TOXIC EFFECT OF CHROMIUM ON GROWTH, YIELD AND NUTRITIONAL ATTRIBUTES OF BRRI dhan69 and BRRI dhan74

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CERTIFICATE

This is to certify that the thesis entitled **"TOXIC EFFECT OF CHROMIUM ON GROWTH, YIELD AND NUTRITIONAL ATTRIBUTES OF BRRI dhan69 and BRRI dhan74"** *submitted to the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (M.S.)*** *in Agricultural Chemistry, embodies the results of a piece of bona fide research work carried out by* ***MOMENUL ISLAM,*** *Registration. No.* ***11-04331*** *under my supervision and guidance. No part of this 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.

Dated:

Dhaka, Bangladesh

(Assoc. Prof. Dr. Sheikh Shawkat Zamil)
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TOXIC EFFECT OF CHROMIUM ON GROWTH, YIELD AND NUTRITIONAL ATTRIBUTES OF BRRI dhan69 and BRRI dhan74

ABSTRACT

The experiment was conducted at the net house of Agro-environmental Chemistry laboratory of department of Agricultural Chemistry of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh during the period from December 2016 to May 2017 to study the toxic effect of chromium on growth, yield and nutritional attributes of BRRI dhan69 and BRRI dhan74. The experiment comprised of two factors, Factor A: two rice cultivars i.e. V_1= BRRI dhan69, V_2= BRRI dhan74; and six levels of Cr application i.e. T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil. The experiment was laid out in Completely Randomized Design (CRD) with four replications. Data on different growth parameters, yield attributes, yield and biochemical properties were recorded and analyzed. Data revealed that Cr absorbed by both variety where V_2 absorbed maximum amount of Cr than V_1. Therefore, the control treatment attributed the highest values of vegetative growth, yield and yield contributing character, and nutrient content with V_2 variety. The combination of V_2T_1 gave the best result for all vegetative, reproductive growth parameters and nutrient content of rice. Thus, variety V_2 is recommended in Cr rich soil for the minimum absorption of Cr by the variety V_2.

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LIST OF ACRONYMS

AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
CV%	Percentage of coefficient of variance
DAT	Days after transplanting
^{0}C	Degree Celsius
et al	And others
FAO	Food and Agriculture Organization
g	gram(s)
ha^{-1}	Per hectare
kg	Kilogram
mg	Milligram
MP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Not significant
%	Percent
SAU	Sher-e-Bangla Agricultural University
SE	Standard error
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate

CHAPTER I

INTRODUCTION

Rice is the staple food of about 160 million people of Bangladesh. Rice sector contributes one-half of the agricultural GDP and one-sixth of the national income in Bangladesh. Rice covers about 81% of the total cropped area (BBS, 2010). Thus, rice plays a vital role in the livelihood of the people of Bangladesh. But cultivation is always vulnerable to unfavorable weather events and abiotic stresses. Chromium contamination is one of them.

Chromium (Cr) is the 17^{th} most abundant element in the Earth's mantle (Avudainayagam, *et al*., 2003). It occurs naturally as chromite ($FeCr_2O_4$) in ultramafic and serpentine rocks or complexed with other metals like crocoite ($PbCrO_4$), bentorite $Ca_6(Cr,Al)_2(SO_4)_3$ and tarapacaite (K_2CrO_4), vauquelinite ($CuPb_2CrO_4PO_4OH$), among others (Babula *et al*., 2009). Cr is widely used in industry as plating, alloying, tanning of animal hides, inhibition of water corrosion, textile dyes and mordants, pigments, ceramic glazes, refractory bricks, and pressure-treated lumber (Avudainayagam, *et al*., 2003). Due to this wide anthropogenic use of Cr, the consequent environmental contamination increased and has become an increasing concern in the last years (Zayed and Terry, 2003). Chromium exists in several oxidation states, but the most stable and common forms are Cr(0), the trivalent Cr(III), and the hexavalent Cr(VI) species. Cr(0) is the metallic form, produced in industry and is a solid with high fusion point usually used for the manufacturing of steel and other alloys. Cr(VI) in the forms of chromate (CrO_4^{2-}), dichromate (CrO_4^{2-}), and CrO_3 is considered the most toxic forms of chromium, as it presents high oxidizing potential, high solubility, and mobility across the membranes in living organisms and in the environment. Cr(III) in the forms of oxides, hydroxides, and sulphates is less toxic as it is relatively insoluble in water, presents lower mobility, and is mainly bound to organic matter in soil and aquatic environments. Moreover, Cr(III) forms tend to form hydroxide precipitates with Fe at typical ground water pH values.

With increasing worldwide industrialization and rapid urbanization, pollution of trace metals (i.e., heavy metals) in the terrestrial environment has become a global problem (Lee *et al*., 2006). Trace metals in soil may accumulate in crops, directly or indirectly threatening human health (Qu *et al*., 2013). Therefore, many regulatory bodies in different countries, such as the Ministry of Health of China, the United States Environment Protection Agency (US EPA), the Food and Agriculture Organization (FAO) and Word Health Organization (WHO) of United Nations, have strictly regulated the maximum permitted concentrations of toxic trace metals in foodstuffs. For Chromium (Cr), the maximum permissible limit in rice grain is 1 mg kg^{-1} in China, and such standards have the force of law.

Heavy metals are integral components of ecosystem with both essential and non-essential types. Cr is a non-essential toxic element to plants. The common anthropogenic sources of heavy metals in environment are wastewater irrigation, sludge applications, solid waste disposal, automobiles exhaust& industrial activities (Shi *et al*., 2005). Out of the two stable states, Cr+6 is considered to be more toxic than Cr+3 (Panda and Patra, 2000). Cr+6 is potent, toxic and carcinogenic to plants (Shankar *et al*., 2005, Liu *et al*., 2008, Mohanty and Patra, 2009). Crops grown in or close to the contaminated sites can uptake & accumulate these metals in their organs (Jarup, 2003). The effect of heavy metals on crops & humans causing functional disorder in their body organs due to exposure of low dose over a long time (Jianjie *et al*., 2008). Heavy metals enter waste water from varieties of sources such as domestic, industrial & mining operations. Many of these dissolved metal ions such as copper, cobalt, nickel, zinc, chromium etc. are toxic to living organisms. Plants have a remarkable ability to absorb, translocate & accumulate heavy metals & organic compounds from the environment.

Heavy metals taken up by plants from contaminated soil and water are toxic to growth performance of plants and posses a hidden threat to consumers (Stobrawa *et al*., 2008). Recent reports have demonstrated that through the proper application of chelating agents to the soil, relatively insoluble elements can be solubilised & made available for plant uptake.

Chromium is the seventh most abundant metal of earth cast (Katz and Salem, 1994) and important environmental contaminant released into the atmosphere due to its heavy industrial use (Nriagu and Nieboer, 1988). In recent years, heavy metal pollution in soil has gained major concern due to its negative impact on agricultural production and human health (Rahman *et al*., 2014). Heavy metals are integral components of ecosystem with both essential and non-essential types. The common anthropogenic sources of heavy metals in environment are waste water irrigation, sludge application, solid waste disposal, automobiles exhaust and industrial activities (Shi *et al*., 2005). Plants have a remarkable ability to absorb, translocate and accumulate heavy metals and organic compounds from the environment. When Cr enter the plant body, it can disturb many biochemical and physiological process and caused oxidative stress to plants that reduced growth and yield (Arun *et al*., 2005). Cr toxicity results in inhibition growth, induced chlorosis, biochemical lesion, reduced crop yield, reduced enzyme activity (Mohanty *et al*., 2010).

With the wide application of chromium (Cr) in industries and due to the absence of proper treatment of Cr-bearing wastewater before flowing into agricultural fields, the soil Cr concentration in certain areas has exceeded the regulated standard. The harmfulness of chromium to the soil-plant system has been identified by scientists and aroused public attention. Zayed *et al*. (2010) investigated the uptake and accumulation of Cr^{3+} and CrO_4^{2-} by 11 vegetable species. They found that the above-ground parts and the under-ground parts of the plants had different Cr accumulation behavior, and different species behaved differently. Compared to the control treatment, the Cr uptake by chickpeas inoculated with nodule bacteria respectively decreased by 14%, 34% and 29% in the roots, shoots and grains (Arun *et al*., 2005). Gupta *et al*. (2018) also investigated the uptake of Cr^{3+} and Cr^{6+} by tumbleweeds.

Chromium, a toxic heavy metal can cause serious problem to microbes, plant and animals even at trace concentrations, and can be highly toxic to human being as well through its bioaccumulation in the food chain (Tiwari *et al*., 2013). Under the stresses of this heavy metals in the soil, the growth of rice plants is inhibited, and the expression of isodynamic enzymes and enzyme activities in rice plant body are affected. Chromium contamination in rice grain is a serious threat to human health especially for those with a rice based food diet. Therefore, defensive measures are needed to decrease uptake of Cr to reduce the risk of health hazards in response to Cr-polluted field. The changes of antioxidant enzymes activities, photosynthetic rate and growth of rice cultivars are reduced by Cr toxicity. The differences in acceptance of different cultivars against Cr toxicity provide a base to study the effects of Cr tolerance in crops.

OBJECTIVES OF THE RESEARCH PROGRAMME

a) To compare the growth and yield of rice cultivars under different levels of chromium containing soil
b) To evaluate the nutrient content of Cr, P, K, S, Na in rice grain, straw and root
c) To find out the variety with higher tolerance to toxicant.

CHAPTER II

REVIEW OF LITERATURES

Yu and Feng (2016) reported that, an investigation was conducted to find out the effects of trivalent chromium on biomass growth (RGR), water use efficiency (WUE) and distribution of nutrient elements in young rice seedlings (*Oryza sativa* L. cv. XZX 45) exposed to chromium nitrate (Cr(III)) hydroponically. Results indicated that phytotoxicity of Cr(III) to rice seedlings was apparent, showing a linear decrease in both RGR and WUE with increasing Cr(III) concentrations. Using the Leven-berg-Marquardt Algorithm, the effective concentrations (EC) obtained from the RGR were always smaller than these from WUE, indicating that the former was more sensitive to change of Cr(III) application than the latter. Although a dose-dependent total accumulation rate of Cr in plant materials was observed, the translocation of Cr into shoots was a restricted process during phytotransport of Cr within plant materials. Results also showed that the effect of Cr(III) application on uptake and distribution of nutrient elements in rice seedlings was variable. In conclusion, the toxic response of young rice seedlings to Cr(III) was obvious and inhibitory effects were highly dependent on the total accumulation rate of Cr in plant materials.

Nagarajan and Ganesh (2015) stated that, chromium is a serious heavy metal and it is considered as an environmental hazard. Toxicity effects of chromium on growth and development of plants including inhibition of germination process decrease of growth and biomass of plant. The aim of this research is to study the accumulation of Cr and its effect on the Germination and growth of some paddy varieties. Thus, the varieties such as ADT-43, ADT-45, IR-50, TKM-9, CO-33, ASD-16 and CO-43 are grown in petriplates treated with different concentrations of Chromium (0, 5, 10, 25, 50, 100, and 200 mg/L). After one week exposure the seedlings were removed and morphophysiological parameters like germination percentage, seedling length and dry weight of paddy varieties and accumulation of Cr were determined. The results indicated that the concentrations more than 100 mg/L chromium cause the reduction of morphophysiological parameters in the treatments rather than control and Cr addition in the cultures caused enhancement of chromium content in roots and shoots of plant seedlings. It was also noted that accumulation of chromium in the roots was much higher than the shoots of the paddy seedlings under treatment.

Qu *et al*. (2015) reported that, the accumulation of a trace metal in rice grain is not only affected by the total concentration of the soil trace metal, but also by crop variety and related soil properties, such as soil pH, soil organic matter (SOM) and so on. However, these factors were seldom considered in previous studies on mapping the pollution risk of trace metals in paddy soil at a regional scale. In this study, the spatial nonstationary relationships between rice-Cr and a set of perceived soil properties (soil-Cr, soil pH and SOM) were explored using geographically weighted regression; and the relationships were then used for calculating the critical threshold (CT) of soil-Cr concentration that may ensure the concentration of rice-Cr being below the permissible limit. The concept of "*loading capacity*" (LC) for Cr in paddy soil was then defined as the difference between the CT and the real concentration of Cr in paddy soil, so as to map the pollution risk of soil-Cr to rice grain and assess the risk areas in Jiaxing city, China. Compared with the information of the concentration of the total soil-Cr, such results are more valuable for spatial decision making in reducing the accumulation of rice-Cr at a regional scale.

Sundaramoorthy and Sankar Genesh (2015) stated that, the aim of this research is to study accumulation of Chromium along with nutrients and its effect on the growth of Paddy plant (*Oryza sativa* L). Thus, paddy seedlings grown in petriplates lined with filter paper undergoing, different treatments of Cr (0, 2.5, 5, 10, 25, 50, 75, 100 and 200 mg/L). After one-week seedlings were removed and morphological parameters like root length, shoot length and dry weight of plants and accumulation of nutrients along with Cr content were determined. The results indicated that the concentrations more than 100 mg/L chromium cause the reduction of morphological parameters in the treatment plants rather than control plant and Cr addition in the cultures caused enhancement of chromium content paddy seedlings. Similarly, nutrient accumulation also affected by increasing concentrations of chromium.

Parmar and Patel (2015) reported that, a pot-house experiment was carried out at Micronutrient Project, AAU, Anand to study the effect of Cr levels (0, 10, 20, 40, 80 and 160 mg/kg soil) in presence and absence of amendments (FYM and gypsum) on rice and wheat under rice-wheat sequences on coarse loamy soil with three replications under factorial completely randomized block design. The experimental results indicated the rice grain yield gradually decreased due to direct effect of Cr while residual effect was found beneficial up to Cr20 which improved grain yield of wheat by 15.09 per cent over control. Similarly, rice and wheat grain as well as straw yield were also found enhanced due to direct and residual effect of FYM and gypsum over their corresponding control. The Cr content in grain and straw of rice and wheat significantly increased with increase in Cr levels due to both direct and residual effect of Cr. The highest Cr content was recorded in straw followed by grain in both the crops. The application of farm yard manure (FYM) and gypsum significantly decreased Cr content of rice and wheat grain and straw due to direct and residual effect. The direct and residual effect of gypsum and FYM decreased Cr content of rice grain by 21.31 and 28.30 per cent over corresponding control. The Cr application increased DTPA-Cr of the soil due to direct and residual effect after rice and wheat. The application of amendments significantly decreased DTPA-Cr in the soil after both rice and wheat in the soil over control. The findings, in general, indicated that the toxic effect of Cr on crop could be mitigated more effectively with FYM application and reduce risk of health hazards for human beings and animals. However, the regular monitoring for soil quality is necessary for managing Cr pollution in the soil.

Xiao *et al*. (2015) stated that, anthropogenic chromium (Cr) pollution in soils poses a great threat to human health through the food chain. It is imperative to understand Cr fate under the range of conditions suitable for rice growth. In this study, the effects of irrigation managements on dynamics of porewater Cr(VI) concentrations in rice paddies and Cr distribution in rice were investigated with pot experiments under greenhouse conditions. Soil redox potential in continuous flooding (CF) treatments showed that reducing conditions remained for the whole duration of rice growing period, while soil redox potential in alternating wetting and drying (AWD) treatments showed that soil conditions alternately changed between reducing and oxic. As soil redox potential is an important factor affecting Cr(VI) reduction in paddy soils, dynamics of Cr(VI) concentration were clearly different under different irrigation managements. In CF treatments, porewater Cr(VI) concentrations decreased with time after planting, while in AWD treatments porewater Cr(VI) concentrations were increased and decreased alternately response to the irrigation cycles. Chromium(VI) concentrations in the CF treatments were lower than those in AWD treatments for most part of rice-growing season. Moreover, Cr concentrations in rice tissues were significantly influenced by irrigation with relatively higher values in the AWD treatments, which might be attributed to the higher porewater Cr(VI) concentrations in AWD treatments. Therefore, it would be better to use CF than AWD management in Cr-contaminated paddy soils to reduce Cr accumulation in rice, and thus to reduce the potential risk to human health.

Dai *et al*. (2015) reported that, Rice husk was used as an adsorbent to study the adsorption of Cr (VI) from wastewater, Based on the experimental studies on influences of the particle size of rice husk, solution pH value, adsorption time, temperature and rice husk dose, the optimal conditions of the adsorption were determined as follows: temperature of 35°C, pH of 2, the particle size of rice husk in the range of 80-100 mesh, adsorption time of 3h, dose of 30g/0.2g. Under the optimal conditions, the removal rate of chromium from wastewater by rice husk can reach 91%.

Mantry and Patra (2015) stated that, the effect of hexavalent chromium (Cr +6) were studied in rice plants by applying two concentrations of Cr, i.e. 10 mg and 50 mg/Kg of soil supplementing with various chelators. The effect of (Cr +6) ions on the physical parameters such as root length, shoot length, fresh weight, dry weight, metal tolerance index and biochemical parameters such as chlorophyll, carotenoid, total sugar and protein content, catalase and peroxidase activity and the uptake of Cr in root and shoot were studied. A decrease in chlorophyll, carotenoid, sugar, protein content and enzyme activity was noticed at higher concentrations of Cr. Supplementation of ethylene diammine tetra acetic acid(EDTA), salicylic acid(SA) and citric acid (CA) as chelating agents also decreases the enzyme activity & other parameters as compared to plant treated with chromium only. Present investigation reports injurious effects of (Cr +6) on different aspects of rice plants. Cr accumulation in plant parts is a matter of serious concern to human health as it causes cardiovascular diseases, kidney failure & cancer.

Trinh *et al*. (2014) reported that, Hexavalent chromium [Cr(VI)] is a non-essential metal for normal plants and is toxic to plants at high concentrations. However, signaling pathways and molecular mechanisms of its action on cell function and gene expression remain elusive. In this study, we found that Cr(VI) induced endogenous reactive oxygen species (ROS) generation and Ca (2+) accumulation and activated NADPH oxidase and calcium-dependent protein kinase. We investigated global transcriptional changes in rice roots by microarray analysis. Gene expression profiling indicated activation of abscisic acid-, ethylene- and jasmonic acid-mediated signaling and inactivation of gibberellic acid-related pathways in Cr(VI) stress-treated rice roots. Genes encoding signaling components such as the protein kinases domain of unknown function 26, receptor-like cytoplasmic kinase, LRK10-like kinase type 2 and protein phosphatase 2C, as well as transcription factors WRKY and apetala2/ethylene response factor were predominant during Cr(VI) stress. Genes involved in vesicle trafficking were subjected to functional characterization. Pretreating rice roots with a vesicle trafficking inhibitor, brefeldin A, effectively reduced Cr(VI)-induced ROS production. Suppression of the vesicle trafficking gene, Exo70, by virus-induced gene silencing strategies revealed that vesicle trafficking is required for mediation of Cr(VI)-induced ROS production. Taken together, these findings shed light on the molecular mechanisms in signaling pathways and transcriptional regulation in response to Cr stress in plants.

