SCREENING OF POTATO VARIETIES FOR ARSENIC TOLERANCE

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SCREENING OF POTATO VARIETIES FOR ARSENIC TOLERANCE

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CERTIFICATE

*This is to certify that the thesis entitled **"SCREENING OF POTATO VARIETIES FOR ARSENIC TOLERANCE"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (M.S.)** in **AGRONOMY,** embodies the results of a piece of bona fide research work carried out by **MD. NAZMUL HAQUE,** Registration. No.* **07-02539** *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

(Prof. Dr. Md. Hazrat Ali)
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The Author

SCREENING OF POTATO VARIETIES FOR ARSENIC TOLERANCE

ABSTRACT

A pot experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November 10, 2012 to February 18, 2013 to find out the effect of 3 different Arsenic (As) levels viz., As_0 (control), As_1 (25 mg As kg^{-1} soil), As_2 (50 mg As kg^{-1} soil) on growth, yield and quality of fourteen potato varieties viz., V_1 (Diamant), V_2 (Cardinal), V_3 (Asterix), V_4 (Granola), V_5 (Lady Rosetta), V_6 (Courage), V_7 (BARI TPS-1), V_8 (Meridian), V_9 (Felsina), V_{10} (Laura), V_{11} (Quincy), V_{12} (Sagitta), V_{13} (Rumana), V_{14} (Jam Alu). The different levels of As had significant effect on most of the growth, yield and quality contributing parameters of potato irrespective of varieties. All parameters studied in this experiment were decreased with the increasing As levels except number of tubers $hill^{-1}$, non-marketable yield $plant^{-1}$, 28-45 mm and <28 mm sized tuber, total soluble solids. Among the fourteen potato varieties, the yield of potato negatively affected by As contamination. The variety ‘Felsina’ produced maximum yield $plant^{-1}$ (426.2 g) whereas, ‘Jam Alu’ showed minimum yield $plant^{-1}$ (77.15 g) irrespective of As levels. The variety ‘Rumana’ accumulated maximum As in peel (2.95 mg kg^{-1}) and in flesh (0.189 mg kg^{-1}) while, ‘Jam alu’’ loaded minimum in peel (2.31 mg kg^{-1}) and ‘Cardinal in flesh (0.100 mg kg^{-1}). The results showed that though most of the parameters were decreased with the increasing As levels but most of the parameters remained statistically similar up to 25 mg As kg^{-1} soil and thereafter drastically decreased. The results also revealed that the yield of potato varieties were decreased with increasing As levels but the accumulation of As increased with increasing As levels. In case of As accumulation, peel always accumulated maximum As than that of tuber flesh. Among the treatment combinations, ‘Felsina’ cultivated with 0 mg As kg^{-1} soil performed the best results and the same variety with 25 mg As kg^{-1} soil also showed the statistical similar results in terms of growth and most of the yield parameters. In contrary, the maximum As accumulation both in peel 6.43 mg kg^{-1} and in flesh 0.313 mg kg^{-1} were found in ‘Rumana’ at 50 mg As kg^{-1} soil. Though the variety ‘Felsina’ produced maximum yield but the accumulation of As was also high in peel (6.02 mg kg^{-1}) and in flesh (0.247 mg kg^{-1}), respectively. On the basis of As accumulation, the variety ‘Cardinal’ and ‘Diamant’ were suitable for cultivating up to 25 mg As kg^{-1} contaminated soil though these two varieties produced little bit lower yield (399.0 and 436.1 g $plant^{-1}$, respectively) than that of ‘Felsina’ (448.8 g $plant^{-1}$).

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LIST OF ACCRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agril.	Agricultural
Anon.	Anonymous
As	Arsenic
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BCF	Bio Concentration Factors
cm	Centi-meter
cm^2	Square centi-meter
CV	Coefficient of Variance
DAP	Days After Planting
Dev.	Devlopment
Environ.	Environmental
et al.	And others
Expt.	Experimental
FAO	Food and Agriculture Organization
WHO	World Health Organization
g	Gram (s)
mg	Milligram
Sci.	Science
$hill^{-1}$	Per hill
i.e.	*id est* (L), that is
Res.	Research
j.	Journal
kg	Kilogram (s)
TSS	Total Soluble Solids
m^2	Meter squares
M.S	Master of Science
DMRT	Duncan’s Multiple Range Test
SAU	Sher-e-Bangla Agricultural University
SE	Standard Error
$t\ ha^{-1}$	Ton per hectare
UNDP	United Nations Development Programme
viz	Namely
%	Percentage

Chapter 1

Introduction

CHAPTER I

INTRODUCTION

Arsenic (As) is a metalloid which is belongs to group V of the periodic table (Tutor, 2010). It has metallic as well as non-metallic characteristics. Its position is 20^{th} in terms of abundance in the earth's crust, 14^{th} in the seawater and 12^{th} in the human body. It is found naturally bound into over 200 different mineral compounds (Pereira *et al.,* 2010). Its origin in soil, water and air is due to various natural processes such as volcanic eruption, weathering of minerals, rocks and anthropogenic activities for instances and the application of pesticides for agricultural purpose (Bhattacharya *et al.,* 2007). The general population may be come into contact of As from air, food, and water (Chou and De Rosa, 2003).

High As contamination of surface and groundwater occurs worldwide and has become a sociopolitical issue in several parts of the globe (Kibria, 2013). For example, several million people are at risk from drinking As-contaminated water in Bangladesh (Rahman *et al.,* 2014) and West Bengal (India) (Dey *et al.,* 2014). Scores of people from Taiwan (Su *et al.,* 2014), Argentina (Giménez *et al.,* 2013), Chile (Steinmaus *et al.,* 2013), China (Rodríguez-Lado *et al.,* 2013), Mexico (Dávila, 2013) and Vietnam (Hanh *et al.,* 2011) are likely at risk as well. Among the countries, Bangladesh is the most affected by As problem (Jiang *et al.,* 2013).

