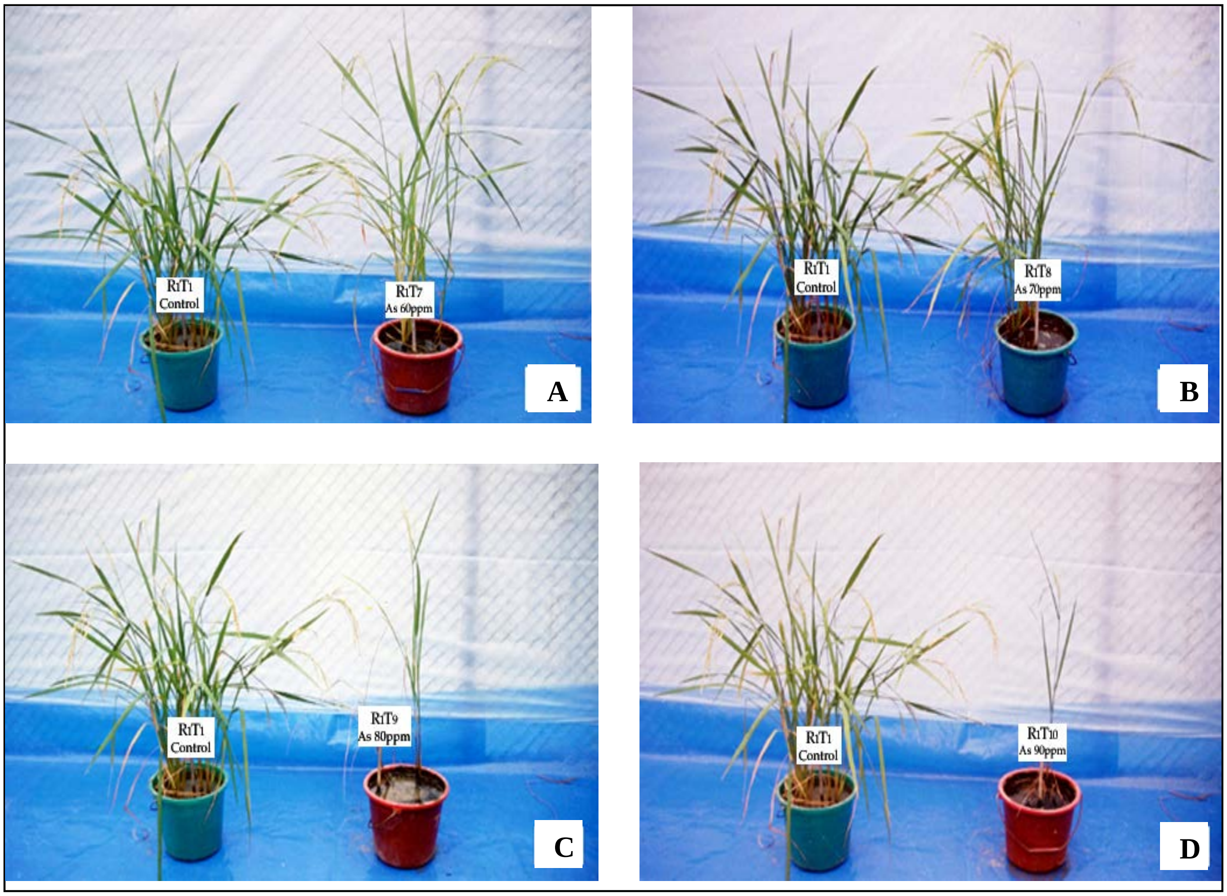

Figure 4: Mature rice plant showing reduced plant height, tillering and panicle number compared to the control, due to straighthead induced by higher soil arsenic concentrations. Soil arsenic concentrations were 60 (A), 70 (B), 80 (C) and 90 mg kg^{-1} (D).