Zou and Liu (2014) stated that, in order to analyze the damage mechanism of Cr6+and Pb2+on seed germination and initial growth of rice seedlings, the hydroponic method was used to study the effect of different concentrations of Cr6+(0,0.05,0.15,0.25,0.35,0.45,0.55 mg/L) and Pb2+(0,0.05,0.10, 0.15,0.25,0.35,0.50 mg/L) on the growth and development of rice seedlings. The results showed that the growth of rice seedlings was promoted by Cr6+at low concentrations(≤0.25mg/L) but inhibited by Cr6+ at high concentrations(0.25mg/L), and the inhibition effect increased with the increase of Cr6+concentrations.The content of chlorophyll was also promoted by Cr6+ at low concentrations and inhibited by Cr6+at high concentrations. Older rice seedlings accumulated more Cr6+, and the content of accumulated Cr6+increased with the increase of Cr6+concentrations.The growth of rice seedlings was promoted by Pb2+ at low concentrations(≤0.15mg/L) but inhibited by Pb2+at high concentrations(0.15mg/L), and the inhibition effect increased with the increase of Pb2+ concentrations. The content of chlorophyll was also promoted by Pb2+ at low concentrations and inhibited by Pb2+at high concentrations, and with the increase of age, the immunity of rice seedlings to Pb2+ decreased. High content of accumulated Pb2+was found in older seedlings, however, the accumulated Pb2+content in rice seedlings at the same age was inversely proportional to Pb2+ concentrations.

Hu *et al*. (2014) reported that, hydroponic experiments were conducted to investigate the role of iron plaque on root surface in chromium accumulation and translocation in three rice cultivars (90-68-2, CDR22 and Jin 23A). Rice seedlings were grown under 1.0 mg L^{-1} trivalent chromium (Cr(III)) stress with and without phosphorus (P) treatments. P addition significantly increased the shoot and root biomass in all three rice cultivars. In the absence of P, the amounts of iron plaque (DCB-extractable Fe) on the root surface increased resulting in the increase of Cr accumulation in iron plaque. Compared to that with P treatment, Cr concentrations in iron plaque without P treatment were enhanced by 2–3 folds in the three rice cultivars. There was a significantly positive correlation between DCB-extractable Cr and DCB-extractable Fe on the root surface of the three rice cultivars. There were no significant effects on Cr concentration in roots and shoots between P treatments, but significant differences among cultivars were observed. Cultivar Jin 23A had the lowest Cr concentration both in roots and shoots regardless of P treatment. The results suggest that iron plaque could be a trap for immobilising Cr from environment but may not affect Cr uptake and translocation. Screening and breeding the cultivars with low Cr accumulation is considered as the most effective approach in Cr contaminated areas.

Oliveira (2012) stated that, In the past decades the increased use of chromium (Cr) in several anthropogenic activities and consequent contamination of soil and water have become an increasing concern. Cr exists in several oxidation states but the most stable and common forms are Cr(0), Cr(III) and Cr(VI) species. Cr toxicity in plants depends on its valence state. Cr(VI) as being highly mobile is toxic, while Cr(III) as less mobile is less toxic. Cr is taken up by plants through carriers of essential ions such as sulphate. Cr uptake, translocation, and accumulation depend on its speciation, which also conditions its toxicity to plants. Symptoms of Cr toxicity in plants are diverse and include decrease of seed germination, reduction of growth, decrease of yield, inhibition of enzymatic activities, impairment of photosynthesis, nutrient and oxidative imbalances, and mutagenesis.

Ahmad *et al*. (2011) reported that, the effects of hexavalent chromium (Cr) were studied in rice plants by applying its different concentrations ranging from 50-500 mg/kg of soil. Cr significantly altered growth of rice plants and reduced dry weights of shoot (7-58%) and roots (7-73%) in different treatments. Cr impact was remarkably high on photosynthetic rate (21-62%), transpiration rate (5-59%), and stomatal conductance (21-66%). Chlorophyll a and b and carotenoid contents were also reduced in Cr-treatment plants by 17-47%, 12-43%, 31-50%, respectively. Highly pronounced reductions were recorded in nitrogen (23-82%), phosphorous (4-37%), and potassium (6-42%) content of treated plant leaves. Cr accumulation was extremely higher in shoots (3575- 19150%), roots (1023-5869%), and seeds (21-249%) of treated plants compared with control. Present investigation has reported injurious effects of Cr6+ on different aspect of rice plants. Cr accumulation in threshold amounts in plant parts and seeds is a matter of serious concern to human health as it causes cardiovascular diseases, kidney failure and cancer.

Zeng *et al*. (2011) stated that, the alleviatory effect of silicon (Si) on chromium (Cr) toxicity to rice plants was investigated using a hydroponic experiment with two Cr levels (0 and 100 μmol L^{-1}), three Si levels (0, 1.25, and 2.5 mmol L^{-1}) and two rice genotypes, differing in grain Cr accumulation (Dan K5, high accumulation and Xiushui 113, low accumulation). The results showed that 100 μmol L^{-1} Cr treatment caused a marked reduction of seedling height, dry biomass, soluble protein content, and root antioxidant enzyme activity, whereas significantly increased Cr concentration and TBARS (thiobarbituric acid reactive substances) content. However, the reductions of seedling height, dry biomass, and soluble content were greatly alleviated due to Si addition to the culture solution. Compared with the plants treated with Cr alone, Si addition markedly reduced Cr uptake and translocation in rice plants. No significant differences were observed between the two Si treatments (1.25 and 2.5 mmol L^{-1}) in shoot Cr concentration and Cr translocation factor. Under the treatment of 100 μmol L^{-1} Cr+2.5 mmol L^{-1} Si, higher root Cr concentration but lower shoot Cr concentration and Cr translocation factor were observed in Dan K5 than those in Xiushui 113, indicating that the beneficial effect of Si on inhibiting Cr translocation was more pronounced in Dan K5 than in Xiushui 113. Si addition also alleviated the reduction of antioxidative enzymes (superoxide dismutase (SOD) and ascorbate peroxidase (APX) in leaves; catalase (CAT) and APX in roots) and the increase of TBARS content in the Cr-stressed plants. Furthermore, the beneficial effects of Si on activities of antioxidative enzymes under Cr stress were genotype-dependent. The highest activities of SOD, POD (guaiacol peroxidase), CAT, and APX in leaves occurred in the treatment of 100 μmol L^{-1} Cr+2.5 mmol L^{-1} Si for Xiushui 113 and in the treatment of 100 μmol L^{-1}Cr+1.25 mmol L^{-1} Si for Dan K5. The beneficial effect of Si on alleviating oxidative stress was much more pronounced in Dan K5 than in Xiushui 113. It may be concluded that Si alleviates Cr toxicity mainly through inhibiting the uptake and translocation of

Cr and enhancing the capacity of defense against oxidative stress induced by Cr toxicity.

Ali *et al*. (2011) reported that, Aluminum (Al) and chromium (Cr) stresses often occur simultaneously in agricultural soils, and pose a great damage to crop growth, yield formation and product safety. In the current study, the influence of combined Al and Cr stresses on plant biomass, metal and nutrient contents was determined in comparison with that of Al or Cr stress alone. A hydroponic experiment was conducted to investigate the effect of pH, Al and Cr in the medium solution on the uptake of mineral elements as well as Al and Cr in the two barley genotypes differing in Al tolerance. Aluminum sensitive genotype Shang 70-119 had significantly higher Cr and Al contents in plants than Al-tolerant genotype Gebeina. Barley roots had much higher Al and Cr contents than above-ground plant parts. Chromium contents were much higher in the solution with pH 4.0 than in that with pH 6.5. Aluminum stress reduced phosphorus (P), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), manganese (Mn), zinc (Zn) and boron (B) contents in roots and restrained potassium (K) and iron (Fe) from being translocated into shoots and leaves. Chromium stress resulted in reduced P, K, Mg, S, Fe, Zn and Mn contents in roots at pH 6.5 and P, K, Ca, Mg, S, Zn and Mn contents at pH 4.0. Translocation of all nutrients from roots to upper parts of plants was inhibited except Ca in pH 6.5 with Cr addition. Lower contents of all nutrients were observed at pH 4.0 as compared to pH 6.5. Combined stress of Cr and Al, on the whole, caused further reduction in mineral content in all plant parts of the two barley genotypes as compared to Al or Cr stress alone. Moreover, the reduction was more pronounced in Al sensitive genotype Shang 70-119.

Mohanty *et al*. (2011) stated that, the level of chromium (Cr) contamination in soils and irrigated mine wastewater at South Kaliapani chromite mine region of Orissa, (India) were investigated. Chromium bioaccumulation in rice plants (Oryza sativa L. cv. Khandagiri) irrigated with Cr+6 contaminated mine wastewater was analyzed along with its attenuation from mine wastewater. The levels of Cr+6 in irrigated mine wastewaters in successive rice grown plots were analyzed on 75 days and 100 days after transplantation of seedlings. Total chromium content in different parts of rice plants and soil samples from different plots was analyzed during harvesting stage (125 days after transplantation). Cr accumulation was significantly high in surface soils (0-20 cm) with a mean value of 11,170 mg kg(-1), but it decreased significantly after the crop harvest. About 70% to 90% reduction of Cr+6 levels was observed in irrigated mine wastewater when passed through successive rice plots. High bio-concentration of Cr in leaves with values ranging from 125-498 mg kg(-1) as compared to stem (25-400 mg kg(-1)) and grain (5-23 mg kg(-1)) was noticed. The reduction of Cr+6 levels is related to plant age, high biomass and area of water passage and was attributed to rhizofiltration technique.

Ali *et al*. (2011) reported that, the effect of aluminum and chromium on two barley genotypes differing in Al tolerance was studied in a hydroponic experiment. Al stress decreased plant growth, biomass production, chlorophyll content and photosynthetic efficiency determined as variable to maximum chlorophyll fluorescence ratio (F_v/F_m), net photosynthetic rate (P_N), intercellular CO_2concentration (c_i), stomatal conductance (g_s) and transpiration rate (E) less in an Al-tolerant genotype Gebeina than in an Al-sensitive genotype Shang 70–119. Cr stress also caused marked reduction in growth and photosynthetic traits in barley plants. Higher reduction was observed at pH 4.0 as compared to pH 6.5. Combined stress of Cr and Al, caused further reduction in growth and photosynthetic parameters.

Huang *et al*. (2010) stated that, the growths of two rice genotypes (Jin23A and CDR22) under the coexistence of As and Cr in solution culture with and without P were investigated. The result showed that rice shoot dry weight decreased due to the complex contamination of As and Cr, however, the influences on plant height, root length and root dry weight were insignificant.

Zeng *et al*. (2010) reported that, a hydroponic experiment was carried out to study effects of chromium (Cr) stress on the subcellular distribution and chemical form of Ca, Mg, Fe, and Zn in two rice genotypes differing in Cr accumulation. The results showed that Ca, Mg, Fe, and Zn ions were mainly located in cell walls and vacuoles in roots. However, large amounts of metal ions were transferred from the vacuole to the nucleus and to other functional organelles in shoots. Chromium concentrations in the nutrient solution of 50 μM and above significantly decreased Ca concentrations in the chloroplast/trophoplast, the nucleus, and in mitochondria. It further increased Mg concentrations in the nucleus and in mitochondria, as well as Zn and Fe concentrations in the chloroplast/trophoplast. These Cr-induced changes in ion concentrations were associated with a significant reduction in plant biomass. It is suggested that Cr stress interferes with the functions of mineral nutrients in rice plants, thus causing a serious inhibition of plant growth. The chemical forms of the four nutrients were determined by successive extraction. Except for Ca, which was mainly chelated with insoluble phosphate and oxalic acid, Mg, Zn, and Fe were extractable by 80% ethanol, d-H_2O, and 1μM NaCl. The results indicated that these low–molecular weight compounds, such as organic acids and amino acids, may play an important role in deposition and translocation of Mg, Zn, and Fe in the xylem system of rice plants.

Zhu *et al*. (2010) stated that, Pot experiments were conducted to reveal the discipline of the heavy metal accumulation of rice (Oryza sativa L.) roots at different growth stages of rice plants under zinc and chromium stresses and provided the basis for safe production of rice grains. The results showed as follows: with increasing concentration of zinc in soil, the zinc content in rice roots increased at first and then decreased at different growth stages of rice plants. With increasing concentration of chromium in soil, the chromium content in rice roots increased at different stages of rice plants. The order of zinc content in rice roots was: tillering stage > filling stage > booting stage, and the order of chromium content was: booting stage > filling stage > tillering stage. Partial correlation analysis showed that: the correlation was achieved at a significant or very significant level between the zinc content in rice roots and zinc concentration in soil at different growth stages, and the correlation was achieved at a significant level about the chromium. The concentration of zinc and chromium in soil did not have compound effects to zinc content or chromium content in rice roots.

Dubey *et al*. (2010) reported that, widespread use of chromium (Cr) contaminated fields due to careless and inappropriate management practices of effluent discharge, mostly from industries related to metallurgy, electroplating, production of paints and pigments, tanning, and wood preservation elevates its concentration in surface soil and eventually into rice plants and grains. In spite of many previous studies having been conducted on the effects of chromium stress, the precise molecular mechanisms related to both the effects of chromium phytotoxicity, the defense reactions of plants against chromium exposure as well as translocation and accumulation in rice remain poorly understood. Detailed analysis of genome-wide transcriptome profiling in rice root is reported here, following Cr-plant interaction. Such studies are important for the identification of genes responsible for tolerance, accumulation and defense response in plants with respect to Cr stress. Rice root metabolome analysis was also carried out to relate differential transcriptome data to biological processes affected by Cr (VI) stress in rice. To check whether the Cr-specific motifs were indeed significantly over represented in the promoter regions of Cr-responsive genes, occurrence of these motifs in whole genome sequence was carried out. In the background of whole genome, the lift value for these 14 and 13 motifs was significantly high in the test dataset. Though no functional role has been assigned to any of the motifs, but all of these are present as promoter motifs in the Database of orthologus promoters. These findings clearly suggest that a complex network of regulatory pathways modulates Cr-response of rice. The integrated matrix of both transcriptome and metabolome data after suitable normalization and initial calculations provided us a visual picture of the correlations between components. Predominance of different motifs in the subsets of genes suggests the involvement of motif-specific transcription modulating proteins in Cr stress response of rice.

Zhu *et al*. (2008) reported that, to reveal the impact of zinc and chromium stresses on the quality of rice grain, a set of experiments were conducted where the quality of rice grain was studied across different concentrations of zinc and chromium in the soil. The results revealed many dependencies. For example, the changes in milling quality and the shape of rice grain were minimal. However, increasing concentrations of zinc and chromium in the soil both produced higher rates of chalky rice. Amylose content was found to increase at lower concentrations of zinc in the soil, yet higher concentrations of chromium also produced higher amylose content. The content of crude protein in rice grain showed an increasing trend with increasing concentrations of either zinc or chromium. Finally, a positive correlation was found between the concentration of zinc in the soil and the concentrations of both zinc and chromium in the rice grain. Whereas increasing concentrations of chromium in the soil yielded higher chromium content in the rice but had no measurable impact on zinc content.

Bhattacharyya *et al*. (2005) stated that, effect of addition of municipal solid waste compost (MSWC) on chromium (Cr) content of submerged rice paddies was studied. Experiments were conducted during the three consecutive wet seasons from 1997 to 1999 on rice grown under submergence, at the Experimental Farm of Calcutta University, India. A sequential extraction method was used to determine the various chromium fractions in MSWC and cow dung manure (CDM). Chromium was significantly bound to the organic matter and Fe and Mn oxides in MSWC and CDM. Chromium content in rice straw was higher than in rice grain. Chromium bound with organic matter in MSWC best correlated with straw Cr (r=0.99**) followed by Fe and Mn oxides (r=0.97*) and water soluble as well as exchangeable fractions (r=0.96*). The water soluble and the exchangeable fractions in MSWC best correlated with grain Cr (r=0.98*). The Cr content of rice grain had the highest correlation with water soluble and exchangeable Cr (r=0.99**) while the straw Cr best correlated with the Fe and Mn oxides (r=0.98*). Both the carbonate bound and residual fractions in MSWC and CDM did not significantly correlate with rice straw and grain Cr. MSWC would be a valuable resource for agriculture if it can be used safely, but long-term use may require the cessation of the dumping by the leather tanneries and other major contributors of pollutants.

Shanker *et al*. (2005) reported that, due to its wide industrial use, chromium is considered a serious environmental pollutant. Contamination of soil and water by chromium (Cr) is of recent concern. Toxicity of Cr to plants depends on its valence state: Cr(VI) is highly toxic and mobile whereas Cr(III) is less toxic. Since plants lack a specific transport system for Cr, it is taken up by carriers of essential ions such as sulfate or iron. Toxic effects of Cr on plant growth and development include alterations in the germination process as well as in the growth of roots, stems and leaves, which may affect total dry matter production and yield. Cr also causes deleterious effects on plant physiological processes such as photosynthesis, water relations and mineral nutrition. Metabolic alterations by Cr exposure have also been described in plants either by a direct effect on enzymes or other metabolites or by its ability to generate reactive oxygen species which may cause oxidative stress. The potential of plants with the capacity to accumulate or to stabilize Cr compounds for bioremediation of Cr contamination has gained interest in recent years.

Samantaray *et al*. (1998) stated that, the beneficial as well as toxic effects of chromium with regard to its absorption, translocation and accumulation in different parts of plants were reviewed. High concentrations of chromium exhibited severe chlorosis, necrosis and a host of other growth abnormalities and anatomical disorders. The regulation of the mineral metabolism, enzyme activity and other metabolic processes by chromium in plants was discussed.