Rising As concentrations in groundwater are alarming due to the health risk to plants, animals, and human's health (Mirza *et al.,* 2014). The inhalation and ingestion of As is perhaps the responsible for human carcinogen (Zhang *et al.,* 2011; Loewenberg, 2007), affecting skin and lungs (Hughes *et al.,* 2011). The chronic levels of As exposure adversely impact on human health which is the reason for skin disorders (Mishra *et al.,* 2014), neurological complications (Naujokas *et al.,* 2013), diabetes mellitus (Bailey *et al.,* 2013), cardiovascular disease (Naujokas *et al.,* 2013; Moon *et al.,* 2012), respiratory effects (Santra *et* *al.,* 2013; Parvez *et al.,* 2010), reproductive disorders (Jomova *et al.,* 2011) as well as various types of cancers including skin, lung, bladder, and kidney (Naujokas *et al.,* 2013). Approximately 6.8 million people have arsenicosis (arsenical skin lesions) due to groundwater As contamination (Chakraborti *et al.,* 2010). Bangladesh is currently facing a risk of long-term epidemic of cancers and other fatal diseases related to As exposure, the extent of which is difficult to gauge (Ahmad *et al.,* 2005).

The people of Bangladesh not only drink the As contaminated groundwater but also irrigate their crops. Now-a-days groundwater is the main source of irrigation (Shirazi *et al.,* 2010), which is about 40 percent of net cultivable area of Bangladesh (Huq *et al.,* 2005). The quantity of As extracted each year through irrigation water in Bangladesh is about 1360 metric tons of As, which ultimately is deposited in the top layer of irrigated soil (Ali *et al.,* 2003). The average soil As level is below 10 mg kg^{-1}, with values exceeding levels as high as 80 mg kg^{-1} in areas where irrigation using As-contaminated water is practiced continuously, and the annual build-up from irrigation in soil has been calculated to be 5.5 kg ha^{-1} (Huq and Naidu, 2005). There are indications that soil concentrations of As as well as uptake of As by the crops are increasing over time because of irrigation (FAO, 2006).

Irrigation with As-enriched groundwater is therefore the main pathway for As to enter the human food chain (Chatterjee *et al.,* 2010; Bhattacharya *et al.,* 2009) and this has led to a number of studies on transfer of As through the water-soil-crop-food system. Recent research suggests that a number of crops and vegetable plant species are reported to accumulate significant amount of As (Bhattacharya *et al.,* 2010a, b; Roberts *et al.,* 2010; Brammer, 2009; Meharg *et al.,* 2009; Dahal *et al.,* 2008; Rahman *et al.,* 2007a; Huang *et al.,* 2006; Norra *et al.,* 2005; Samal, 2005). As accumulation by agricultural plants depends on availability of As (content, water requirement, soil properties) and also on the physiological properties of the plant (Norra *et al.*, 2005; Lehoczky *et al.*, 2002). A wide and variable range of As contents were found in tropical fruits, vegetables, pulses and spices in Nepal (Dahal *et al.*, 2008), Bangladesh (Williams *et al.*, 2006) and West Bengal (Roychowdhury *et al.*, 2002). In case of vegetables, the highest As accumulation was observed in potato, arum, amaranth, radish, lady's finger, cauliflower, brinjal where as lower level of As accumulation was observed in beans, green chilli, tomato, bitter guard, lemon, turmeric etc. due to the As-contaminated irrigation water (Santra *et al.*, 2013). As contents of vegetables varied; those exceeding the food hygiene concentration limit of 1.0 mg kg^{-1} as described by Abedin *et al.* (2002) included kachu sak (*Colocasia antiquorum*) (0.09-3.99 mg kg^{-1}), potatoes (*Solanum tuberosum*) (0.07-1.36 mg kg^{-1}) and kalmi sak (*Ipomoea reptoms*) (0.1-1.53 mg kg^{-1}). It was reported that As concentrations in agricultural plants varied from 0.007 to about 7.50 mg kg^{-1} (Bhattacharya *et al.*, 2010b; Dahal *et al.*, 2008; Liao *et al.*, 2005).

The As concentration was further found to vary between different parts of the plants. On an average the As accumulation in tuberous vegetables > leafy vegetables > fruity vegetables (Santra *et al.*, 2013). Some previous reports clearly showed that the As contents in the agricultural plants were correlated to the degree of As contamination in irrigation water and soil (Dahal *et al.*, 2008; Roychowdhury *et al.*, 2005). The accumulation of As in plants occurs primarily through the root system and the highest As concentrations have been reported in plant roots and tubers (Marin *et al.*, 2003). Therefore, tuber crops are expected to have higher As contents than that of other crops when those are grown in As contaminated soil as root system is the main parts of accumulate As in plants.

Potato (*Solanum tuberosum* L.) is the 4th world crop after wheat, rice and maize. Bangladesh is the 7th potato producing country in the world (FAOSTAT, 2012). In Bangladesh, it ranks 2nd after rice in terms of production. The total area under potato crop, national average yield and total production in Bangladesh are 430446 hectares, 19.071 t ha^{-1} and 8205470 metric tons, respectively. The total production is increasing over time as such consumption also rapidly increasing in Bangladesh (BBS, 2012).

The statistics available for the As contamination in ground water indicate that 59 districts (around 85% of the total area of Bangladesh) and about 75 million people are at risk (Ali *et al.*, 2003). People of As affected areas are consuming contaminated potatoes and creating serious problem of health. Several research have been examined the sources and behavior of As in different plants, but speciation and toxicity in potatoes and its impact on sustainable potato production are not established. Under this circumstance, the proposed study was undertaken to examined the effect of As on growth, yield and quality of potato with the following objectives:

i. Study the effect of As on the growth, yield and quality of potatoes;

ii. Screen out the As tolerant and As susceptible potato varieties; and

iii. Find out the most As accumulation layers of potato tuber.