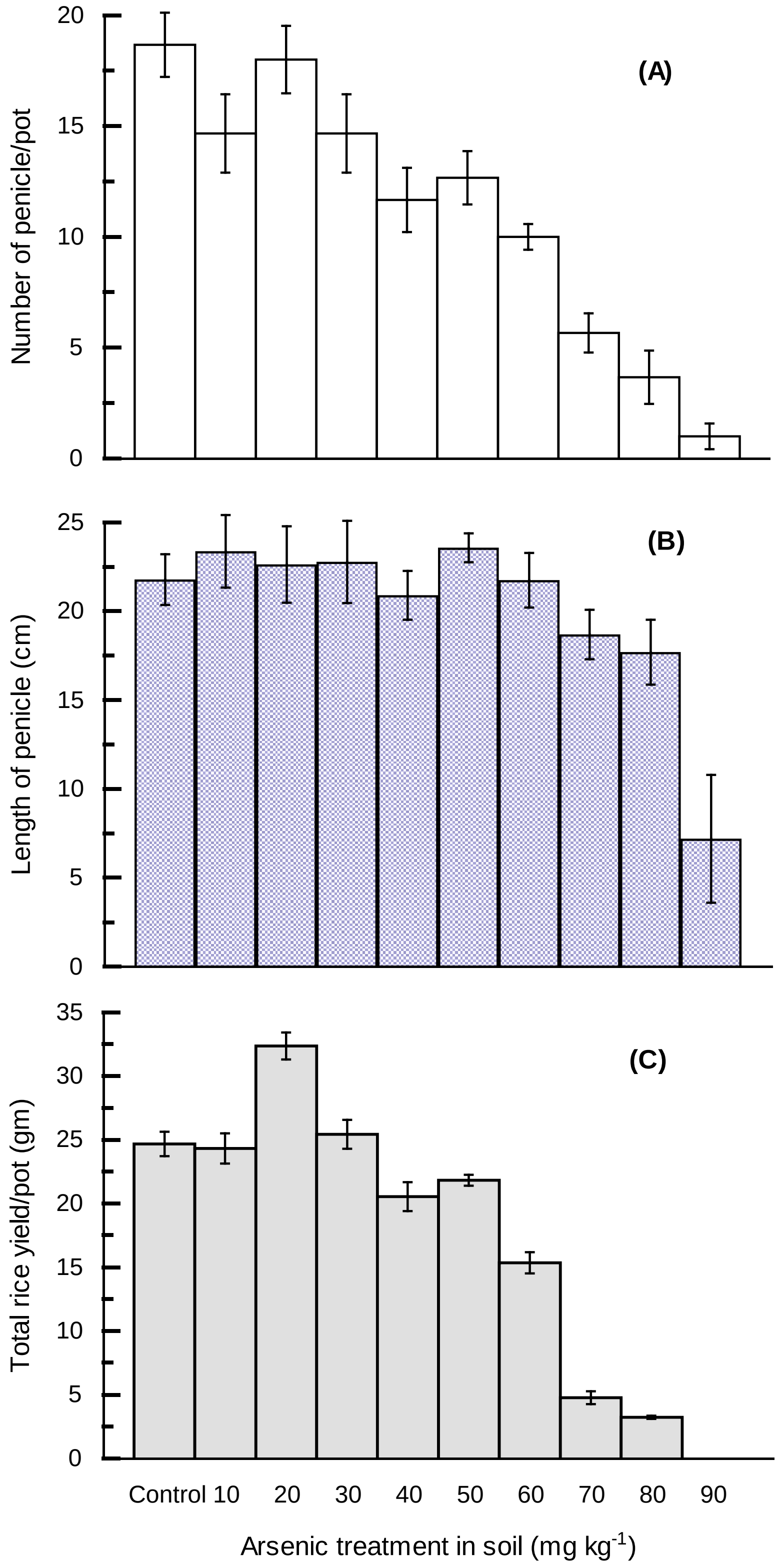

Figure 5: Rice yield affected by straighthead resulted from arsenic toxicity. Error bars represent mean ⁊ S.E.M. (n = 3). Penicle number (A); Penicle length (B); Rice yield (C).