Smith *et al.* (1989) reported that, the predominant pathway for human exposure to chromium in non-occupationally exposed individuals is via food with a daily intake of around 30–100 μgd^{-1}, with vegetables providing a major contribution. Unlike reports of chromium essentiality to man and animals, plants appear not to require chromium in spite of some early reports of a stimulatory growth effect. Most reports on chromium in plants have been concerned with their growth on soils amended with sewage sludge, pF-ash, tannery waste, or on ultra basic soils, which contain extreme concentrations of the element.

Experimental studies with plants grown in hydroponic solution have often been undertaken at unrealistically high concentrations to examine the uptake of chromium in various forms, either as CrIII or CrVI at different pHs. In most cases, reports on chromium in plants deal with element concentrations and plant/soil relationships rather than detailed biochemical and physiological processes. In general, chromium is largely retained in the roots of plants, although the oxidation state of chromium, pH, presence of humates and fulvates and plant species, affect plant uptake and transport. Leaves usually contain higher concentrations than grains. The uptake of CrIII is largely a passive process, whereas CrVI uptake is a metabolically mediated process via the sulphate pathway and is thus readily transported around the plant. The presence of a compound similar to trioxalate CrIII has been recorded while little chromium has been reported to be associated with cell organelles or soluble proteins.

CHAPTER III

MATERIALS AND METHODS

The study was conducted at the net house and laboratory of Agro-Environmental chemistry laboratory of Department of Agricultural Chemistry Laboratory of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh from December 2016 to May 2017 to study the toxic effect of chromium on growth, yield and nutritional attributes of BRRI dhan69 and BRRI dhan74. This chapter will deals with a brief description on experimental site, climate, soil, land preparation, layout, experimental design, intercultural operations, data recording and data analysis.

3.1 Experimental site

The study was conducted at the net house and laboratory of Agro-Environmental chemistry laboratory of Department of Agricultural Chemistry Laboratory of Sher-e-Bangla Agricultural University, Dhaka, under the Agro-ecological zone of Modhupur Tract, AEZ-28. The location of the site is $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitude with an elevation of 8.2 meter from sea level.

3.2 Climate and weather

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon period or hot season from March to April and monsoon period from May to October. Details of the meteorological data of air temperature, relative humidity and rainfall during the period of the experiment were collected from the SAU mini weather station, Sher-e-Bangla Agricultural University, Dhaka presented in Appendix I.

3.3 Soil

The soil belongs to "The Modhupur Tract", AEZ – 28 (FAO, 1988). Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish-brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land. The details were presented in Appendix II.

3.4 Plant material

In this research work, two inbreed varieties i.e. BRRI dhan69 and BRRI dhan74 were used as plant materials. The seeds were collected from the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh.

3.5 Experimental details

3.5.1 Treatments

Two factor experiments were conducted to evaluate the toxic effect of chromium on growth, yield, biochemical and nutritional attributes of rice. The test varieties that were used in the present study were as follows:

Factor A: Two rice varieties

i. V_1= BRRI dhan69

ii. V_2= BRRI dhan74

Factor B: Different Cr levels

i) T_1= 0 mg Cr/kg soil

ii) T_2= 12.5 mg Cr/kg soil

iii) T_3= 25 mg Cr/kg soil

iv) T_4= 50 mg Cr/kg soil

v) T_5= 75 mg Cr/kg soil

vi) T_6 =100 mg Cr/kg soil

Treatment combination

V_1T_1, V_1T_2, V_1T_3, V_1T_4, V_1T_5, V_1T_6, V_2T_1, V_2T_2, V_2T_3, V_2T_4, V_2T_5, V_2T_6

3.5.2 Experimental design

The experiment was laid out in Completely Randomized Design (CRD) with four replications. The layout of the experiment was prepared for distributing the varieties and Cr concentration. There were 48 pots for this experiment having.

The treatments of the experiment were assigned at random into each replication following the experimental design. Seed were sown in the seed bed. When age of seedling was 35 days then up rooted and transplanted maintaining line to line distance 25 cm and hill to hill distance 15 cm. Two seedlings $hill^{-1}$ (pot^{-1}) were used during transplanting.

3.6 Growing of crops

3.6.1 Raising seedlings

3.6.1.1 Seed sprouting

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then it was kept tightly in gunny bags. The seeds started sprouting after 48 hours.

3.6.1.2 Preparation of nursery bed and seed sowing

As per BRRI recommendation seedbed was prepared with 1 m wide adding nutrients as per the requirements of soil. Seed were sown in the seed bed @ 70 g m^{-2} on 01 November, 2016.

3.6.2 Preparation of the pots

The pots were filled with soil of the central experiment field. Weeds free soil was used and before transplanting the seedling herbicide was also applied.

3.6.3 Fertilizers and manure application

The following doses of manure and fertilizers (BRRI, 2013) were used.

Manure and Fertilizer	Doses
Cowdung	5 t ha^{-1}
Urea	220 kg ha^{-1}
TSP	165 kg ha^{-1}
MoP	180 kg ha^{-1}
Gypsum	70 kg ha^{-1}
Zinc	10 kg ha^{-1}

Whole amount of cow-dung, TSP, MP, Gypsum and Zinc and one third of urea were applied at the time of final pots preparation. Half of the rest two third of urea was applied at 20 DAT and the rest amount of urea was applied at 45 DAT.

3.6.4 Uprooting seedlings

The nursery bed was made wet by application of water one day before uprooting the seedlings. The seedlings were uprooted on December 14, 2015 without causing much mechanical injury to the roots.

3.6.5 Transplanting of seedlings in the field

The seedlings were transplanted in the main field on December 14, 2016 and the rice seedlings were transplanted in lines each having a line to line distance of 20 cm and plant to plant distance was 15 cm for all test varieties in the well-prepared plot.

3.6.6 Cultural operations

The details of different cultural operations performed during the course of experimentation are given below:

3.6.6.1 Irrigation and drainage

Three water regimes namely, low land transplant, raised upland, raised transplant were used as main plot treatment.

3.6.6.2 Gap filling

Gap filling was done for all of the plots at 7-10 days after transplanting (DAT) by planting same aged seedlings.

3.6.6.3 Weeding

First weeding was done from each plot at 15 DAT and second weeding was done from each plot at 40 DAT. Mainly hand weeding was done from each plot.

3.6.6.4 Plant protection

Furadan 57 EC was applied before the time of translating and Dimecron 50 EC was applied at 30 DAT.

3.7 Harvesting, threshing and cleaning

The rice plant was harvested depending upon the maturity of grains and harvesting was done manually from each plot. Maturity of crop was determined when 80-90% of the grains become golden yellow in color. Enough care was taken for harvesting, threshing and also cleaning of rice seed.

Fresh weight of grain and straw were recorded pot wise. Finally, the weight was adjusted to a moisture content of 14%. The straw was sun dried and the yields of grain and straw plot^{-1} were recorded and converted to t ha^{-1}.

3.8 Data recording

A. Plant height (cm)
B. Number of tillers hill^{-1}
C. Number of effective tillers hill^{-1}
D. Number of non-effective tillers hill^{-1}
E. Number of leaves hill^{-1}
F. Length of leaves
G. Panicle length (cm)
H. Number of filled grain
I. Number of unfilled grain
J. Weight of 1000 grains
K. Grain yield (t ha^{-1})
L. Chemical analysis (Cr, Na, P, K and S)

3.8.1 Plant height

The height of plant was recorded in centimeter (cm) at the time of 75 DAT (days after transplanting) and at harvest. The height was measured from the ground level to the tip of the plant.

3.8.2 Tillers hill^{-1}

The number of tillers hill^{-1} was recorded at 75 DAT (days after transplanting) and at harvest by counting total tillers.

3.8.3 Number of effective tillers hill^{-1}

Number of effective tillers were counted from each hill.

3.8.4 Number of non-effective tillers hill^{-1}

Number of non-effective tillers were also counted from each hill.

3.8.5 Number of leaves hill^{-1}

Number of leaves per hill was counted from each treatment.

3.8.6 Length of leaves

Leaf from each treatment was selected and length was calculated using the measuring tape.

3.8.7 Panicle length

The length of the panicle was measured using the measuring tape and expressed as centimeter (cm).

3.8.8 Number of filled grain

The filled grain was counted from each treatment and recorded as number of filled grain.

3.8.9 Number of filled grain

The unfilled grain was counted from each treatment and recorded as number of unfilled grain.

3.8.10 Weight of 1000 grains

One thousand grains were counted randomly from the total cleaned harvested grains of each individual plot and then weighed with an electric balance in grams and recorded.

3.8.11 Grain yield

The matured plant from each pot were harvested, threshed, dried, weighed and finally converted to yield as t ha^{-1} basis.

3.8.12 'Cr' analysis

Cr was analyzed using the atomic absorption spectrophotometer.

3.8.13 'Na' Analysis

The element Na was analyzed using the flame photometer.

3.8.14 'P' analysis

Another important element P was analyzed using the Spectrophotometer.

3.8.15 'K' analysis

The important element K was analyzed using the flame photometer.

3.8.16 'S' analysis

An important element S was analyzed using the Spectrophotometer.

3.9 Statistical Analysis

The data obtained for different characters were statistically analyzed using statistix 10 software to observe the significant difference among the treatment. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means were estimated by the Tukey's test at 5% level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to study the toxic effect of chromium on growth, yield and nutritional attributes of BRRI dhan69 and BRRI dhan74. Data on different growth, other parameter, yield attributes and biochemical properties were recorded. The analyses of variance (ANOVA) of the data on different parameters are presented in Appendix section. The results have been presented with the help of graphs and table and possible interpretations given under the following headings

4.1 Plant height

4.1.1 Effect of Chromium

Due to application of chromium plant height of rice showed positively significant variations (Figure 1 and Appendix III). The plant height ranges from 38.87 cm to 43.25 cm, 65.87 cm to 79.25 cm, 79.62 cm to 92.00 cm and 81.00 cm to 92.87 cm at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. For the application of chromium, the tallest plant was recorded in T_1 treatment while the shortest plant was recorded in T_5 treatment at all sampling dates. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*.

(2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.1.2 Effect of variety

The height of rice plant showed statistically positive and significant impact due to different varieties of rice cultivation (Figure 1 and Appendix III). The tallest rice plant was recorded in V_2 while the shortest plant was in V_1. The plant height ranges from 39.62 cm to 41.20 cm, 69.62 cm to 72.33 cm, 81.62 cm to 90.16 cm and 82.54 cm to 91.04 cm at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. This might be genetic variation among the varieties while V_2 showed superior result than others. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

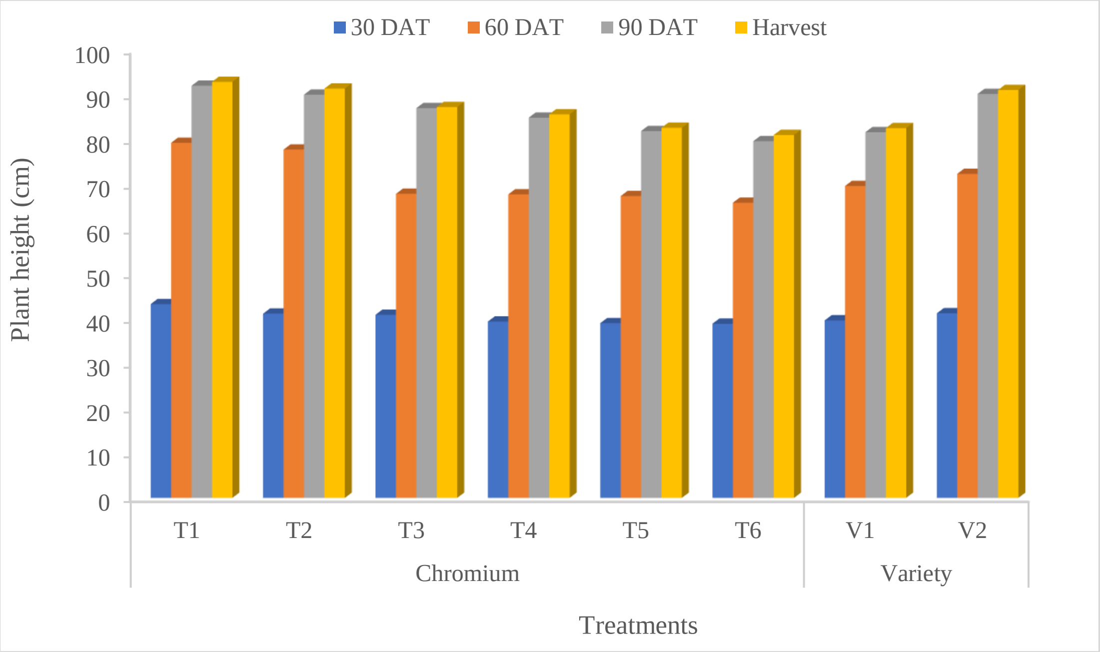

Figure 1. Effect of chromium and variety on plant height

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.1.3 Combined effect of chromium and variety

The interaction effect of chromium and variety produced statistically significant plant height at all sampling dates except at 90 DAT (Table 1 and Appendix III). For the interaction effect the height of rice plant ranges from 39.25 cm to 45.25 cm, 65.50 cm to 83.75 cm, 75.00 cm to 96.25 cm and 76.25 cm to 97.75 cm at 30 DAT, 60 DAT and 90 DAT and harvest time, respectively. The tallest plant was found in T_1V_2 and the shortest plant was found in T_6V_1 combination compared to the others combination.

Table 1. Combined effect of chromium and variety on plant height

Treatment	Plant height (cm) at			
	30 DAT	60 DAT	90 DAT	Harvest
T_1V_1	41.25 bc	74.75 b	87.75	88.00 bcd
T_2V_1	40.50 bc	72.75 bc	85.00	86.00 cde
T_3V_1	40.50 bc	70.00 cd	83.25	84.50 ef
T_4V_1	39.50 bcd	65.50 e	81.00	82.25 f
T_5V_1	38.00 d	69.00 d	77.75	78.25 g
T_6V_1	38.00 d	65.75 e	75.00	76.25 g
T_1V_2	45.25 a	83.75 a	96.25	97.75 a
T_2V_2	41.75 b	82.75 a	95.00	96.75 a
T_3V_2	41.25 bc	65.50 e	90.75	90.00 b
T_4V_2	39.25 cd	70.25 cd	88.75	89.00 bc
T_5V_2	40.00 bcd	65.75 e	86.00	87.00 bcde
T_6V_2	39.75 bcd	66.00 e	84.25	85.75 de
SE (±)	0.68	0.83	NS	0.91
CV (%)	2.39	1.66	-	1.48

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.2 Number of tillers hill^{-1}

4.2.1 Effect of chromium

The number of tiller hill^{-1} showed positively significant difference for different chromium (Figure 2 and Appendix IV). Due to chromium, the ranges of number of tillers hill^{-1} was found 16.12 to 21.00, 34.37 to 45.87, 48.75 to 64.87 and 58.50 to 63.00 at 30 DAT, 60 DAT, 90 DAT and harvest times, respectively. The maximum number of tillers hill^{-1} was recorded in T_1 while the minimum number of leaves hill^{-1} was recorded in treatment T_6. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.2.2 Effect of variety

The different varieties of rice showed positively significant effect for number of tillers hill^{-1} only at 30 DAT (Figure 2 and Appendix IV). The maximum number of tillers hill^{-1} was found in V_2 treatment while the minimum number of tillers hill^{-1} was recorded in V_1 treatment. The tillers number ranges from 17.50 to 19.04, 39.33 to 40.00, 57.08 to 57.62 and 61.54 to 61.67 at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

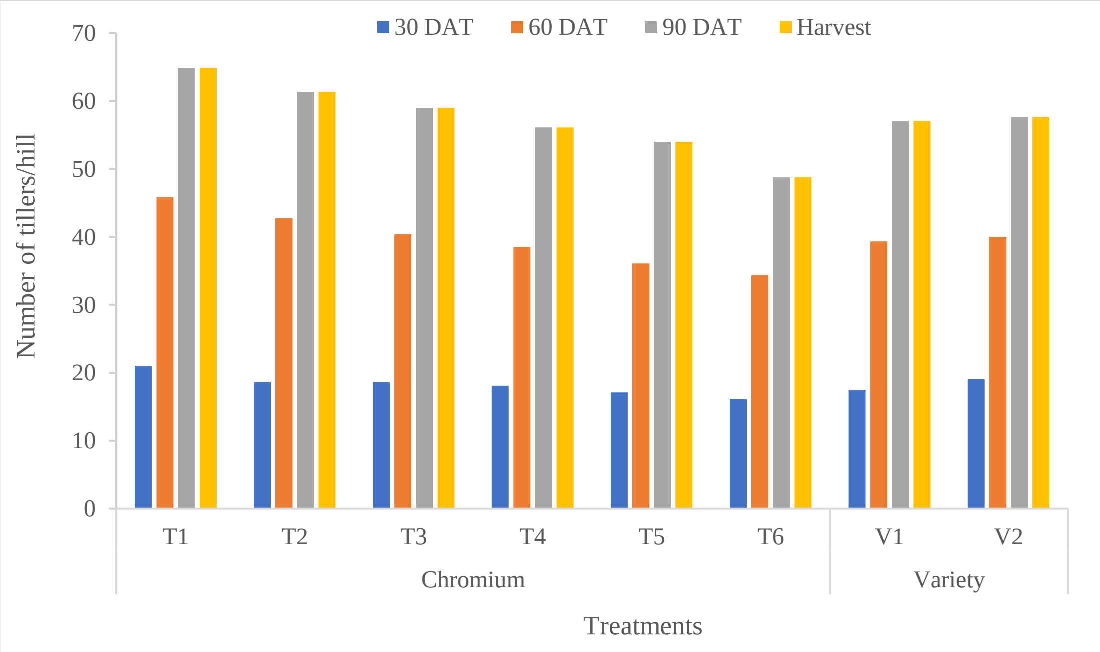

Figure 2. Effect of chromium and variety on number of tillers hill^{-1}

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.2.3 Combined effect of chromium and variety

The interaction effect of chromium and variety showed non-significant impact on number of tillers hill^{-1} only at all sampling dates (Table 2 and Appendix IV). In spite of having non-significant effect, the number of tillers hill^{-1} ranges from 16.00 to 19.25, 34.00 to 45.25, 48.25 to 65.00 and 57.75 to 63.25 at 30 DAT, 60

DAT, 90 DAT and harvest time, respectively while T_1V_1 produced the maximum number of tillers and T_6V_1 produced minimum number of tillers.