Chapter 2
Review of literature

CHAPTER II

REVIEW OF LITERATURE

Potato is the most important tuber crop in the world as well as in Bangladesh. Numerous experiments have been conducted throughout the world on potato crop but information regarding arsenic (As) contamination in potato varieties and their effects on growth, yield and quality parameters are still inadequate. Brief reviews of available literature pertinent to the present study have been reviewed in this chapter.

2.1 Arsenic effect

Bergqvist *et al.* (2014) conducted an experiment to evaluate the accumulation and speciation of As in carrot, lettuce and spinach cultivated in soils with various As concentrations. They showed that the As accumulation was higher in plants cultivated in soil with higher As extractability.

Paul *et al.* (2014) investigated the effects of arsenic on radish in the pot (green house experiment), result revealed that length, fresh weight and dry weight of plant (edible part and leaf) was significantly ($P<0.05$) affected at higher concentration of As ($\geq$40 mg kg^{-1}) treatment. Chlorophyll a and chlorophyll b was significantly affected at >40 mg kg^{-1} As treated plant compared with control. Total soluble solids (TSS) and proline content in plant showed increasing trend at increasing concentration of As. About 70 μg of As g^{-1} of dry weight of edible part accumulate after 60 DAS at $\geq$ 40 to 80 mg kg^{-1}, it was more than leaf.

Bhatti *et al.* (2013) used a pot trial to determine the As uptake of four vegetable species (carrot, radish, spinach and tomato) with As irrigation levels ranging from 50 to 1000 μg L^{-1}. Only the 1000 μg As L^{-1} treatment showed a significant increase of As concentration in the vegetables over all other treatments ($P < 0.05$). The distribution of As in vegetable tissues was species dependent; As was mainly found in the roots of tomato and spinach, but accumulated in the leaves and skin of root crops. There was a higher concentration of As in the vegetables grown under flood irrigation relative to non-flood irrigation. The trend of As bioaccumulation was spinach > tomato > radish > carrot.

Halder (2013) investigated the risk of As exposure from staple diet to the communities in rural Bengal, even when they have been supplied with As safe drinking water. Among the vegetables generally consumed in rural villages, the accumulation of As was highest in the leafy type of vegetables (0.21 mg kg^{-1}), compared to non-leafy (0.07 mg kg^{-1}) and root vegetables (0.10 mg kg^{-1}). Arsenic (As) predominantly accumulates in rice (>90%) and vegetables (almost 100%) in inorganic species.

Monica *et al.* (2013) was conducted a controlled greenhouse and home garden experiment to characterize the uptake of As by common homegrown vegetables. The greenhouse and home garden As soil concentrations varied considerably, ranging from 2.35 to 533 mg kg^{-1}. All vegetables accumulated As in both the greenhouse and home garden experiments, ranging from 0.01 to 23.0 mg kg^{-1} dry weight. Bioconcentration factors were determined and showed that As uptake decreased in the order: Asteraceae > Brassicaceae > Amaranthaceae > Cucurbitaceae > Liliaceae > Solanaceae > Fabaceae.

Norton *et al.* (2013) conducted a field study of locally grown fruits and vegetables from historically mined regions of southwest England (Cornwall and Devon). They found that the concentration of total As in potatoes, swedes, and carrots was lower in peeled produce compared to unpeeled produce. For baked potatoes, the concentration of total As in the skin was higher compared to the total As concentration of the potato flesh.

Rahaman *et al.* (2013) found the highest As concentration in potato (0.456 mg kg^{-1}), followed by rice grain (0.429 mg kg^{-1}). The total mean As content (milligrams kg^{-1} dry weight) in cereals ranged from 0.121 to 0.429 mg kg^{-1}, in pulses and oilseeds ranged from 0.076 to 0.168 mg kg^{-1}, in tuber crops ranged from 0.243 to 0.456 mg kg^{-1}, in spices ranged from 0.031 to 0.175 mg kg^{-1}, in fruits ranged from 0.021 to 0.145 mg kg^{-1} and in vegetables ranged from 0.032 to 0.411 mg kg^{-1}, respectively.

Rahman *et al.* (2013) assessed the daily consumption by adults of As in drinking water and home-grown vegetables in a severely As-contaminated area of Bangladesh. The median concentrations of As in vegetables were 90 μg kg^{-1}. Daily intakes of As from vegetables and drinking water for adults were 839 μg. Vegetables alone contribute 0.05 μg of As and 0.008 mg of body weight daily.

Santra *et al.* (2013) studied As accumulation in different vegetables, they found that tuberous vegetables accumulated higher amount of As than leafy vegetables and leafy vegetables followed by fruity vegetable. The highest As accumulation was observed in potato, brinjal, arum, amaranth, radish, lady's finger, cauliflower whereas lower level of As accumulation was observed in beans, green chilli, tomato, bitter guard, lemon, turmeric.

Biswas *et al.* (2012) examined total As concentrations in 32 types of vegetables and 7 types of pulses. Range of total As concentration in edible parts of vegetables collected from grown fields was 0.114-0.910 mg kg^{-1}. Highest arsenic values were in spinach 0.910 mg kg^{-1}. Vegetable samples were grouped into leafy, non-leafy-fruity, root-tubers. Eighteen common types of vegetables and pulses were collected through market basket survey, total As were approximately 100 mg lower than those observed for the vegetables collected from the fields.

Islam *et al.* (2012) studied As accumulation pattern in eight types of vegetables commonly found in Bangladesh. They found that As accumulation decreased in the order: arum > arum leaf > amaranth > brinjal > radish > Indian spinach > carrot > okra. A single harvesting of 10 irrigations with water (3.0 L/irrigation) having arsenic concentrations of ≥0.45 mg L^{-1} to 0.071 m^2 area (equivalent to 1.89 kg As ha^{-1}) exceeded the maximum permissible limit in vegetables (1 mg kg^{-1}, wet weight).