Table 2. Combined effect of chromium and variety on number of tillers hill^{-1}

Treatment	Number of tiller at			
	30 DAT	60 DAT	90 DAT	Harvest
T_1V_1	19.25	45.25	65.00	65.00
T_2V_1	17.50	43.50	62.25	62.25
T_3V_1	18.25	39.00	58.50	58.50
T_4V_1	17.25	38.25	56.50	56.50
T_5V_1	16.75	36.00	54.25	54.25
T_6V_1	16.00	34.00	49.25	49.25
T_1V_2	22.75	46.50	64.75	64.75
T_2V_2	19.75	42.00	60.50	60.50
T_3V_2	19.00	41.75	59.50	59.50
T_4V_2	19.00	38.75	55.75	55.75
T_5V_2	17.50	36.25	53.75	53.75
T_6V_2	16.25	34.75	48.25	48.25
SE (±)	NS	NS	NS	NS
CV (%)	-	-	-	-

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.3 Number of effective tillers hill^{-1}

4.3.1 Effect of Chromium

The number of effective tillers hill^{-1} showed positively significant difference for different doses of chromium application (Figure 3 and Appendix V). Due to chromium application, the ranges of number of effective tillers hill^{-1} was found 28.00 to 42.87. The maximum number of effective tillers hill^{-1} was recorded in T_1 while the minimum number of effective tillers hill^{-1} was recorded in T_6. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.3.2 Effect of variety

The different varieties of rice showed positively significant effect for number of effective tillers hill^{-1} (Figure 3 and Appendix V). The maximum number of effective tillers hill^{-1} was found in V_2 treatment while the minimum number of effective tillers hill^{-1} was recorded in V_1 treatment. The number of effective tillers ranges from 34.83 to 37.54. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

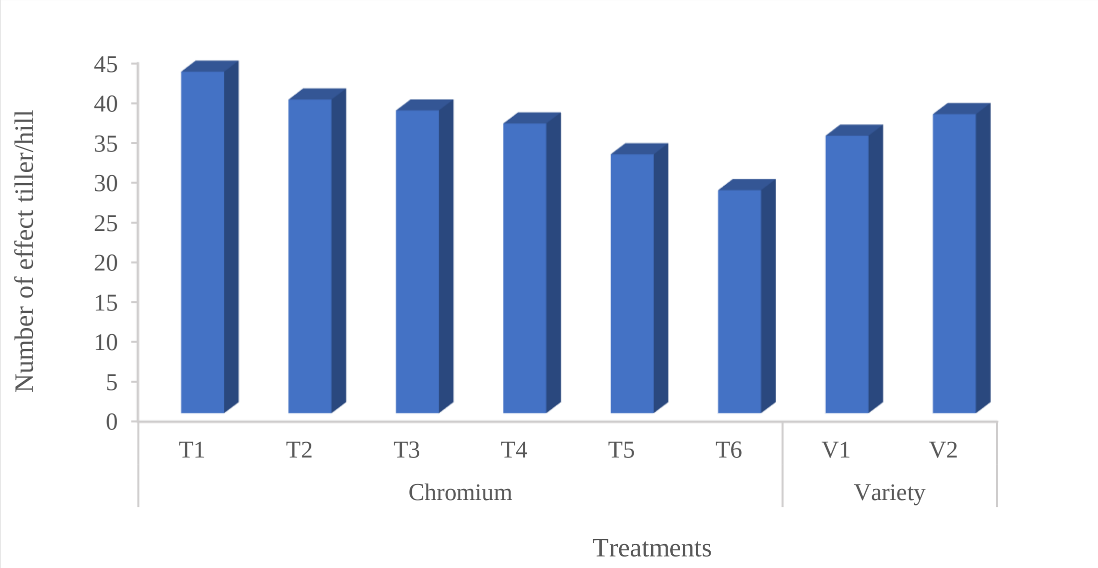

Figure 3. Effect of chromium and variety on number of effective tillers hill^{-1}

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.3.3 Combined effect of chromium and variety

The interaction effect of chromium and variety showed significant impact ($p \leq 0.05$) on number of effective tillers hill^{-1} (Table 3 and Appendix V). The number of effective tillers hill^{-1} ranges from 25.75 to 42.25 while T_1V_1 produced the maximum number of effective tillers and T_6V_1 produced the minimum number of effective tillers.

Table 3. Combined effect of chromium and variety on number of effective and non-effective tiller

Treatment	Number of effect tiller	Number of non-effective tiller

T_1V_1	42.25 ab	20.75
T_2V_1	38.75 cd	23.75
T_3V_1	36.75 def	26.50
T_4V_1	35.00 ef	27.50
T_5V_1	30.50 g	29.75
T_6V_1	25.75 h	32.00
T_1V_2	43.50 a	19.50
T_2V_2	40.00 bc	21.00
T_3V_2	39.25 cd	22.25
T_4V_2	37.75 cde	25.50
T_5V_2	34.50 f	27.50
T_6V_2	30.25 g	29.00
SE (±)	0.83	NS
CV (%)	3.27	-

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.4 Number of non-effective tillers hill^{-1}

4.4.1 Effect of Chromium

The number of non-effective tillers hill^{-1} showed positively significant variations for different doses of chromium application (Figure 4 and Appendix VI). Due to chromium application, the ranges of number of non-effective tillers hill^{-1} was found 20.12 to 30.50. The maximum number of non-effective tillers hill^{-1} was recorded in T_6 while the minimum number of non-effective tillers hill^{-1} was recorded in T_1. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*.

(2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.4.2 Effect of variety

The different varieties of rice showed positively significant effect for number of non-effective tillers hill^{-1} (Figure 4 and Appendix VI). The maximum number of non-effective tillers hill^{-1} was found in V_2 treatment while the minimum number of non-effective tillers hill^{-1} was recorded in V_1 treatment. The number of non-effective tillers ranges from 24.12 to 26.70. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

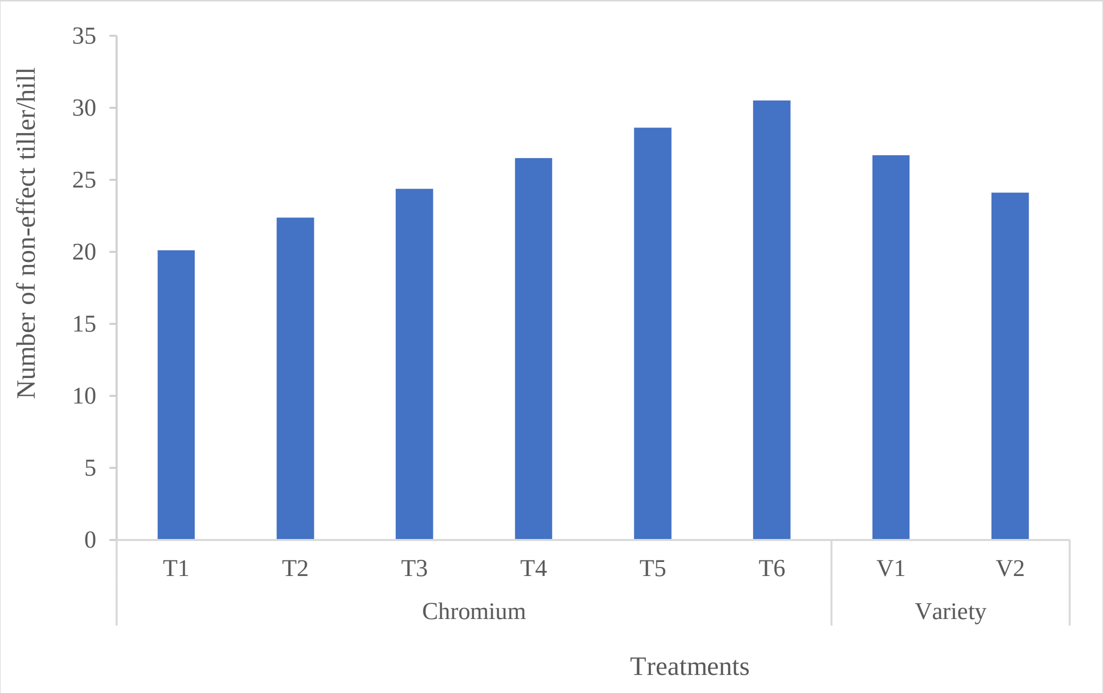

Figure 4. Effect of chromium and variety on number of non-effective tillers hill^{-1}

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.4.3 Combined effect of chromium and variety

The interaction effect of chromium and variety showed non-significant impact ($P \leq 0.05$) on number of non-effective tillers hill^{-1} (Table 4 and Appendix VII). The number of non-effective tillers hill^{-1} ranges from 20.75 to 32.00 while T_1V_1 produced the minimum number of effective tillers and T_6V_1 produced the maximum number of effective tillers.

4.5 Number of leaves hill^{-1}

4.5.1 Effect of chromium

The number of leaves hill^{-1} showed positively significant difference for different levels of chromium application (Figure 5 and Appendix VII). The ranges of number of leaves hill^{-1} was found 44.75 to 57.50, 73.25 to 87.87 and 94.75 to 107.50 at 30 DAT, 60 DAT and 90 DAT, respectively. The maximum number of leaves hill^{-1} was recorded in T_1 while the minimum number of leaves hill^{-1} was recorded in T_6 at all sampling dates. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.5.2 Effect of variety

The different types of varieties of rice showed positively significant influence on number of leaves hill^{-1} (Figure 5 and Appendix VII). The maximum number of leaves hill^{-1} was found in V_2 treatment while the minimum number of leaves hill^{-1} was recorded in V_1 treatment. The leaves number ranges from 46.54 to 55.54, 75.87 to 84.94 and 97.25 to 104.29 at 30 DAT, 60 DAT and 90 DAT, respectively. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

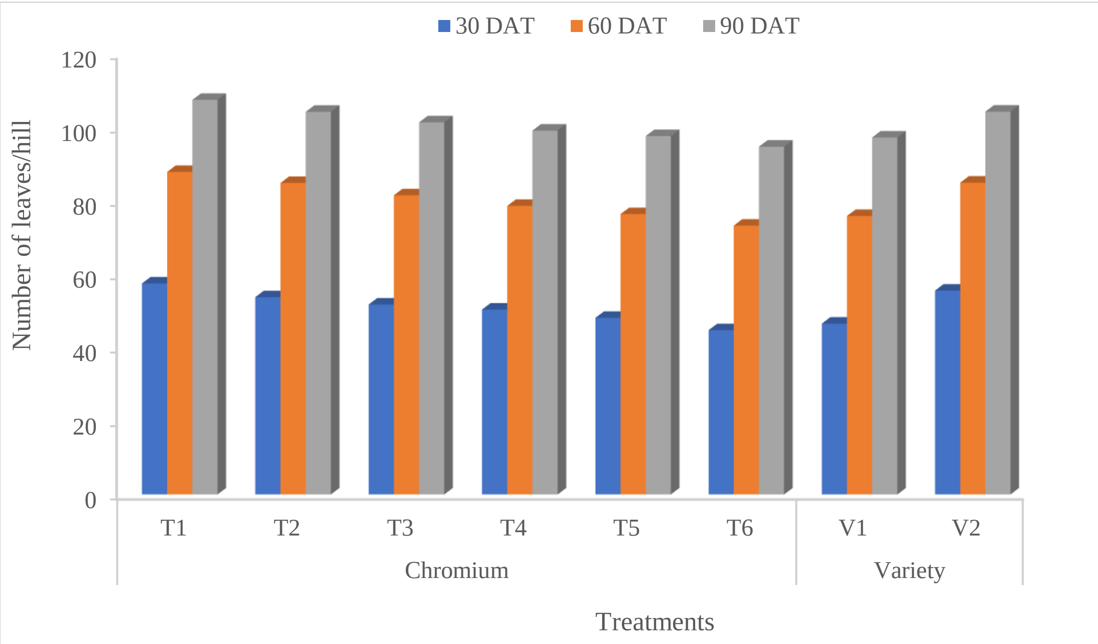

Figure 5. Effect of chromium and variety on number of leaves hill^{-1}

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.5.3 Combined effect of chromium and variety

The interaction effect of chromium and variety showed significant impact on number of leaves hill^{-1} only at harvest time (Table 4 and Appendix VII). The number of leaves hill^{-1} ranges from 41.00 to 53.00, 69.00 to 83.25, 92.00 to 102.75 at 30 DAT, 60 DAT and 90 DAT, respectively while T_1V_1 produced the maximum number of leaves and T_6V_1 produced minimum number of leaves.

Table 4. Combined effect of chromium and variety on number of leaves hill^{-1}

Treatment	Number of leaves at		
	30 DAT	60 DAT	90 DAT
T_1V_1	53.00	83.25	102.75 cd
T_2V_1	49.50	80.50	100.50 de
T_3V_1	47.00	76.75	98.00 ef
T_4V_1	45.00	74.00	95.50 fg
T_5V_1	43.75	71.75	94.75 gh
T_6V_1	41.00	69.00	92.00 h
T_1V_2	62.00	92.50	112.25 a
T_2V_2	58.00	89.25	108.00 b
T_3V_2	56.50	86.25	104.75 c
T_4V_2	55.75	83.25	102.75 cd
T_5V_2	52.50	81.00	100.50 de
T_6V_2	48.50	77.50	97.50 fg
SE (±)	NS	NS	0.81
CV (%)	-	-	1.14

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.6 Leaf length

4.6.1 Effect of chromium

Due to the chromium application leaf length showed positively significant variations (Figure 6 and Appendix VIII). The leaf length ranges from 24.25 cm to 35.25 cm, 54.00 cm to 68.12 cm and 67.62 cm to 79.37 cm at 30 DAT, 60 DAT and 90 DAT. The height leaf length was recorded in T_1 treatment and the lowest leaf length was recorded in T_6 treatment. This might be due to that Cr application made a toxic effect in plant and ultimately reduce the vegetative growth of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.6.2 Effect of variety

The leaf length showed statistically significant impact due to cultivation of different rice varieties (Figure 6 and Appendix VIII). The highest leaf length was recorded in V_2 while the lowest leaf length was found in treatment V_1. The leaf length ranges from 28.75 cm to 30.37 cm, 54.66 cm to 65.87 cm and 71.00 cm ti 76.29 cm at 30 DAT, 60 DAT and 90 DAT. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

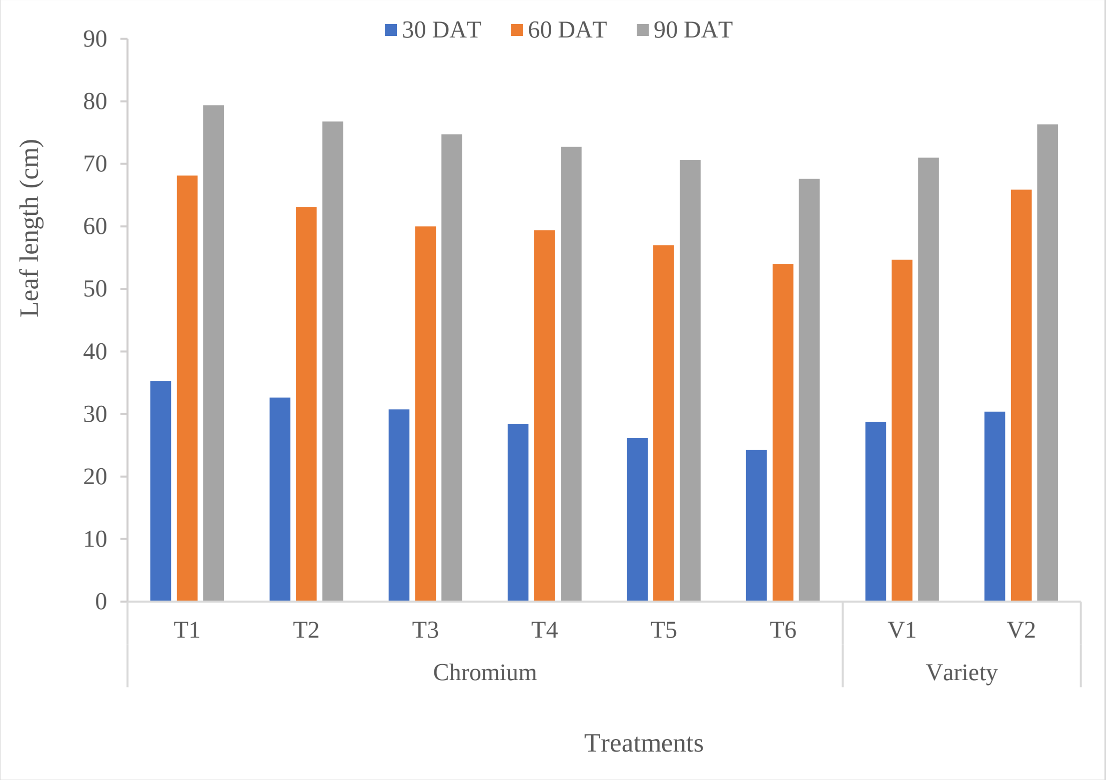

Figure 6. Effect of chromium and variety on leaf length

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.6.3 Combined effect of chromium and variety

The interaction effect of chromium and variety produced statistically significant variation in terms of leaf length of rice only at 90 DAT (Table 5 and Appendix VIII). Though the rest of the sampling dates the length showed non-significant variations, the highest leaf length was found in T_1V_2 and lowest leaf length was found in T_6V_1 combination compared to the others interaction. For combined effect the leaf length ranges from 23.50 cm to 36.50 cm, 49.50 cm to 72.75 cm, 63.50 cm to 81.50 cm at 30 DAT, 60 DAT and 90 DAT.