Jameel *et al.* (2012) conducted an experiment to evaluate the translocation of As by different vegetables grown in agricultural soil irrigated for long period with tube well water as test vegetable samples and compared those vegetables of same species grown in agricultural soil irrigated with fresh canal water marked as control vegetable samples. Moreover, the total and ethylene-diamine-tetra acetic acid (EDTA) extractable contents of As in soil irrigated by tube well and canal water were determined and correlate with total concentrations of As in edible parts of vegetables. High level of total and EDTA extractable As were found in tested vegetable samples as compared to controlled vegetable samples. This investigation highlights the increased danger of growing vegetables in the agricultural land continuously irrigated by As contaminated water.

Kundu *et al.* (2012) carried out an experiment to study the arsenic accumulation in potato tuber and the varietal tolerance vis-à-vis yield by nine selected popular potato cultivars at framers' fields of two different sites at village Nonaghata, Haringhata block in Nadia district of West Bengal during winter season of 2007-08. Results revealed that, different cultivars potato accumulated different amount of arsenic at different sites of arsenic endemic areas. Regarding varietal effect, the cultivar Asoka and S-Punjab recorded maximum As accumulation, while the least As recovery was noted from the cultivar Kufri Chandramukhi at both the sites among all cultivars. The yields of different cultivars of potato were significantly different from each other.

Kundu *et al.* (2012a) conducted a field experiment to evaluate the varietal tolerance and accumulation of As by different potato cultivars at village Nonaghata in Nadia district of West Bengal during winter season of 2008-09 and 2009-10. As content in the irrigation water was 0.094 to 0.108 mg L^{-1}. As accumulation of different plant parts was in the following sequence: root > stem > leaf > tuber irrespective of all cultivars. After harvesting, the least As loading was observed in cultivar Kufri Jyoti (0.05 mg kg^{-1}) which also showed the highest productivity (32.32 t ha^{-1}). Cultivar Kufri Chandramukhi and locally grown variety Lal alu accumulated a lesser amount of As and had also a higher yield compared with the other entries.

Temmerman *et al.* (2012) carried out an experiment where root crops, carrot and celeriac, were exposed to atmospheric deposition in a polluted versus reference area. An effect was observed on the As, Cd and Pb concentrations of the leaves and the storage organs. As such the experiments allowed deriving regression equations, useful for modeling the atmospheric impact of trace elements on the edible parts of root crops.

Wright *et al.* (2012) determined the concentrations of nine residual metals in some Jamaican foods by using inductively coupled plasma mass spectrometry technique. They found that sweet potato had the highest concentrations of As (0.70 mg kg^{-1}), lead (0.31 mg kg^{-1}) and mercury (0.35 mg kg^{-1}). These results suggest that the elements were available in soluble forms in the soil for absorption by food crops.

Bergqvist (2011) performed a greenhouse cultivation with three different species of vegetables to determine the risks of dietary As intake from vegetables cultivated in soil with elevated levels of As. In general, with increasing $[As]_{soil}$, there was a concomitant increase in $[As]_{plant}$. Vegetables cultivated in As containing soil had elevated concentrations of As in the biomass.

Kundu *et al.* (2011) conducted field experiments at Nonaghata village of Nadia district during 2007-2008 and 2008-2009 to evaluate the varietal tolerance and accumulation of As in different taro (*Colocasia esculenta* [L.] *Schott.)* cultivars. They reported that presence of As in vegetables and tuber crops was found to vary with crops and even among the cultivars of the same crop. Results revealed that accumulation of As in different plant parts was in the order of leaf > petiole > cormel, irrespective of cultivars.

Samal *et al.* (2011) worked with human As exposure through the drinking of groundwater, consumption of locally grown foodstuffs (e.g., crops and vegetables) and cooked food in Nadia district, West Bengal. Significant levels of As were also found in other common crops and vegetables cultivated in this area (for example, the mean As in arum and radish was 780 and 674 μg kg^{-1}, respectively).

Abdullah *et al.* (2010) measured As concentrations in water, soil and arum (vegetables) samples using the Neutron Activation Analysis method and a correlation between As concentrations in the samples was investigated. As concentration of all the water samples ranged from 0.09 to 0.87 mg L^{-1}. The concentrations in soil and aurum samples were found to be in the range of 2.22-35.21 and 0.07-0.73 mg kg^{-1}, respectively. A positive correlation between As concentrations in soil and water samples was observed. Aurum sample was found to be contaminated by As to a harmful level if the corresponding water sample was also highly contaminated.

Bhattacharya *et al.* (2010) reported that the As-contaminated irrigation water (0.318-0.643 mg L^{-1}) and soil (5.70-9.71 mg kg^{-1}) considerably influenced in the accumulation of As in rice, pulses, and vegetables. As concentrations of irrigation water samples were many folds higher than the FAO permissible limit (0.10 mg L^{-1}). The highest and lowest mean As concentrations (mg kg^{-1}) were found in potato (0.654) and in turmeric (0.003), respectively. Higher mean arsenic concentrations (mg kg^{-1}) were observed in Boro rice grain (0.451), arum (0.407), amaranth (0.372), radish (0.344), Aman rice grain (0.334), lady's finger (0.301), cauliflower (0.293), and Brinjal (0.279). Apart from a few potato samples, As concentrations in the studied crop samples, including rice grain samples were found not to exceed the food hygiene concentration limit (1.0 mg kg^{-1}).

Imtiaz *et al.* (2010) collected a total of 120 vegetable samples from five different markets of three different villages of Pabna district of Bangladesh and were tested for As concentration. They reported that the mean concentration of As in leafy vegetables (0.52 μg g^{-1}) was significantly higher compared to those found in fruity (0.422 μg g^{-1}) and root and tuber vegetables (0.486 μg g^{-1}).

Khan *et al.* (2010) measured As and cadmium (Cd) in foods from Matlab, a rural area in Bangladesh that is extensively affected by As. Raw and cooked food samples were collected from village homes (households, n=13) and analyzed to quantify concentrations of As and Cd using atomic absorption spectrophotometry. Compared to raw vegetables (e.g. arum), concentration of As increased significantly (p=0.024) when cooked with As-contaminated water.

Li *et al.* (2010) carried out an experiment on the As content in the soils and plants surrounding Shimen arsenic sulphide mine. The As content in top soils (0-20 cm) was averagely 99.51 mg kg^{-1}. The As content in edible parts of foodstuff, vegetables, and fruits was 0.16, 0.06, and 0.01 mg kg^{-1}, respectively, and the arsenic exceeding rate of crop samples compared to food security standard ranked in the order of foodstuff > vegetables > fruits. Rice and sweet potato were relatively seriously contaminated by As.

Marconi *et al.* (2010) conducted an experiment on the evaluation of As effect on radish tuber (*Raphanus sativus* L.). Experimental plots with sandy and clay-loamy soil were cultivated with radish and treated with three different concentrations of As water solution: 19, 44 and 104 µg L^{-1}. Magnetic resonance imaging was used to visualize the tuber structural changes, and the content of elements and the As amount were evaluated by inductively coupled plasma atomic emission spectroscopy. The data obtained demonstrate that As contamination in radish tuber was underlined with the dual approach.

Srek *et al.* (2010) conducted an experiment to investigate how potato yield, the concentrations of elements (N, P, K, Ca, Mg, S, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in tubers and their uptake are affected by mineral N, P and K fertilizers, straw and pig slurry application. They found that the concentrations of As, Cd, Cr, Cu, Fe, Mn, Pb and Zn in tubers were not significantly affected by fertilizer treatment. Therefore, normal cropping practices do not significantly increase the concentrations of trace elements in potatoes.

Surdyk *et al.* (2010) studied in a three years experiment on the accumulation of heavy metals in soil and potato plants (*Solanum tuberosum* L.) irrigated with treated low quality surface water. The low quality surface water used for irrigation experiments contained a significant proportion of urban sewage and was spiked with selected heavy metals (Cd, Cr, Cu, Pb) and As before treatment for years 2 and 3. They found that after the third harvest, no impact of the irrigation water on potato quality could be detected except for total sugar and sugar in total solids. The principal conclusion of this investigation is that, when appropriately treated, low quality feed waters with high heavy metal contents can be used for irrigation over several years without significant degradation of soil and produces.

Sushant and Ghosh (2010) conducted a pot experiment to investigate the effect of As on photosynthetic pigments, Chl a and b, growth behavior, and its accumulation in the tissues of different parts of onion plants (*Allium cepa*). They found that both chl a and b contents in onion leaf increased significantly with the increase of water As concentrations. The highest chl a and chl b contents were estimated in the onion leaf irrigated with 0.800 mg L^{-1} of As whereas, in control plant it was lowest. A high positive correlation was observed between water As and soil As with chl a and chl b respectively. High positive correlation was also observed even for onion growth verses soil As and water As and water As with leaf biomass respectively. However, no As accumulation was detected in the tissues of different parts of the onion plants suggesting that, As influenced the biochemistry of photosynthesis which ultimately resulted in the increase of onion growth and yield. Onion plants can be cultivated in the area where As containing water is being utilized for irrigating crops.

Arain *et al.* (2009) developed a database of As in lake water, ground water, sediment, soil, vegetables, grain crops and fish to evaluate the potential human health risks posed by higher level of As, in south east part of Sindh, Pakistan during 2005-2007. The concentration of As in lake sediment and agricultural soil samples ranged between 11.3-55.8 and 8.7-46.2 mg kg^{-1}. It was observed that the leafy vegetables (spinach, coriander and peppermint) contain higher As levels (0.90-1.20 mg kg^{-1}) as compared to ground vegetables (0.048-0.25) and grain crops (0.248-0.367 mg kg^{-1}) on dried weight basis.

Moyano *et al.* (2009) carried out an experiment in an intensively cultivated agricultural area of central Spain where high As concentrations in groundwater were previously reported. The concentrations and distribution of As in soils and crops (wheat, potato, sugar beet and carrot) were determined to know the effect of irrigation with As-rich groundwater in the agricultural fields, and to estimate its impact on the food chain contamination. Irrigation water shows high As concentrations ranging between 38 and 136 µg L^{-1}. As contents in potato tuber samples are 35 times higher than that measured in potato tuber of uncontaminated control sites (0.03 mg kg^{-1}). Elevated As contents (3.9-5.4 mg kg^{-1} dry weight) were also found in root samples of sugar beet. The As contents in vegetable samples are higher than As content (0.1 mg kg^{-1} dry weight) in plants of uncontaminated control areas.

Smith *et al.* (2009) hydroponically grew common Australian garden vegetables with As-contaminated irrigation water to determine the uptake and species of As present in vegetable tissue. The highest concentrations of total As were observed in the roots of all vegetables and declined in the aerial portions of the plants. Total As accumulation in the edible portions of the vegetables decreased in the order radish ≫ mungbean > lettuce = chard. Arsenic was present in the roots of radish, chard, and lettuce as arsenate (AsV) and comprised between 77 and 92% of the total As present, whereas in mungbean, arsenite (AsIII) comprised 90% of the total As present. In aerial portions of the vegetables, As was distributed equally between both AsV and AsIII in radish.