Table 5. Combined effect of chromium and variety on leaf length

Treatment	Leaf length (cm) at		
	30 DAT	60 DAT	90 DAT
T_1V_1	34.00	63.50	77.25 bc
T_2V_1	32.00	48.25	74.75 de
T_3V_1	29.75	58.75	72.75 f
T_4V_1	27.75	56.00	70.00 g
T_5V_1	25.50	52.00	67.75 h
T_6V_1	23.50	49.50	63.50 i
T_1V_2	36.50	72.75	81.50 a
T_2V_2	33.25	70.50	78.75 b
T_3V_2	31.75	67.50	76.75 c
T_4V_2	29.00	64.00	75.50 cd
T_5V_2	26.75	62.00	73.50 ef
T_6V_2	25.00	58.50	71.75 fg
SE (±)	NS	NS	0.81
CV (%)	-	-	1.09

DAT= Day after transplanting; T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.7 Panicle length

4.7.1 Effect of Chromium

Panicle length of rice showed positive significant difference for the application of different doses of chromium (Figure 7 and Appendix IX). The highest value of panicle length (31.00 cm) was recorded in T_1 while the lowest value of the same traits was (21.00 cm) was recorded in the treatment T_6. This might be due to that Cr application made a toxic effect in plant which ultimately reduce the vegetative growth as well as reproductive development of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.7.2 Effect of variety

Impact of variety on rice showed positively significant effect for the panicle length (Figure 7 and Appendix IX). The highest value of the panicle length (27.66 cm) was found in V_2 treatment while the lowest value of the panicle length (24.66 cm) was recorded in V_1 treatment. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

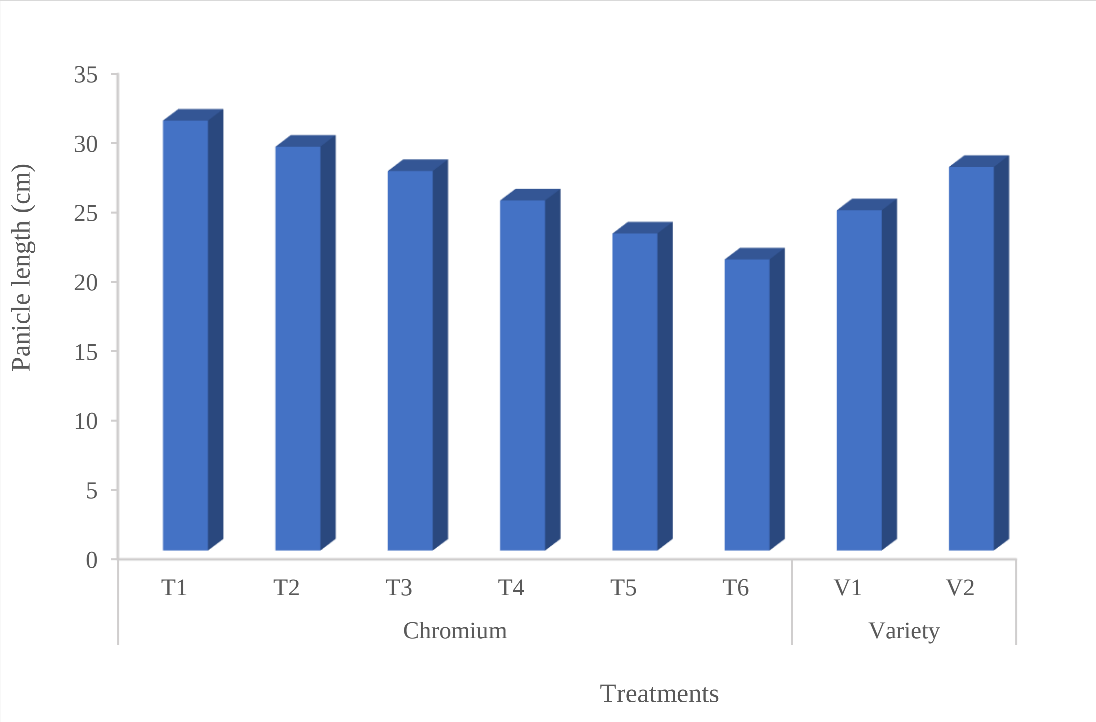

Figure 7. Effect of chromium and variety on panicle length

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.7.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant variations on panicle length of rice (Table 6 and Appendix IX). The T_1V_2 produced the height value of panicle length and the combination T_6V_1 produced the lowest value of panicle length. The panicle length ranges from 20.25 cm to 34.00 cm.

Table 6. Combined effect of chromium and variety on panicle length

Treatments	Panicle length (cm)
T_1V_1	28.00 d
T_2V_1	26.75 de
T_3V_1	25.25 fg
T_4V_1	24.00 gh
T_5V_1	23.00 hi
T_6V_1	20.25 j
T_1V_2	34.00 a
T_2V_2	31.50 b
T_3V_2	29.50 c
T_4V_2	26.50 ef
T_5V_2	22.75 hi
T_6V_2	21.75 i
SE (±)	0.42
CV (%)	2.3

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.8 Number of filled grains panicle^{-1}

4.8.1 Effect of Chromium

Due to chromium number of filled grains panicle^{-1} showed positively significant variations (Figure 8 and Appendix X). The number of filled grains panicle^{-1} range from 181.00 to 203.00. The maximum number of filled grains panicle^{-1} was recorded in T_1 treatment and the minimum number of filled grains panicle^{-1}

was recorded in T_6 treatment. This might be due to that Cr application made a toxic effect in plant which ultimately reduce the vegetative growth as well as reproductive development of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.8.2 Effect of variety

The number of filled grains panicle^{-1} showed positively and statistically significant impact due to different variety of rice (Figure 8 and Appendix X). The maximum number of filled grains panicle^{-1} was recorded in V_2 while the lowest values of number of filled grains panicle^{-1} was found in V_1. The number of filled grains panicle^{-1} ranges from 201.58 to 182.00. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

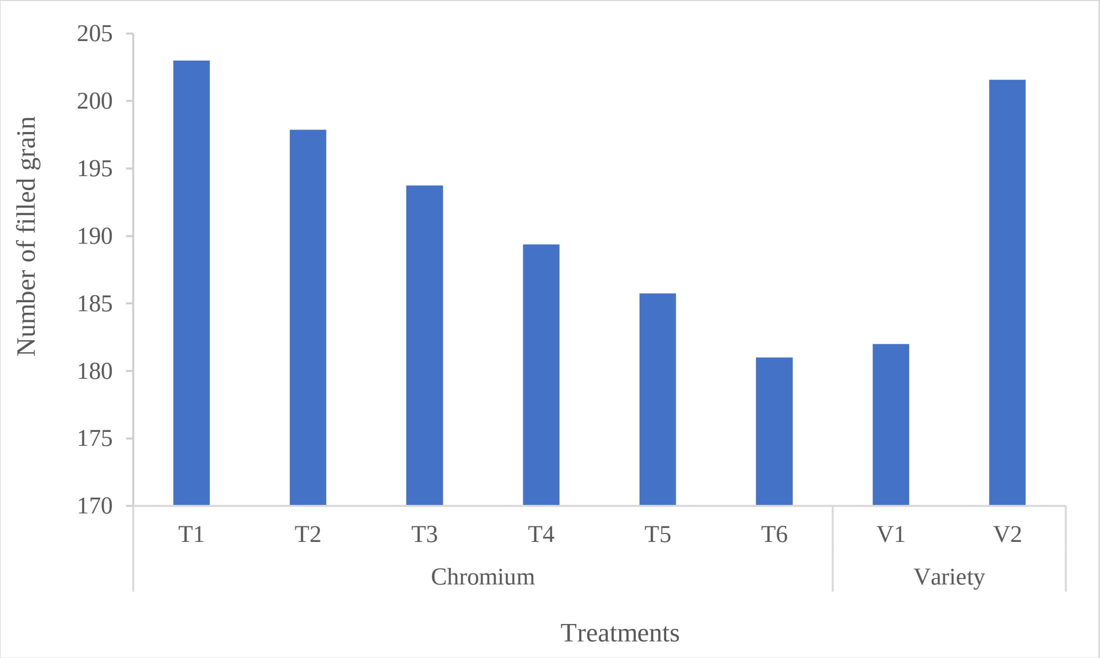

Figure 5. Effect of chromium and variety on number of filled grains

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.8.3 Combined effect of chromium and variety

Combined effect of chromium and variety produced statistically significant variations on number of filled grains panicle^{-1} (Table 7 and Appendix X). For the combined effect, the number of filled grains panicle^{-1} ranges from 211.50 to 194.50. The maximum number of filled grains panicle^{-1} was found in T_1V_2 and minimum number of filled grains panicle^{-1} was recorded in T_5V_1 combination compared to the others combination.

Table 7. Combined effect of chromium and variety on number of filled and unfilled grain

Treatments	Number of filled grain	Number of unfilled grain
T_1V_1	194.50 e	45.75 f
T_2V_1	188.50 f	48.00 e
T_3V_1	183.50 g	51.00 d
T_4V_1	179.25 h	53.50 c
T_5V_1	175.50 i	56.50 b
T_6V_1	170.75 j	60.75 a
T_1V_2	211.50 a	35.00 i
T_2V_2	207.25 b	37.25 h
T_3V_2	204.00 c	39.00 h
T_4V_2	199.50 d	41.00 g
T_5V_2	196.00 e	44.25 f
T_6V_2	191.25 f	48.00 e
SE (±)	0.85	0.53
CV (%)	0.63	1.62

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.9 Number of unfilled grains pancile^{-1}

4.9.1 Effect of chromium

Number of unfilled grains panicles^{-1} showed positive significant difference for different doses of chromium application (Figure 9 and Appendix XI). Due to chromium application, the unfilled grains panicles^{-1} ranges were found from 40.37 to 54.37. The maximum number of unfilled grains panicles^{-1} was recorded in T_6 while the minimum number of unfilled grains panicles^{-1} was recorded in T_1. This might be due to that Cr application made a toxic effect in plant which ultimately reduce the vegetative growth as well as reproductive development of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.9.2 Effect of variety

Impact of variety on rice showed positively significant variations on number of unfilled grains panicles^{-1} (Figure 9 and Appendix XI). The maximum number of unfilled grains panicles^{-1} was found in V_1 while minimum number of unfilled grains panicles^{-1} was recorded in V_2 treatment. The number of unfilled grains panicles^{-1} ranges from 40.75 to 52.58. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

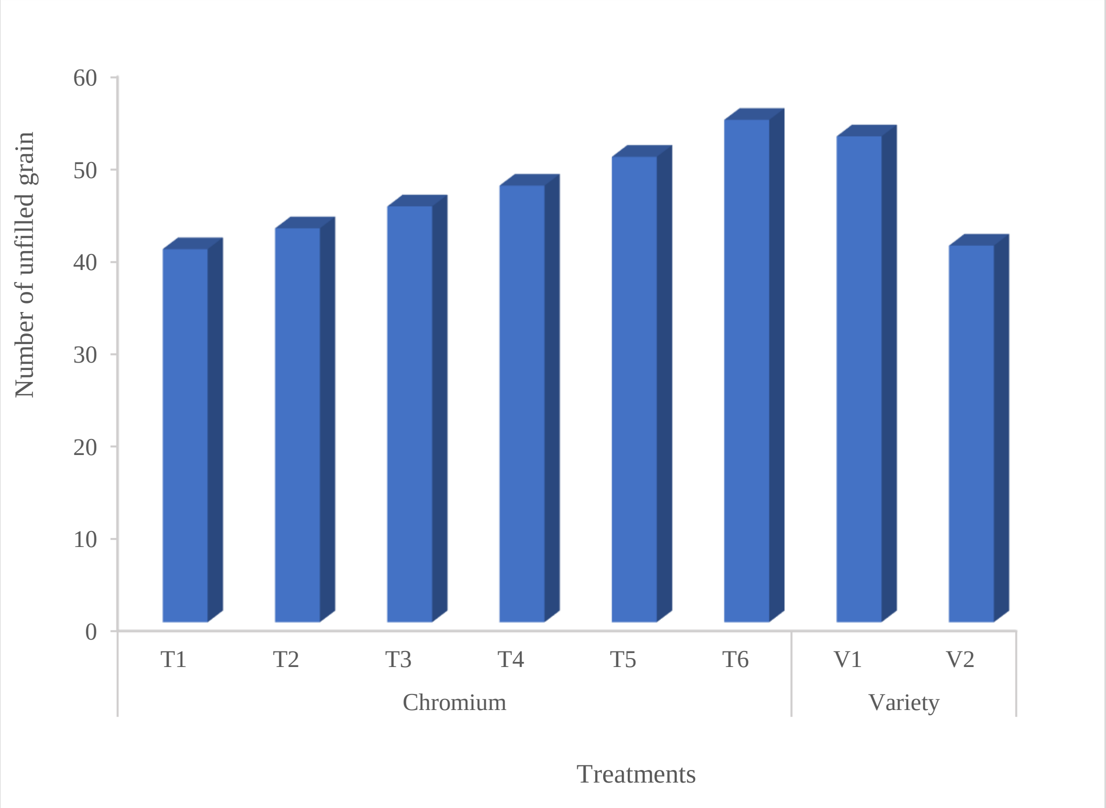

Figure 9. Effect of chromium and variety number of unfilled grains

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.9.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant impact on number of unfilled grains panicles^{-1} (Table 8 and Appendix XI). The number of unfilled grains panicles^{-1} ranges from 35.00 to 60.75 while T_6V_1 produced the maximum number of unfilled grains panicles^{-1} and T_1V_2 produced minimum number of unfilled grains panicles^{-1}.

4.10 Weight of 1000 grains

4.10.1 Effect of chromium

Due to chromium application the 1000 grains weight showed positively significant result of rice plant (Figure 10 and Appendix XII). The 1000 grains weight ranges from 22.62 g to 29.25 g. The highest 1000 grains weight was recorded in T_1 treatment and the lowest 1000 grains weight was recorded in T_6 treatment. This might be due to that Cr application made a toxic effect in plant which ultimately reduce the vegetative growth as well as reproductive development of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.10.2 Effect of variety

The 1000 grains weight showed statistically significant impact due to different variety of rice cultivation (Figure 10 and Appendix XII). The highest 1000 grains weight was recorded in V_2 while lowest 1000 grains weight was in V_1. The 1000 grains weight ranges from 24.58 g to 26.16 g. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

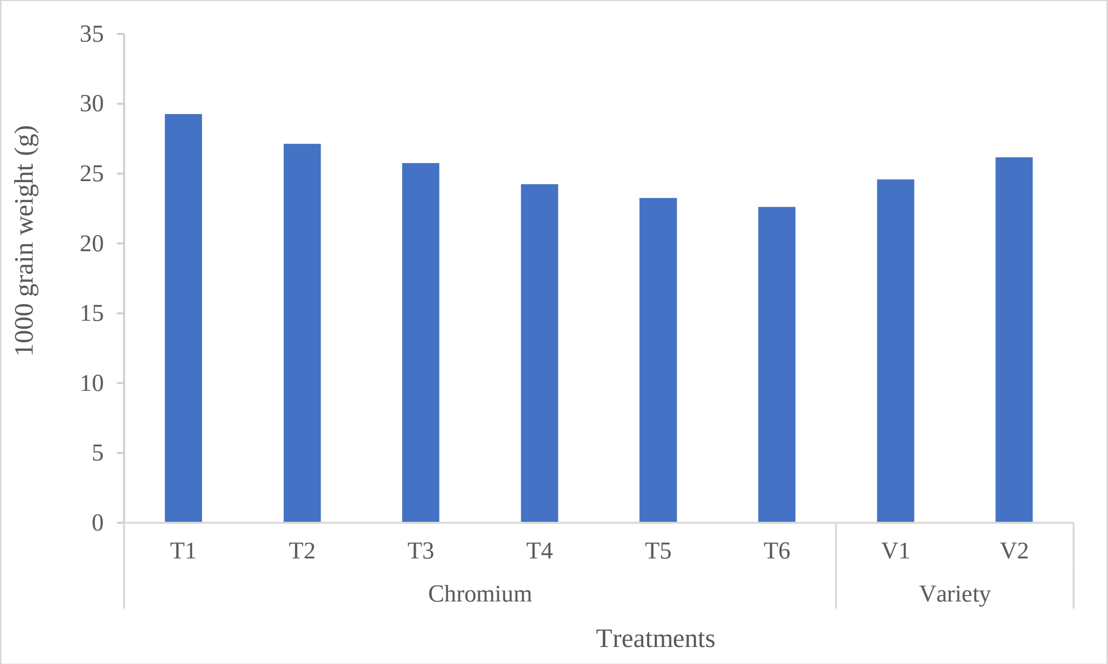

Figure 10. Effect of chromium and variety on 1000 grains weight

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.10.3 Combined effect of chromium and variety

The combined effect of chromium and variety produced statistically significant 1000 grains weight (Table 6 and Appendix XII). For combined effect, the 1000 grains weight ranges from 30.75 g to 22.25 g. The highest 1000 grains weight found in T_1V_2 and lowest 1000 grains weight was found in T_6V_1 combination compared to the others combination.