Bronkowska *et al.* (2008) determined As contents in plant products originating from the region of two copper works, Głogów and Legnica. Analyses were carried out by means of atomic absorption spectrometry, using an MHS-10 unit for hydride generation (acetylene/argon), after wet mineralization of samples. The maximum permissible level of As was not exceeded in any of the examined samples of cereals, potatoes, carrots, beetroots, cabbages, tomatoes, apples and pears, originating from the regions under scrutiny.

Dahal *et al.* (2008) monitored the influence of As-contaminated irrigation water on alkaline soils and As uptake in agricultural plants at field level. The As concentrations in irrigation water ranges from <0.005 to 1.014 mg L^{-1}. The As content in different parts of plants are found in the order of roots>shoots>leaves>edible parts. The mean As content of edible plant material (dry weight) were found in the order of onion leaves (0.55 mg As kg^{-1}) > onion bulb (0.45 mg As kg^{-1}) > cauliflower (0.33 mg As kg^{-1}) > rice (0.18 mg As kg^{-1}) > brinjal (0.09 mg As kg^{-1}) > potato (<0.01 mg As kg^{-1}).

Gaw *et al.* (2008) found that radish and lettuce grown in soils that had formerly been treated with arsenical pesticides accumulated As, though not in concentrations that exceeded the U.S. Food and Drug Administration (FDA) standard. They also estimated the bioaccumulation factor (BAF) for lettuce and radishes grown in soils that contained As in concentrations of 0.4 to 35.6 mg kg^{-1}. They found the BAF for both vegetables to be small, much less than 1.0.

Juhasz *et al.* (2008) determined the concentration and speciation of As in chard, radish, lettuce and mungbean was following hydroponic growth of the vegetables using As-contaminated water. While As concentrations ranged from 3.0 to 84.2mg As kg^{-1} (dry weight), only inorganic As (arsenite and arsenate) was detected in the edible portions of the vegetables. When As bioavailability was assessed through monitoring blood plasma As concentrations following swine consumption of As-contaminated vegetables, between 50% and 100% of the administered As dose was absorbed and entered systemic circulation. As bioavailability decreased in the order mungbean>radish>lettuce=chard.

Karim *et al.* (2008) conducted an experiment to investigate the As poisoning in soils and vegetables in five upazillas under Feni district of Bangladesh.

Samples were assessed and screened for As, Br, U, Th, Cr, Sc, Fe, Zn and Co in soils and As, Br, Na, K, Cr, Sc, Fe, Zn and Co in vegetables (i.e; eddoe, taro, green papaya, plantain, potato, callaloo, bottle ground and carambola). They reported that the mean levels of As in Parsuram, Feni Sadar and Pulgazi upazillas are higher than the world typical value of 2 mg kg^{-1}. For the case of vegetables, the mean concentration of As is found only in Eddoe (5.33 mg kg^{-1}) and Taro (1.46 mg kg^{-1}) collected from Sonagazi and Feni Sadar upazilla; which are higher than the values in Samta (0.1 mg kg^{-1} for eddoe and 0.44 mg kg^{-1} for taro) under Jessore district of Bangladesh. The mean estimated daily dietary intake of As from vegetables are found to be 0.105 mg, which are higher than the recommended values of some countries.

Lim *et al.* (2008) set up an experiment to estimate the bioaccessible fraction of the metals in soil and crop plant in Songcheon Au-Ag mine, Korea. After appropriate preparation, all samples were analyzed for As, Cd, Cu, Pb and Zn by ICP-AES and ICP-MS. Especially, maximum levels of As in farmland soil was up to 626 mg kg^{-1}. The highest levels in crop plant were 33 mg As kg^{-1} and 3.8 mg Pb kg^{-1} (in green onion root), 0.87 mg Cd kg^{-1} and 226 mg Zn kg^{-1} (in lettuce root), 16.3 mg Cu kg^{-1} (in sesame leaves). Vegetables grown on the contaminated soil were rich in As and heavy metals.

Loźna and Biernat (2008) conducted an experiment with amount of As ranged within 1-5300 µg L^{-1} comes from countries where earth water is used as drinking water. The relatively small arsenic contents is characteristic for vegetables and fruits (<0.1 mg kg^{-1}), higher amount is observed in leaf vegetables (up to 0.6 mg kg^{-1}) and potatoes (0.86 mg kg^{-1}).

Roychowdhury (2008) found that As concentrations are high in cooked food and skin of the vegetables. As concentration in cooked rice increases with water As concentration.

Laizu (2007) collected a total 400 vegetable sample of 20 varieties of three categories from a local market of Dhaka city, Bangladesh. In case of As accumulation the fruiting vegetables, root and tuber vegetables (arum, arum loti, carrot, radish and potato) and leafy vegetables showed significant variation. In root and tuber vegetables, significant relationship was present in arum.

Rahman and Hasan (2007) assessed mean, minimum and maximum As content in some common garden vegetables, e.g. bean, bitter gourd, bottle gourd, brinjal, chilli, green papaya, mint, okra, palwal, potato, red amaranth, string bean and sweet gourd, from an arsenic prone locality of Bangladesh. They showed that garden vegetables grown in As-tainted soil uptake and accumulate significant amount of As in their tissue.

Huang *et al.* (2006) investigated the bioavailability, soil-to-plant transfer and associated health risks of As in soils collected from paddy rice fields and vegetable fields in suburban areas of some major cities of Fujian Province. The total soil concentrations of As ranged from 1.29 to 25.28 mg $kg^{-1}$with a mean of 6.09 mg kg^{-1}. The accumulation ability of the crops decreased in the order of rice>radish>water spinach>celery>onion>taro>leaf mustard>fragrant flowered garlic>pakchoi>Chinese cabbage>lettuce>garlic>cowpea>cauliflower>bottle gourd>towel gourd>egg plant. Daily consumption of rice and other As-rich vegetables could result in an excessive intake of As, based on the provisional tolerable intake for adults for As recommended by WHO.