Table 8. Combined effect of chromium and variety on 1000 grain weight

Treatments	1000 grain weight (g)
T_1V_1	27.75 bc
T_2V_1	26.00 cd
T_3V_1	25.00 de
T_4V_1	23.50 ef
T_5V_1	23.00 f
T_6V_1	22.25 f
T_1V_2	30.75 a
T_2V_2	28.25 b
T_3V_2	26.50 bcd
T_4V_2	25.00 de
T_5V_2	23.50 ef
T_6V_2	23.00 f
SE (±)	0.52
CV (%)	2.93

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.11 Yield

4.11.1 Effect of Chromium

The yield of rice showed positive significant difference for different doses of chromium application (Figure 11 and Appendix XIII). Due to chromium application, the ranges of yield of rice was found 5.72 t ha^{-1} to 7.83 t ha^{-1}. The highest grains yield was recorded in T_1 while lowest yield was recorded in T_6. This might be due to that Cr application made a toxic effect in plant which ultimately reduce the vegetative growth as well as reproductive development of plant. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh

(2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.11.2 Effect of variety

Impact of variety on rice showed positively significant variations for grain yield of rice (Figure 11 and Appendix XIII). Due to the effect of variety on yield of rice, the highest yield was found in V_2 while the lowest yield was recorded in V_1 treatment. The grains yield ranges from 6.72 t ha^{-1} to 7.62 t ha^{-1}. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

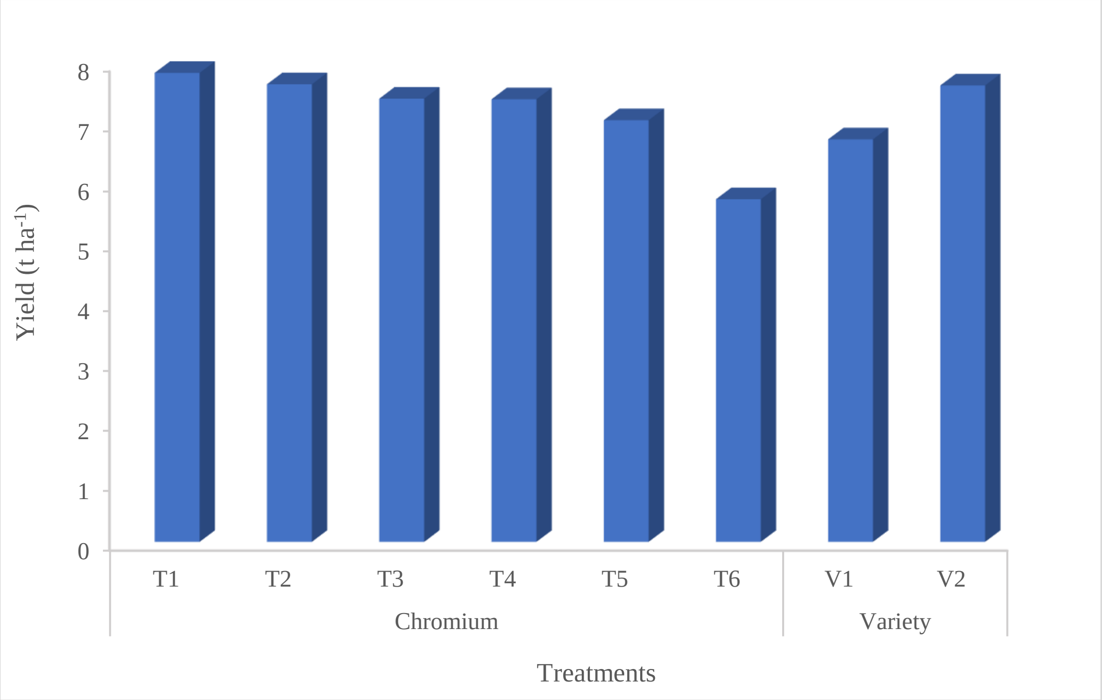

Figure 11. Effect of chromium and variety on grains yield

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.11.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant variations on grains yield of rice (Table 9 and Appendix XIII). The grain yield of rice ranges from 5.02 t ha^{-1} to 8.13 t ha^{-1} while T_1V_2 produced the highest grains yield and T_1V_6 produced lowest grains yield.

Table 9. Combined effect of chromium and variety on yield ha^{-1}

Treatments	Yield (t ha^{-1})
T_1V_1	7.54 abcd
T_2V_1	7.31 abcd
T_3V_1	7.12 bcd
T_4V_1	6.89 cd
T_5V_1	6.45 d
T_6V_1	5.02 e
T_1V_2	8.13 ab
T_2V_2	7.96 abc
T_3V_2	7.65 abc
T_4V_2	7.18 bcd
T_5V_2	8.36 a
T_6V_2	6.43 d
SE (±)	3.33
CV (%)	6.58

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.12 Phosphorus content

4.12.1 Effect of chromium

After harvesting, phosphorus content was analyzed in grain straw and root. Due to application of chromium phosphorus content showed positively significant variations (Figure 12 and Appendix XIV). The phosphorus content ranges from 0.231 ppm to 0.348 ppm, 0.126 ppm to 0.271 ppm and 0.111 ppm to 0.198 ppm in grain, straw and root, respectively. The highest values of phosphorus content were recorded in T_1 treatment and the lowest value of phosphorus content was recorded in T_6 treatment. This might be due to that Cr application made a toxic effect in plant which ultimately reduce nutritient content. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.12.2 Effect of variety

The phosphorus content showed statistically and positively significant impact due to different variety of rice cultivation (Figure 12 and Appendix XIV). The significant influence of variety facilitated highest phosphorus content in V_2 while the lowest phosphorus content was in V_1. The phosphorus content ranges from 0.22 ppm to 0.35 ppm, 0.17 ppm to 0.21 ppm and 0.15 ppm to 0.16 ppm in in grain, straw and root, respectively. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

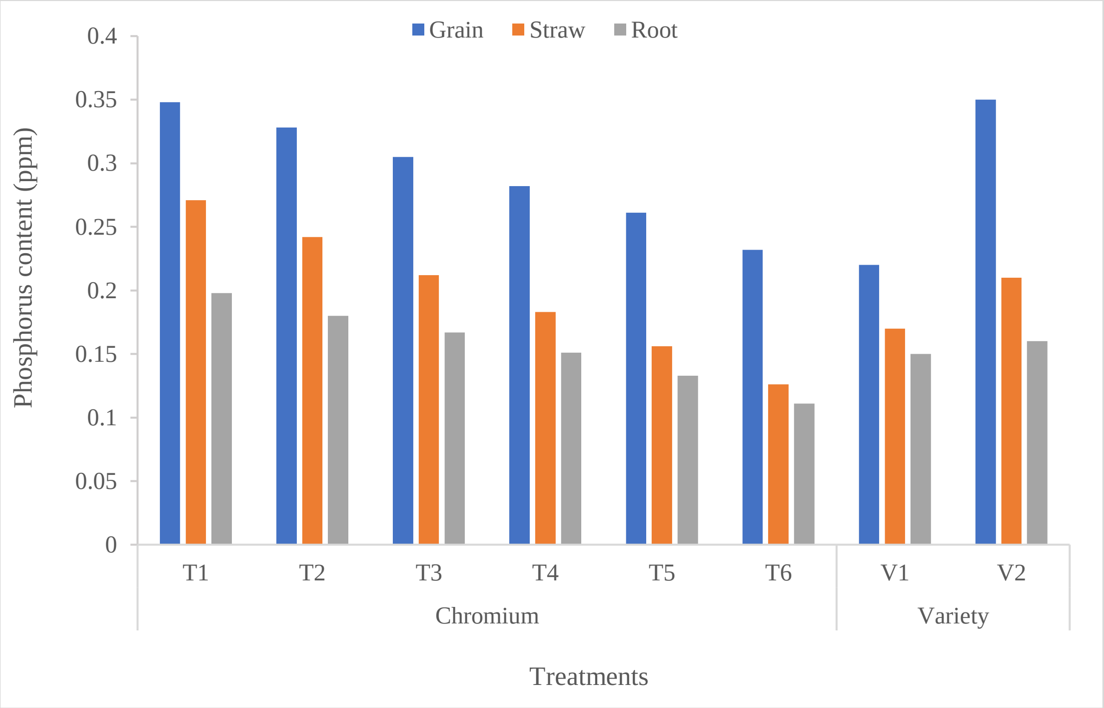

Figure 12. Effect of chromium and variety on phosphorus content

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.12.3 Combined effect of chromium and variety

Combined effect of chromium and variety produced statistically significant phosphorus content of rice only in grain (Table 10 and Appendix XIV). For the interaction effect, phosphorus content ranges from 0.18 ppm to 0.42 ppm, 0.112 ppm to 0.292 ppm and 0.107 ppm to 0.205 ppm in grain, straw and root, respectively. The highest phosphorus content was found in T_1V_2 and the lowest phosphorus content was found in T_6V_1 combination compared to the others combination.

Table 10. Combined effect of chromium and variety on phosphorus content

Treatment	Phosphorus content in (ppm)		
	Grain	Straw	Root
T_1V_1	0.27 fg	0.250	0.192
T_2V_1	0.26 g	0.220	0.175
T_3V_1	0.23 h	0.187	0.162
T_4V_1	0.21 hi	0.160	0.147
T_5V_1	0.20 i	0.137	0.132
T_6V_1	0.18 j	0.112	0.107
T_1V_2	0.42 a	0.292	0.205
T_2V_2	0.39 b	0.265	0.185
T_3V_2	0.37 c	0.237	0.172
T_4V_2	0.35 d	0.207	0.155
T_5V_2	0.32 e	0.175	0.135
T_6V_2	0.28 f	0.140	0.115
SE (±)	5.885E-03	NS	NS
CV (%)	2.84	-	-

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.13 Sulphur content

4.13.1 Effect of chromium

The sulphur content in grain, straw and root showed positively significant difference for different doses of chromium application (Figure 13 and Appendix XV). The ranges of sulphur content was found 0.175 ppm to 0.283 ppm, 0.047 ppm to 0.150 ppm and 0.115 ppm to 0.213 ppm in grain, straw and root. The highest value of sulphur content was recorded in T_1 while the lowest value of sulphur content was recorded in T_6. This might be due to that Cr application made a toxic effect in plant which ultimately reduce nutrient content. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.13.2 Effect of variety

Impact of variety on rice showed positively significant variation for sulphur content (Figure 13 and Appendix XV). The highest values of sulphur content in grain was found in V_2 while the lowest value of sulphur content was recorded in V_1 treatment. But the rest of the sampling units i.e. straw and root showed highest value in V_2 treatment and lowest value in V_1 treatment. The sulphur content ranges from 0.220 ppm to 0.231 ppm, 0.090 ppm to 0.101 ppm and 0.12 ppm to 0.20 ppm in grain, straw and root. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

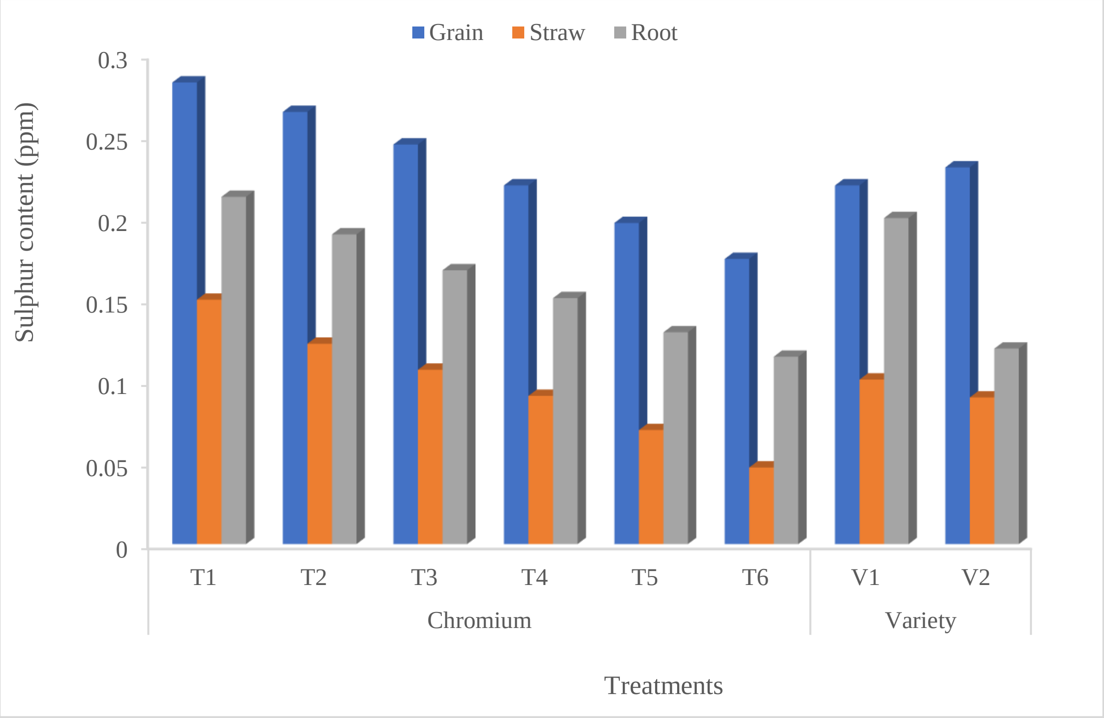

Figure 13. Effect of chromium and variety on sulphur content

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.13.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant impact on sulphur content at all samples except in straw (Table 11 and Appendix XV). The sulphur content was ranges from 0.175 ppm to 0.297 ppm, 0.040 ppm to 0.155 ppm and 0.085 ppm to 0.262 ppm in grain, straw and root, respectively. The T_1V_1 produced the highest value of sulphur content and T_6V_2 produced lowest value of sulphur content in straw and root. Again, the highest value of this trait was found in T_1V_2 and lowest value found in T_6V_2 and T_6V_1 in the grain sample.

Table 11. Combined effect of chromium and variety on sulphur content

Treatment	Sulphur content in (ppm)		
	Grain	Straw	Root
T_1V_1	0.270	0.155	0.262 a
T_2V_1	0.250	0.130	0.240 b
T_3V_1	0.237	0.117	0.212 c
T_4V_1	0.215	0.097	0.192 d
T_5V_1	0.195	0.082	0.162 e
T_6V_1	0.175	0.055	0.145 f
T_1V_2	0.297	0.145	0.165 e
T_2V_2	0.280	0.117	0.140 fg
T_3V_2	0.252	0.097	0.125 gh
T_4V_2	0.225	0.085	0.110 hi
T_5V_2	0.200	0.057	0.097 ij
T_6V_2	0.175	0.040	0.085 j
SE (±)	4.849E-03	NS	4.952E-03
CV (%)	2.97	-	4.34

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.14 Sodium content

4.14.1 Effect of chromium

Sodium content showed positive significant difference for different doses of chromium application except in grain (Figure 14 and Appendix XVI). Due to the chromium application, the ranges of sodium content were found 0.130 ppm to 0.255 ppm and 0.136 ppm to 0.246 ppm in straw and root. In case of grain the sodium content was constant for all treatment and that is 0.530 ppm. The highest value of sodium content was recorded in T_1 while the lowest value of sodium content was recorded in T_6. This might be due to that Cr application made a toxic effect in plant which ultimately reduce nutrient content. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.14.2 Effect of variety

Impact of variety on rice showed positively significant effect sodium content only in root (Figure 14 and Appendix XVI). The highest sodium content was found in V_1 while the lowest sodium content was recorded in V_2 treatment in straw and root. As like the chromium application variety also showed the constant value of sodium content in grain. The value of sodium content ranges from 0.190 ppm to 0.192 ppm and 0.170 ppm to 0.200 ppm in straw and root, respectively. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

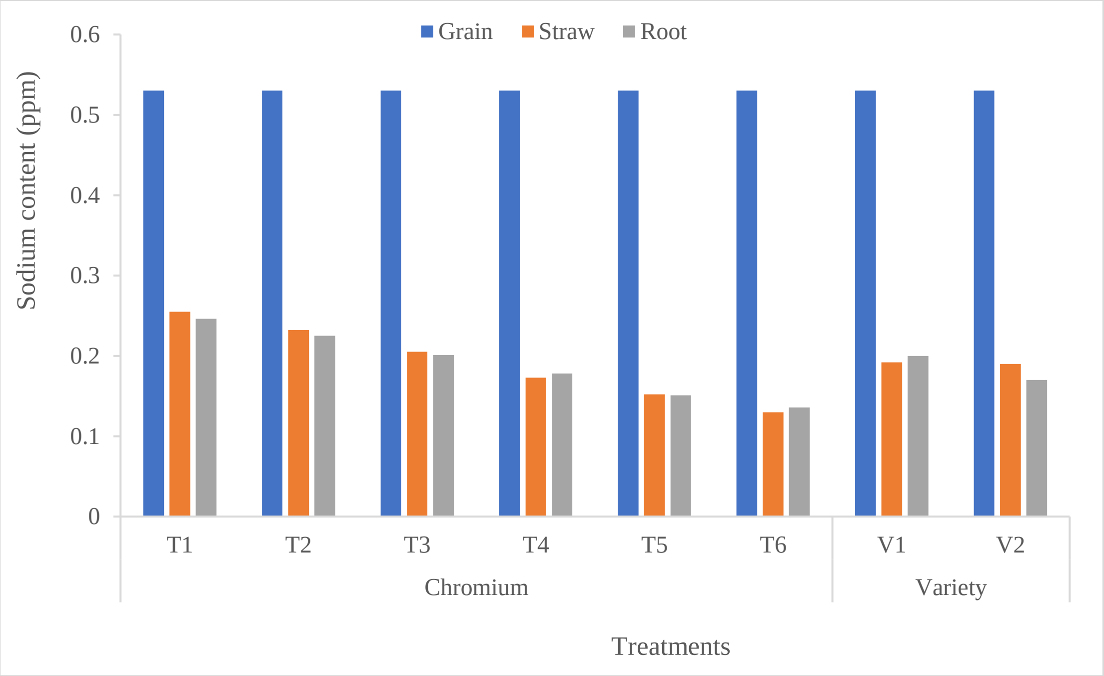

Figure 14. Effect of chromium and variety sodium content

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.14.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant impact on sodium content in straw and root but in grain it showed non-significant variations (Table 12 and Appendix XVI). The values of sodium content were ranges from 0.125 ppm to 0.260 ppm and 0.117 ppm to 0.250 ppm while T_1V_1 produced the highest value of sodium content in straw and root, respectively. The lowest sodium content was found in straw in T_6V_1 and in root T_6V_2. It showed the constant value of sodium content in grain.