Huq *et al.* (2006) analyzed As content of 2,500 water, soil and vegetable samples from As-affected and As-unaffected areas during 1999-2004. They reported that some commonly-grown vegetables, which would usually be suitable as good sources of nourishment, accumulate substantially-elevated amounts of As. For example, more than 150 mg kg^{-1} of As has been found to be accumulated in arum (kochu) vegetable.

Panaullah *et al.* (2006) conducted an experiment to assess the As contamination status of irrigation water, soil and crop samples (both rice and non-rice crops) from 184 unions of 92 of the 450 thanas (a thana is the smallest administrative unit in Bangladesh) across the country were collected and analyzed for As using the HG-AAS procedure. The As contents in the human edible parts of 70 different non-rice crops, like wheat, maize, leafy vegetables, tomato, chili, beans, etc. were also determined. While As in the upland cereals, maize and wheat, was found to be negligible, most other crops, especially, the leafy vegetables and tubers appeared to accumulate As in amounts double or triple that of rice. However, the risk from these crops would be low since the human consumption of the edible parts is much lower than that of rice.

Smith *et al.* (2006) carried out an experiment to measure the main types of As in commonly consumed foods in Bangladesh. They found that the mean total As levels in 39 vegetable samples were 333 μg kg^{-1} (range: 19 to 2334 μg kg^{-1} dry weight). Inorganic As calculated as arsenite and arsenate made up 96% of the total As in vegetables. Total As in water ranged from 200 to 500 μg L^{-1}.

Williams *et al.* (2006) conducted food market-basket survey from Bangladesh, which addresses the speciation and concentration of As in rice, vegetables, pulses, and spices. Three hundred thirty aman and boro rice, 94 vegetables, and 50 pulse and spice samples were analyzed for total As, using inductivity coupled plasma mass spectrometry (ICP-MS). Vegetables, pulses, and spices are less important to total As intake than water and rice.

Huq and Naidu (2005) revealed that of the many vegetables, arum has been found to be a hyper accumulator for As. The amount of rice consumed per person per day (450 g uncooked) along with As contaminated drinking water (4L d^{-1}) including vegetables with high As is sufficient enough to cross the limit of MADL of 220 μg d^{-1}. The largest contributor to As intake by Bangladesh villagers in affected regions is contaminated drinking water, followed food, notably rice and vegetables.

Rmalli *et al.* (2005) found highest As values in the skin of Arum tuber, 540 μg kg^{-1}, followed by Arum Stem, 168 μg kg^{-1}, and Amaranthus, 160 μg kg^{-1}. The As content of the vegetables from the UK was approximately 2 to 3 fold lower than those observed for the vegetables imported from Bangladesh. The levels of As found in vegetables imported from Bangladesh in this study, in some cases, are similar to those previously recorded for vegetables grown in As-affected areas of West Bengal, India, although lower than the levels reported in studies from Bangladesh. While the total As content detected in vegetables, imported from Bangladesh, is far less than the recommended maximum permitted level of As, it does provide an additional source of As in the diet.

Roychowdhury *et al.* (2005) revealed that higher the As in groundwater, higher the As in agricultural land soil and plants. Mean As concentrations in root, stem, leaf and all parts of plants are 996 ng g^{-1} (range: <0.04-4850 ng g^{-1}), 297 ng g^{-1} (range: <0.04-2900 ng g^{-1}), 246 ng g^{-1} (range: <0.04-1600 ng g^{-1}) and 513 ng g^{-1} (range: <0.04–4850 ng g^{-1}) respectively. Approximately 3.1-13.1, 0.54-4.08 and 0.36-3.45% of arsenic is taken up by the root, stem and leaf respectively, from the soil.

A greenhouse experiment was conducted by Cao and Ma (2004) to evaluate As accumulation by vegetables from the soils adjacent to rhe CCA-treated utility poles and fences and examine the effects of soil amendments on plant As accumulation. As expected, elevated As concentrations were observed in the pole soil (43 mg As kg^{-1}) and in the fence soil (27 mg As kg^{-1}), resulting in enhanced As accumulation of 44 mg As kg^{-1} in carrot (*Daucus carota* L.) and 32 mg As kg^{-1} in lettuce (*Lactuca sativa* L.). Addition of phosphate to soils increased As accumulation by 4.56-9.3 times for carrot and 2.45-10.1 for lettuce due to increased soil water-soluble As via replacement of arsenate by phosphate in soil.

Das *et al.* (2004) determined the level of contamination in 100 samples of crop and vegetables collected from three different regions in Bangladesh those grown in fields irrigated with As contaminated water. As concentrations were determined by hydride generation atomic absorption spectrophotometry. As contents of vegetables varied; those exceeding the food safety limits included kachu sak (*Colocasia antiquorum*) (0.09-3.99 mg kg^{-1}), potatoes (*Solanum* *tuberosum*) (0.07-1.36 mg kg^{-1}), and kalmi sak (*Ipomoea reptoms*) (0.1-1.53 mg kg^{-1}). These results indicate that As contaminates some food items in Bangladesh.

Haque (2004) conducted an experiment to determine the status of As in different vegetables of Chapai Nawabganj. He found that the As concentrations were higher in leafy vegetables compared to fruits and root and tuber vegetables. The vegetables were arranged in the descending order of As concentrations (µg g^{-1}) as: cabbage (0.812)> mustard shak (0.798)> bitter gourd (0.787)> radish (0.750)> tomato (0.749)> cauliflower (0.725)> sponge gourd (0.712)> spinach (0.675)> aroid leaf (0.625)> brinjal (0.612)> okra (0.537)> potato (0.487) >chilli (0.470)> onion (0.450)> garlic (0.314)> bottle gourd (0.312).