Table 12. Combined effect of chromium and variety on sodium content

Treatment	Sodium content in (ppm)		
	Grain	Straw	Root
T_1V_1	0.53	0.260 a	0.250 a
T_2V_1	0.53	0.240 bc	0.230 bc
T_3V_1	0.53	0.205 d	0.207 de
T_4V_1	0.53	0.165 f	0.190 f
T_5V_1	0.53	0.145 gh	0.170 g
T_6V_1	0.53	0.125 i	0.155 g
T_1V_2	0.53	0.250 ab	0.242 ab
T_2V_2	0.53	0.225 c	0.220 cd
T_3V_2	0.53	0.205 d	0.195 ef
T_4V_2	0.53	0.182 e	0.167 g
T_5V_2	0.53	0.160 fg	0.132 h
T_6V_2	0.53	0.135 hi	0.117 h
SE (±)	NS	4.875E-03	4.582E-03
CV (%)	-	3.6	3.41

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.15 Potassium content

4.15.1 Effect of chromium

Due to chromium application the potassium content showed positively significant result of rice plant in grain and straw but in case of root is showed non-significant variation (Figure 15 and Appendix XVII). The potassium content ranges from 0.038 ppm to 0.052 ppm, 0.058 ppm to 0.145 ppm and 0.021 ppm to 0.029 ppm in grain, straw and root, respectively. The highest potassium content was recorded in T_1 treatment and the lowest potassium content was recorded in T_6 treatment. This might be due to that Cr application made a toxic effect in plant which ultimately reduce nutrient content. The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.15.2 Effect of variety

The potassium content showed statistically significant variations due to different variety of rice cultivation in grain and straw but it showed non-significant variations in root (Figure 15 and Appendix XVII). The highest potassium content was recorded in V_1 while lowest potassium content was in V_5 in grain and straw. But in case of root the highest value of potassium content was found in V_2. The potassium content ranges from 0.043 ppm to 0.148 ppm, 0.081 ppm to 0.112 ppm and 0.021 ppm to 0.041 ppm in grain, straw and root, respectively. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

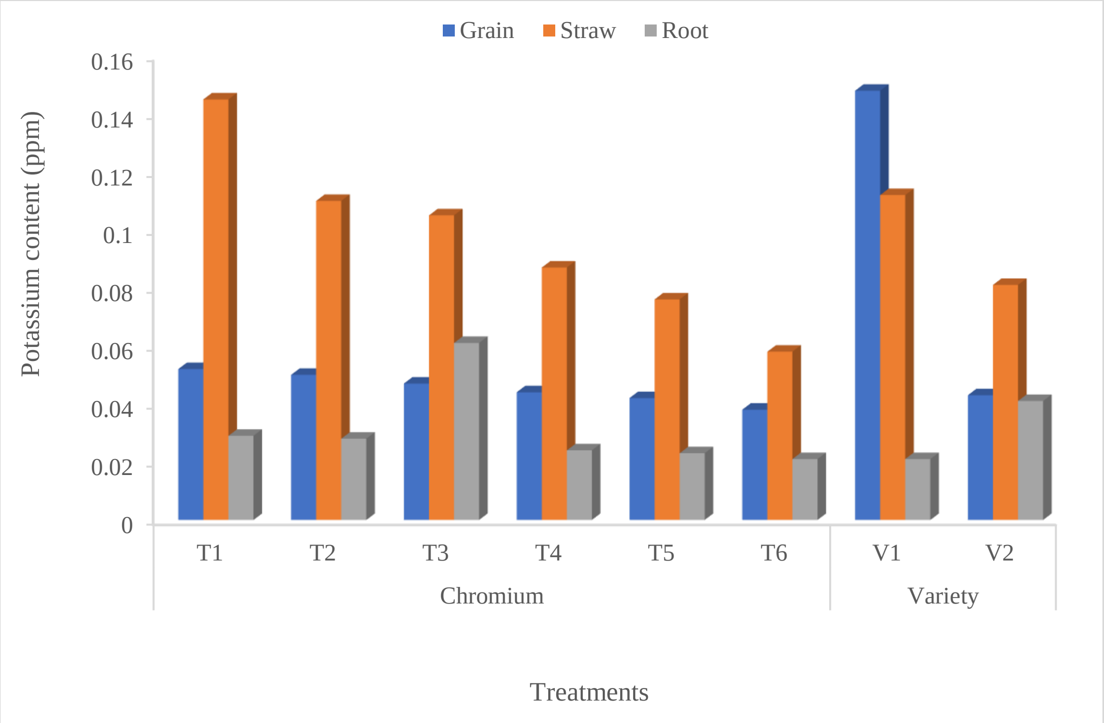

Figure 15. Effect of chromium and variety on potassium content

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.15.3 Combined effect of chromium and variety

Combined effect of chromium and variety produced statistically significant potassium content only in grain (Table 13 and Appendix XVII). For combined effect, the potassium content ranges from 0.0360 ppm to 0.0545 ppm, 0.0400 ppm to 0.1575 ppm and 0.0180 ppm to 0.1030 ppm in grain, straw and root, respectively. The highest potassium content found in T_1V_1 and lowest potassium content was found in T_6V_2 combination compared to the others combination in grain and straw. In case of root, the highest value of potassium content was found in T_3V_2 and lowest was found in T_6V_1.

Table 13. Combined effect of chromium and variety on potassium content

Treatment	Potassium content in (ppm)		
	Grain	Straw	Root
T_1V_1	0.0545 a	0.1575	0.0248
T_2V_1	0.0525 b	0.1325	0.0243
T_3V_1	0.0505 c	0.1175	0.0225
T_4V_1	0.0478 d	0.1025	0.0205
T_5V_1	0.0455 e	0.0900	0.0197
T_6V_1	0.0415 f	0.0775	0.0180
T_1V_2	0.0502 c	0.1325	0.0350
T_2V_2	0.0475 d	0.0878	0.0333
T_3V_2	0.0445 e	0.0925	0.1013
T_4V_2	0.0413 f	0.0725	0.0293
T_5V_2	0.0387 g	0.0625	0.0267
T_6V_2	0.0360 h	0.0400	0.0245
SE (±)	4.647E-04	NS	NS
CV (%)	1.43	-	-

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.16 Chromium content

4.16.1 Effect of chromium

Chromium content showed positive significant difference for different doses of chromium application except in root (Table 14 and Appendix XVIII). Due to the chromium application, the ranges of chromium content were found 0.00 ppm to 0.275 ppm and 0.210 ppm to 0.404 ppm in grain and straw, respectively. The highest value of chromium content was recorded in T_6 while the lowest value of chromium content was recorded in T_1. In case of root, there was no value of chromium was found. This might be due to that, applied chromium was transferred from root to grain and straw. This might be due to that Cr application made a toxic effect in plant which ultimately increased the chromium content.

The present finding agree with the result of Yu and Feng (2016), Nagarajan and Ganesh (2015), Qu *et al*. (2015), Sundaramoorthy and Sankar Genesh (2015), Parmar and Patel (2015), Xiao *et al*. (2015), Dai *et al*. (2015), Mantry and Patra (2015), Trinh *et al*. (2014), Zou and Liu (2014), Hu *et al*. (2014), Oliveira (2012), Ahmad *et al*. (2011), Zeng *et al*. (2011), Ali *et al*. (2011), Mohanty *et al*. (2011), Ali *et al*. (2011), Huang *et al*. (2010), Zeng *et al*. (2010), Zhu *et al*. (2010), Dubey *et al*. (2010), Zhu *et al*. (2008), Bhattacharyya *et al*. (2005).

4.16.2 Effect of variety

Impact of variety on rice showed positively significant effect chromium content except in root (Table 16 and Appendix XVIII). The highest chromium content was found in V_2 while the lowest value of chromium content was recorded in V_1 treatment in grain and straw, respectively. The value of chromium content ranges from 0.056 ppm to 0.138 ppm and 0.284 ppm to 0.332 ppm in grain and straw, respectively. In case of root, there was no value of chromium was found. This might be due to that, applied chromium was transferred from root to grain and straw. The fact that genetic variations among the variety. Nagarajan and Ganesh (2015) also reported the similar result.

Table 16. Effect of chromium and variety chromium content

Treatments	Chromium content in (ppm)		
	Grain	Straw	Root
T1	0.000 d	0.210 f	0.0
T2	0.000 d	0.242 e	0.0
T3	0.000 d	0.291 d	0.0
T4	0.090 c	0.329 c	0.0
T5	0.213 b	0.373 b	0.0
T6	0.277 a	0.404 a	0.0
V1	0.056 b	0.284 b	0.0
V2	0.138 a	0.332 a	0.0
CV (%)	31.40	0.27	-
SE (±)			
T	0.015	4.090E-04	-
V	8.802E-03	2.361E-04	-

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

4.14.3 Combined effect of chromium and variety

Combined effect of chromium and variety showed positively significant impact on chromium content (Table 15 and Appendix XVIII). The values of chromium content were ranges from 0.000 ppm to 0.363 ppm and 0.178 ppm to 0.422 ppm while T_1V_1 produced the lowest value of chromium content in grain and straw, respectively. The highest chromium content was found in T_6V_2. In case of root, there was no value of chromium was found. This might be due to that, applied chromium was transferred from root to grain and straw.

Table 15. Combined effect of chromium and variety on chromium content

Treatment	Chromium content in (ppm)		
	Grain	Straw	Root
T_1V_1	0.000 d	0.178 j	0.000
T_2V_1	0.000 d	0.222 i	0.000
T_3V_1	0.000 d	0.261 g	0.000
T_4V_1	0.000 d	0.305 f	0.000
T_5V_1	0.144 c	0.354 d	0.000
T_6V_1	0.192 c	0.385 c	0.000
T_1V_2	0.000 d	0.242 h	0.000
T_2V_2	0.000 d	0.262 g	0.000
T_3V_2	0.000 d	0.321 e	0.000
T_4V_2	0.181 c	0.352 d	0.000
T_5V_2	0.283 b	0.392 b	0.000
T_6V_2	0.363 a	0.422 a	0.000
SE (±)	0.0216	5.784E-04	-
CV (%)	31.40	0.27	-

T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil; V_1= BRRI dhan69, V_2= BRRI dhan74.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh during the period from December 2016 to May 2017 to study the toxic effect of chromium on growth, yield and nutritional attributes of BRRI dhan69 and BRRI dhan74. The experiment comprised as two factors, Factor A: two rice cultivars i.e. V_1= BRRI dhan69, V_2= BRRI dhan74; and six levels of Cr application i.e. T_1= 0 mg Cr/kg soil, T_2= 12.5 mg Cr/kg soil, T_3= 25 mg Cr/kg soil, T_4= 50 mg Cr/kg soil, T_5= 75 mg Cr/kg soil, T_6 =100 mg Cr/kg soil. The experiment was laid out in Completely Randomized Design (CRD) with three replications. Data on different growth parameters, yield attributes, yield and biochemical properties were recorded and analyzed.

The plant height ranges from 38.87 cm to 43.25 cm, 65.87 cm to 79.25 cm, 79.62 cm to 92.00 cm and 81.00 cm to 92.87 cm at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. For the application of chromium, the tallest plant was recorded in T_1 treatment while the shortest plant was recorded in T_5 treatment at all sampling dates. The tallest rice plant was recorded in V_2 while the shortest plant was in V_1. The plant height ranges from 39.62 cm to 41.20 cm, 69.62 cm to 72.33 cm, 81.62 cm to 90.16 cm and 82.54 cm to 91.04 cm at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. This might be genetic variation among the varieties while V_2 showed superior result than others. For the interaction effect the height of rice plant ranges from 39.25 cm to 45.25 cm, 65.50 cm to 83.75 cm, 75.00 cm to 96.25 cm and 76.25 cm to 97.75 cm at 30 DAT, 60 DAT and 90 DAT and harvest time, respectively. The tallest plant was found in T_1V_2 and the shortest plant was found in T_6V_1 combination compared to the others combination.

Due to chromium, the ranges of number of tillers hill^{-1} was found 16.12 to 21.00, 34.37 to 45.87, 48.75 to 64.87 and 58.50 to 63.00 at 30 DAT, 60 DAT, 90 DAT and harvest times, respectively. The maximum number of tillers hill^{-1} was recorded in T_1 while the minimum number of leaves hill^{-1} was recorded in treatment T_6. The maximum number of tillers hill^{-1} was found in V_2 treatment while the minimum number of tillers hill^{-1} was recorded in V_1 treatment. The tillers number ranges from 17.50 to 19.04, 39.33 to 40.00, 57.08 to 57.62 and 61.54 to 61.67 at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively. In spite of having non-significant effect, the number of tillers hill^{-1} ranges from 16.00 to 19.25, 34.00 to 45.25, 48.25 to 65.00 and 57.75 to 63.25 at 30 DAT, 60 DAT, 90 DAT and harvest time, respectively while T_1V_1 produced the maximum number of tillers and T_6V_1 produced minimum number of tillers.

Due to chromium application, the ranges of number of effective tillers hill^{-1} was found 28.00 to 42.87. The maximum number of effective tillers hill^{-1} was recorded in T_1 while the minimum number of effective tillers hill^{-1} was recorded in T_6. The maximum number of effective tillers hill^{-1} was found in V_2 treatment while the minimum number of effective tillers hill^{-1} was recorded in V_1 treatment. The number of effective tillers ranges from 34.83 to 37.54. The number of effective tillers hill^{-1} ranges from 25.75 to 42.25 while T_1V_1 produced the maximum number of effective tillers and T_6V_1 produced the minimum number of effective tillers.

Due to chromium application, the ranges of number of non-effective tillers hill^{-1} was found 20.12 to 30.50. The maximum number of non-effective tillers hill^{-1} was recorded in T_6 while the minimum number of non-effective tillers hill^{-1} was recorded in T_1. The maximum number of non-effective tillers hill^{-1} was found in V_2 treatment while the minimum number of non-effective tillers hill^{-1} was recorded in V_1 treatment. The number of non-effective tillers ranges from 24.12 to 26.70. The number of non-effective tillers hill^{-1} ranges from 20.75 to 32.00 while T_1V_1 produced the minimum number of effective tillers and T_6V_1 produced the maximum number of effective tillers.

The ranges of number of leaves hill^{-1} was found 44.75 to 57.50, 73.25 to 87.87 and 94.75 to 107.50 at 30 DAT, 60 DAT and 90 DAT, respectively. The maximum number of leaves hill^{-1} was recorded in T_1 while the minimum number of leaves hill^{-1} was recorded in T_6 at all sampling dates. The maximum number of leaves hill^{-1} was found in V_2 treatment while the minimum number of leaves hill^{-1} was recorded in V_1 treatment. The leaves number ranges from 46.54 to 55.54, 75.87 to 84.94 and 97.25 to 104.29 at 30 DAT, 60 DAT and 90 DAT, respectively. The number of leaves hill^{-1} ranges from 41.00 to 53.00, 69.00 to 83.25, 92.00 to 102.75 at 30 DAT, 60 DAT and 90 DAT, respectively while T_1V_1 produced the maximum number of leaves and T_6V_1 produced minimum number of leaves.

The leaf length ranges from 24.25 cm to 35.25 cm, 54.00 cm to 68.12 cm and 67.62 cm to 79.37 cm at 30 DAT, 60 DAT and 90 DAT. The height leaf length was recorded in T_1 treatment and the lowest leaf length was recorded in T_6 treatment. The highest leaf length was recorded in V_2 while the lowest leaf length was found in treatment V_1. The leaf length ranges from 28.75 cm to 30.37 cm, 54.66 cm to 65.87 cm and 71.00 cm ti 76.29 cm at 30 DAT, 60 DAT and 90 DAT. Though the rest of the sampling dates the length showed non-significant variations, the highest leaf length was found in T_1V_2 and lowest leaf length was found in T_6V_1 combination compared to the others interaction. For combine effect the leaf length ranges from 23.50 cm to 36.50 cm, 49.50 cm to 72.75 cm, 63.50 cm to 81.50 cm at 30 DAT, 60 DAT and 90 DAT.

The highest value of panicle length (31.00 cm) was recorded in T_1 while the lowest value of the same traits was (21.00 cm) was recorded in the treatment T_6. The highest value of the panicle length (27.66 cm) was found in V_2 treatment while the lowest value of the panicle length (24.66 cm) was recorded in V_1 treatment. The T_1V_2 produced the height value of panicle length and the combination T_6V_1 produced the lowest value of panicle length. The panicle length ranges from 20.25 cm to 34.00 cm.

The number of filled grains panicle^{-1} range from 181.00 to 203.00. The maximum number of filled grains panicle^{-1} was recorded in T_1 treatment and the minimum number of filled grains panicle^{-1} was recorded in T_6 treatment. The maximum number of filled grains panicle^{-1} was recorded in V_2 while the lowest values of number of filled grains panicle^{-1} was found in V_1. The number of filled grains panicle^{-1} ranges from 201.58 to 182.00. For the combine effect, the number of filled grains panicle^{-1} ranges from 211.50 to 194.50. The maximum number of filled grains panicle^{-1} was found in T_1V_2 and minimum number of filled grains panicle^{-1} was recorded in T_1V_1 combination compared to the others combination.

Due to chromium application, the unfilled grains panicles^{-1} ranges from was found 40.37 to 54.37. The maximum number of unfilled grains panicles^{-1} was recorded in T_6 while the minimum number of unfilled grains panicles^{-1} was recorded in T_1. The maximum number of unfilled grains panicles^{-1} was found in V_1 while minimum number of unfilled grains panicles^{-1} was recorded in V_2 treatment. The number of unfilled grains panicles^{-1} ranges from 40.75 to 52.58. The number of unfilled grains panicles^{-1} ranges from 35.00 to 60.75 while T_6V_1 produced the maximum number of unfilled grains panicles^{-1} and T_1V_2 produced minimum number of unfilled grains panicles^{-1}.

Due to chromium application, the ranges of yield of rice was found 5.72 t ha^{-1} to 7.83 t ha^{-1}. The highest grains yield was recorded in T_1 while lowest yield was recorded in T_6. Due to the effect of variety on yield of rice, the highest yield was found in V_2 while the lowest yield was recorded in V_1 treatment. The grains yield ranges from 6.72 t ha^{-1} to 7.62 t ha^{-1}. The grain yield of rice ranges from 5.02 t ha^{-1} to 8.13 t ha^{-1} while T_1V_2 produced the highest grains yield and T_1V_6 produced lowest grains yield.

The phosphorus content ranges from 0.231 ppm to 0.348 ppm, 0.126 ppm to 0.271 ppm and 0.111 ppm to 0.198 ppm in grain, straw and root, respectively.

The highest values of phosphorus content were recorded in T_1 treatment and the lowest value of phosphorus content was recorded in T_6 treatment. The significant influence of variety facilitated highest phosphorus content in V_2 while the lowest phosphorus content was in V_1. The phosphorus content ranges from 0.22 ppm to 0.35 ppm, 0.17 ppm to 0.21 ppm and 0.15 ppm to 0.16 ppm in in grain, straw and root, respectively. For the interaction effect, phosphorus content ranges from 0.18 ppm to 0.42 ppm, 0.112 ppm to 0.292 ppm and 0.107 ppm to 0.205 ppm in grain, straw and root, respectively. The highest phosphorus content was found in T_1V_2 and the lowest phosphorus content was found in T_6V_1 combination compared to the others combination.

The ranges of sulphur content was found 0.175 ppm to 0.283 ppm, 0.047 ppm to 0.150 ppm and 0.115 ppm to 0.213 ppm in grain, straw and root. The highest value of sulphur content was recorded in T_1 while the lowest value of sulphur content was recorded in T_6. The highest values of sulphur content in grain was found in V_2 while the lowest value of sulphur content was recorded in V_1 treatment. But the rest of the sampling units i.e. straw and root showed highest value in V_2 treatment and lowest value in V_1 treatment. The sulphur content ranges from 0.220 ppm to 0.231 ppm, 0.090 ppm to 0.101 ppm and 0.12 ppm to 0.20 ppm in grain, straw and root. The sulphur content was ranges from 0.175 ppm to 0.297 ppm, 0.040 ppm to 0.155 ppm and 0.085 ppm to 0.262 ppm in grain, straw and root, respectively. The T_1V_1 produced the highest value of sulphur content and T_6V_2 produced lowest value of sulphur content in straw and root. Again, the highest value of this trait was found in T_1V_2 and lowest value found in T_6V_2 and T_6V_1 in the grain sample.

Due to the chromium application, the ranges of sodium content were found 0.130 ppm to 0.255 ppm and 0.136 ppm to 0.246 ppm in straw and root. In case of grain the sodium content was constant for all treatment and that is 0.530 ppm. The highest value of sodium content was recorded in T_1 while the lowest value of sodium content was recorded in T_6. The highest sodium content was found in V_1 while the lowest sodium content was recorded in V_2 treatment in straw and root. As like the chromium application variety also showed the constant value of sodium content in grain. The value of sodium content ranges from 0.190 ppm to 0.192 ppm and 0.170 ppm to 0.200 ppm in straw and root, respectively. The values of sodium content were ranges from 0.125 ppm to 0.260 ppm and 0.117 ppm to 0.250 ppm while T_1V_1 produced the highest value of sodium content in straw and root, respectively. The lowest sodium content was found in straw in T_6V_1 and in root T_6V_2. It showed the constant value of sodium content in grain.

The potassium content ranges from 0.038 ppm to 0.052 ppm, 0.058 ppm to 0.145 ppm and 0.021 ppm to 0.029 ppm in grain, straw and root, respectively. The highest potassium content was recorded in T_1 treatment and the lowest potassium content was recorded in T_6 treatment. The highest potassium content was recorded in V_1 while lowest potassium content was in V_5 in grain and straw. But in case of root the highest value of potassium content was found in V_2. The potassium content ranges from 0.043 ppm to 0.148 ppm, 0.081 ppm to 0.112 ppm and 0.021 ppm to 0.041 ppm in grain, straw and root, respectively. For combine effect, the potassium content ranges from 0.0360 ppm to 0.0545 ppm, 0.0400 ppm to 0.1575 ppm and 0.0180 ppm to 0.1030 ppm in grain, straw and root, respectively. The highest potassium content found in T_1V_1 and lowest potassium content was found in T_6V_2 combination compared to the others combination in grain and straw. In case of root, the highest value of potassium content was found in T_3V_2 and lowest was found in T_6V_1.

Due to the chromium application, the ranges of chromium content were found 0.00 ppm to 0.275 ppm and 0.210 ppm to 0.404 ppm in grain and straw, respectively. The highest value of chromium content was recorded in T_6 while the lowest value of chromium content was recorded in T_1. The highest chromium content was found in V_2 while the lowest value of chromium content was recorded in V_1 treatment in grain and straw, respectively. The value of chromium content ranges from 0.056 ppm to 0.138 ppm and 0.284 ppm to 0.332 ppm in grain and straw, respectively. The values of chromium content were ranges from 0.000 ppm to 0.363 ppm and 0.178 ppm to 0.422 ppm while T_1V_1 produced the lowest value of chromium content in grain and straw, respectively. The highest chromium content was found in T_6V_2. In case of root, there was no value of chromium was found.

Recommendations

The present experiment was conducted only one season even in a single location. So, it is difficult to recommend this finding without conducting and validating by further study. By considering the results of the present experiment, further studies should have carried out in different location with an increasing and decreasing the treatments.

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APPENDIX

Appendix I. Monthly recorded the average air temperature, rainfall, relative humidity and sunshine of the experimental site during the period from December 2016 to May 2017.

Month	Air temperature (^{0}C)		Relative humidity (%)	Total rainfall(mm)	Sunshine (hr)
	Maximum	Minimum			
December, 2016	26.4	14.1	69	12.8	5.5
January, 2017	25.4	12.7	68	7.7	5.6
February, 2017	28.1	15.5	68	28.9	5.5
March, 2017	32.5	20.4	64	65.8	5.2
April, 2017	38.9	23.6	70	76.4	5.7
May, 2017	40.5	24.5	75	80.6	5.8

Source: Sher-e-Bangla Agricultural University Weather Station

Appendix II. Physical and chemical soil properties of experimental plot

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI)

Appendix III.a. Factorial anova table for plant height at 30 DAT

Source	DF	SS	MS	F	P
Replic	3	4.667	1.5556		
Treatment	5	113.667	22.7333	24.33	0.0000
Variety	1	30.083	30.0833	32.20	0.0000
Treatment*Variety	5	20.417	4.0833	4.37	0.0037
Error	33	30.833	0.9343		
Total	47	199.667			

Appendix III.b. Factorial anova table for plant height at 60 DAT

Source	DF	SS	MS	F	P
Replic	3	5.40	1.799		
Treatment	5	1386.85	277.371	199.62	0.0000
Variety	1	88.02	88.021	63.35	0.0000
Treatment*Variety	5	380.85	76.171	54.82	0.0000
Error	33	45.85	1.390		
Total	47	1906.98			

Appendix III.c. Factorial anova table for plant height at 90 DAT

Source	DF	SS	MS	F	P
Replic	3	4.56	1.521		
Treatment	5	894.85	178.971	170.26	0.0000
Variety	1	875.52	875.521	832.93	0.0000
Treatment*Variety	5	8.85	1.771	1.68	0.1658
Error	33	34.69	1.051		
Total	47	1818.48			

Appendix III.d. Factorial anova table for plant height at harvest

Source	DF	SS	MS	F	P
Replic	3	4.75	1.583		
Treatment	5	883.92	176.783	106.55	0.0000
Variety	1	867.00	867.000	522.58	0.0000
Treatment*Variety	5	39.50	7.900	4.76	0.0022
Error	33	54.75	1.659		
Total	47	1849.92			

Appendix IV.a. Factorial anova table for number of tillers at 30 DAT

Source	DF	SS	MS	F	P
Replic	3	6.063	2.0208		
Treatment	5	109.104	21.8208	13.05	0.0000
Variety	1	28.521	28.5208	17.05	0.0002
Treatment*Variety	5	14.604	2.9208	1.75	0.1515
Error	33	55.188	1.6723		
Total	47	213.479			

Appendix IV.b. Factorial anova table for number of tillers at 60 DAT

Source	DF	SS	MS	F	P
Replic	3	2.833	0.944		
Treatment	5	723.667	144.733	89.00	0.0000
Variety	1	5.333	5.333	3.28	0.0793
Treatment*Variety	5	19.167	3.833	2.36	0.0619
Error	33	53.667	1.626		
Total	47	804.667			

Appendix IV.c. Factorial anova table for number of tillers at 90 DAT

Source	DF	SS	MS	F	P
Replic	3	0.06	0.021		
Treatment	5	1297.85	259.571	149.79	0.0000
Variety	1	3.52	3.521	2.03	0.1634
Treatment*Variety	5	8.35	1.671	0.96	0.4538
Error	33	57.19	1.733		
Total	47	1366.98			

Appendix IV.d. Factorial anova table for number of tillers at harvest

Source	DF	SS	MS	F	P
Replic	3	7.229	2.4097		
Treatment	5	112.354	22.4708	7.45	0.0001
Variety	1	0.188	0.1875	0.06	0.8046
Treatment*Variety	5	22.187	4.4375	1.47	0.2256
Error	33	99.521	3.0158		
Total	47	241.479			

Appendix V. Factorial anova table for number of effective tillers

Source	DF	SS	MS	F	P
Replic	3	4.06	1.354		
Treatment	5	1110.69	222.137	158.71	0.0000
Variety	1	88.02	88.021	62.89	0.0000
Treatment*Variety	5	18.35	3.671	2.62	0.0420
Error	33	46.19	1.400		
Total	47	1267.31			

Appendix VI. Factorial anova table for number of non-effective tillers

Source	DF	SS	MS	F	P
Replic	3	13.833	4.611		
Treatment	5	605.167	121.033	132.40	0.0000
Variety	1	80.083	80.083	87.60	0.0000
Treatment*Variety	5	10.417	2.083	2.28	0.0694
Error	33	30.167	0.914		
Total	47	739.667			

Appendix VII.a. Factorial anova table for number of leaves at 30 DAT

Source	DF	SS	MS	F	P
Replic	3	2.92	0.972		
Variety	1	972.00	972.000	587.65	0.0000
Treatment	5	784.67	156.933	94.88	0.0000
Variety*Treatment	5	11.75	2.350	1.42	0.2426
Error	33	54.58	1.654		
Total	47	1825.92			

Appendix VII.b. Factorial anova table for number of leaves at 60 DAT

Source	DF	SS	MS	F	P
Replic	3	13.83	4.611		
Variety	1	990.08	990.083	1180.94	0.0000
Treatment	5	1180.67	236.133	281.65	0.0000
Variety*Treatment	5	1.42	0.283	0.34	0.8862
Error	33	27.67	0.838		
Total	47	2213.67			

Appendix VII.c. Factorial anova table for number of leaves at 90 DAT

Source	DF	SS	MS	F	P
Replic	3	1.90	0.632		
Variety	1	595.02	595.021	447.75	0.0000
Treatment	5	852.85	170.571	128.35	0.0000
Variety*Treatment	5	20.85	4.171	3.14	0.0200
Error	33	43.85	1.329		
Total	47	1514.48			

Appendix VIII.a. Factorial anova table for number of leaf length at 30 DAT

Source	DF	SS	MS	F	P
Replic	3	4.396	1.465		
Variety	1	31.687	31.687	51.37	0.0000
Treatment	5	676.687	135.337	219.42	0.0000
Variety*Treatment	5	2.687	0.537	0.87	0.5107
Error	33	20.354	0.617		
Total	47	735.812			

Appendix VIII.b. Factorial anova table for number of leaf length at 60 DAT

Source	DF	SS	MS	F	P
Replic	3	308.73	102.91		
Variety	1	1507.52	1507.52	23.57	0.0000
Treatment	5	965.85	193.17	3.02	0.0236
Variety*Treatment	5	296.85	59.37	0.93	0.4752
Error	33	2110.52	63.96		
Total	47	5189.48			

Appendix VIII.c. Factorial anova table for number of leaf length at 90 DAT

Source	DF	SS	MS	F	P
Replic	3	5.90	1.965		
Variety	1	336.02	336.021	519.28	0.0000
Treatment	5	718.85	143.771	222.18	0.0000
Variety*Treatment	5	26.85	5.371	8.30	0.0000
Error	33	21.35	0.647		
Total	47	1108.98			

Appendix IX. Factorial anova table for panicle length

Source	DF	SS	MS	F	P
Replic	3	4.896	1.632		
Variety	1	117.188	117.188	326.23	0.0000
Treatment	5	575.354	115.071	320.34	0.0000
Variety*Treatment	5	53.187	10.637	29.61	0.0000
Error	33	11.854	0.359		
Total	47	762.479			

Appendix X. Factorial anova table for number of filled grains

Source	DF	SS	MS	F	P
Replic	3	8.25	2.75		
Variety	1	4602.08	4602.08	3115.26	0.0000
Treatment	5	2602.17	520.43	352.29	0.0000
Variety*Treatment	5	20.67	4.13	2.80	0.0326
Error	33	48.75	1.48		
Total	47	7281.92			

Appendix XI. Factorial anova table for number of unfilled grains

Source	DF	SS	MS	F	P
Replic	3	14.17	4.72		
Variety	1	1680.33	1680.33	2944.30	0.0000
Treatment	5	1057.67	211.53	370.65	0.0000
Variety*Treatment	5	7.67	1.53	2.69	0.0382
Error	33	18.83	0.57		
Total	47	2778.67			

Appendix XII. Factorial anova table for 1000 grains weight

Source	DF	SS	MS	F	P
Replic	3	1.750	0.5833		
Variety	1	30.083	30.0833	54.40	0.0000
Treatment	5	252.500	50.5000	91.32	0.0000
Variety*Treatment	5	8.667	1.7333	3.13	0.0201
Error	33	18.250	0.5530		
Total	47	311.250			

Appendix XIII. Factorial anova table for grains yield

Source	DF	SS	MS	F	P
Replic	3	5143	1714.2		
Variety	1	96302	96302.1	43.19	0.0000
Treatment	5	229328	45865.6	20.57	0.0000
Variety*Treatment	5	38888	7777.6	3.49	0.0122
Error	33	73583	2229.8		
Total	47	443244			

Appendix XIV.a. Factorial anova table for phosphorus content in grain

Source	DF	SS	MS	F	P
Replic	3	0.00024	0.00008		
Variety	1	0.20410	0.20410	2947.11	0.0000
Treatment	5	0.07447	0.01489	215.06	0.0000
Variety*Treatment	5	0.00254	0.00051	7.32	0.0001
Error	33	0.00229	0.00007		
Total	47	0.28363			

Appendix XIV.b. Factorial anova table for phosphorus content in straw

Source	DF	SS	MS	F	P
Replic	3	0.00038	0.00013		
Variety	1	0.02083	0.02083	302.20	0.0000
Treatment	5	0.11718	0.02344	339.94	0.0000
Variety*Treatment	5	0.00067	0.00013	1.93	0.1151
Error	33	0.00227	0.00007		
Total	47	0.14133			

Appendix XIV.c. Factorial anova table for phosphorus content in root

Source	DF	SS	MS	F	P
Replic	3	0.00007	2.500E-05		
Variety	1	0.00083	8.333E-04	20.00	0.0001
Treatment	5	0.04039	8.078E-03	193.88	0.0000
Variety*Treatment	5	0.00012	2.333E-05	0.56	0.7297
Error	33	0.00138	4.167E-05		
Total	47	0.04279			

Appendix XV.a. Factorial anova table for sulphur content in grain

Source	**DF**	**SS**	**MS**	**F**	**P**
Replic	3	0.00017	0.00006		
Variety	1	0.00255	0.00255	54.26	0.0000
Treatment	5	0.06811	0.01362	289.63	0.0000
Variety*Treatment	5	0.00146	0.00029	6.21	0.0004
Error	33	0.00155	0.00005		
Total	47	0.07385			

Appendix XV.b. Factorial anova table for sulphur content in straw

Source	**DF**	**SS**	**MS**	**F**	**P**
Replic	3	0.00022	0.00007		
Variety	1	0.00301	0.00301	96.07	0.0000
Treatment	5	0.05469	0.01094	349.32	0.0000
Variety*Treatment	5	0.00032	0.00006	2.02	0.1011
Error	33	0.00103	0.00003		
Total	47	0.05927			

Appendix XV.c. Factorial anova table for sulphur content in root

Source	**DF**	**SS**	**MS**	**F**	**P**
Replic	3	0.00016	0.00005		
Variety	1	0.08085	0.08085	1648.26	0.0000
Treatment	5	0.05484	0.01097	223.58	0.0000
Variety*Treatment	5	0.00274	0.00055	11.15	0.0000
Error	33	0.00162	0.00005		
Total	47	0.14020			

Appendix XVI.a. Factorial anova table for sodium content in grain

Source	DF	SS	MS	F	P
Replic	3	7.648E-32	2.549E-32		
Variety	1	5.830E-33	5.830E-33	2.31241561680767712E32	0.0000
Treatment	5	1.292E-31	2.585E-32	1.02530835699959328E33	0.0000
Variety*Treatment	5	4.066E-65	8.132E-66	0.32	0.8958
Error	33	8.319E-64	2.521E-65		
Total	47	2.116E-31			

Appendix XVI.b. Factorial anova table for sodium content in straw

Source	DF	SS	MS	F	P
Replic	3	0.00001	2.083E-06		
Variety	1	0.00010	1.021E-04	2.15	0.1523
Treatment	5	0.09211	0.01842	387.52	0.0000
Variety*Treatment	5	0.00181	3.621E-04	7.62	0.0001
Error	33	0.00157	4.754E-05		
Total	47	0.09560			

Appendix XVI.c. Factorial anova table for sodium content in root

Source	DF	SS	MS	F	P
Replic	3	0.00039	0.00013		
Variety	1	0.00542	0.00542	129.07	0.0000
Treatment	5	0.07226	0.01445	344.24	0.0000
Variety*Treatment	5	0.00184	0.00037	8.78	0.0000
Error	33	0.00139	0.00004		
Total	47	0.08130			

Appendix XVII.a. Factorial anova table for potassium content in grain

Source	DF	SS	MS	F	P
Replic	3	1.750E-06	5.833E-07		
Variety	1	3.853E-04	3.853E-04	892.35	0.0000
Treatment	5	1.029E-03	2.058E-04	476.59	0.0000
Variety*Treatment	5	8.917E-06	1.783E-06	4.13	0.0051
Error	33	1.425E-05	4.318E-07		
Total	47	1.439E-03			

Appendix XVII.b. Factorial anova table for potassium content in straw

Source	DF	SS	MS	F	P
Replic	3	0.00048	0.00016		
Variety	1	0.01200	0.01200	45.45	0.0000
Treatment	5	0.03619	0.00724	27.41	0.0000
Variety*Treatment	5	0.00063	0.00013	0.48	0.7915
Error	33	0.00871	0.00026		
Total	47	0.05802			

Appendix XVII.c. Factorial anova table for potassium content in root

Source	DF	SS	MS	F	P
Replic	3	0.00487	1.622E-03		
Variety	1	0.00482	4.820E-03	2.99	0.0933
Treatment	5	0.00920	1.840E-03	1.14	0.3591
Variety*Treatment	5	0.00829	1.658E-03	1.03	0.4176
Error	33	0.05325	1.614E-03		
Total	47	0.08042			

Appendix XVIII.a. Factorial anova table for chromium content in grain

Source	DF	SS	MS	F	P
Replic	3	0.00284	0.00095		
Variety	1	0.08064	0.08064	86.74	0.0000
Treatment	5	0.59711	0.11942	128.46	0.0000
Variety*Treatment	5	0.08272	0.01654	17.80	0.0000
Error	33	0.03068	0.00093		
Total	47	0.79400			

Appendix XVIII.b. Factorial anova table for chromium content in straw

Source	DF	SS	MS	F	P
Replic	3	0.00002	6.472E-06		
Variety	1	0.02708	0.02708	40459.25	0.0000
Treatment	5	0.22461	0.04492	67130.04	0.0000
Variety*Treatment	5	0.00132	2.646E-04	395.40	0.0000
Error	33	0.00002	6.692E-07		
Total	47	0.25305			

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