Alam *et al.* (2003) conducted an experiment in Samta village in the Jessore district of Bangladesh to see the As level of various vegetables. They reported that the highest As concentrations of snake gourd, ghotkol taro, green papaya, elephant foot and bottle ground leaf were 0.489, 0.440, 0.446, 0.389, 0.338, and 0.306 µg g^{-1}, respectively. They found that BCF values for As in ladies finger, potato, ash gourd, brinjal, green papaya, ghotkol and snake gourd were 0.001, 0.006, 0.006, 0.014, 0.030, 0.034 and 0.038, respectively.

Ali *et al.* (2003) conducted a research on As concentration in different vegetables which were irrigated with low level of As rich pond water. They found the highest accumulation of As in the root of potato plants (up to 2.9 mg kg^{-1}) whereas, As concentration in the edible parts varied from 0.12 to 0.85 mg kg^{-1}.

Farid *et al.* (2003) conducted an experiment in both As free and As contaminated irrigation plots, were analyzed for As. As concentration (mg kg^{-1}) of different vegetables grown with As containing irrigation water were found in the descending order of: amaranth (0.572) > china shak (0.539) > red amaranth (0.321) > katua data (0.284) > Indian spinach (0.189) > chilli (0.112) > potato

(0.103) > bitter gourd (0.091) > cabbage (0.072) > brinjal (0.049) > okra (0.040) > tomato (0.030) > cauliflower (0.011) and that for As free irrigation water were much lower and in the order of: china shak (0.278) > red amaranth (0.163) > amaranth (0.139) > katua data (0.114) > chilli (0.103) > Indian spinach (0.100) > potato (0.063) > cabbage (0.055 ppm) > brinjal (0.045) > Bitter gourd (0.039) > okra (0.031) > tomato (0.011) > cauliflower (0.001). Relationship between As in irrigation water and As accumulation of 4 vegetables were strongly positive and followed the descending order of tomato > potato > red amaranth > katua data.

Farago *et al.* (2003) reported that normally plants tolerate arsenic in soil within the concentration range 1-50 mg kg^{-1} dry weight. Hlusek *et al.* (2003) conducted an experiment on the effect of increasing doses of As on two potato varieties (very early 'Rosara' and semi-early 'Korela') in three-year field trials established on two sites (ZabCice and Valecov). The results were unambiguous and confirmed that the uptake of As by potatoes is based on the level of its active forms in the soil; distribution in the plant is different. The average content of As in the potato tops was many times higher than in the tubers, i.e. of dry matter, respectively. In both cases the dependence on the degree of As contamination of the soil was statistically significant. There were no substantial differences between the varieties in view of the content of As in the tubers; in the tops the differences were greater but they were still on the margin of statistical significance. The dependence of the concentration and distribution of As in potatoes on the locality was found to be highly significant both in tubers and in the tops.

Warren *et al.* (2003) conducted an field trials to assess the uptake of As by vegetables from contaminated soils. Four UK locations were used, where soil was contaminated by As from different sources. At the most contaminated site, a clay loam containing a mean of 748 mg As kg^{-1} soil, beetroot, calabrese, cauliflower, lettuce, potato, radish and spinach were grown. For all crops except spinach, ferrous sulfate treatment caused a significant reduction in the bioavailability of As in some part of the crop. Differences between sites in the bioavailable fraction of soil As may be related to the soil texture or the source of As. The highest bioavailability was found on the soil which had been contaminated by aerial deposition and had a high sand content.

Roychowdhury *et al.* (2003) carried out an experiment to know the concentration of As, copper, nickel, manganese, zinc and selenium in foodstuffs in the arsenic-affected areas of the Jalangi and Domkal blocks, Murshidabad district, West Bengal. The shallow large diameter tubewells, installed for agricultural irrigation contain an appreciable amount of As (mean: 0.094 mg L^{-1}). The mean As levels in food categories are vegetables (20.9 and 21.2 μg kg^{-1}), cereals and bakery goods (130 and 179 μg kg^{-1}) and spices (133 and 202 μg kg^{-1}) for the Jalangi and Domkal blocks, respectively.

Adak *et al.* (2002) conducted an experiment where two potato (cv. Kufri Jyoti)-based sequential cropping systems viz., potato-maize-green gram (Sc_1) and potato-sesame-jute (*Corchorus olitorius*)-green gram (Sc_2) were utilized to determine the effects of 8 irrigation treatments with As-contaminated water on the yield of potato and the As uptake of the leaves, stems, roots and economic produce of the crops 15 days before and during harvest. Potato tuber yield was higher in Sc_1 (18.5 t ha^{-1}) compared to Sc_2 (14.7 t ha^{-1}). As concentrations in the leaves, stems and tubers of potato in Sc_1 were higher at harvest than 15 days before harvest. On the other hand, As concentrations in the leaves and stems of potato in Sc_2 were higher 15 days before harvesting, whereas those of potato tubers were higher at harvest.

Juzl and Stefl (2002) used a method of growth analysis to evaluate the yield results in experiments conducted during years 1999-2001 on school co-operative farm in Zabcice. In sequential terms of sampling from two potato varieties with different duration of growing season, the effect of leaf area index (LAI), on yield of tubers in soils contaminated by cadmium, As and beryllium, was evaluated. From a growers view the phytotoxic influence on development of assimilatory apparatus and yields during the growth of a very-early variety

Rosara and a medium-early Korela were evaluated. These varieties were grown under field conditions in soils contaminated by graded levels of cadmium, As and beryllium. The yields of tubers were positively influenced by duration of growing season and increased of leaf area index during three experimental years. On the contrary, graded levels of heavy metals had negative influence on both chosen varieties. The highest phytotoxic influence was recorded of As and the lowest of cadmium. Significant influence of As and beryllium on size of leaf area index in the highest applied variants was found. The influence of experimental years on tuber yields was also statistically significant.

Miteva (2002) studied the phytotoxic action of arsenic trioxide on tomato plants, noting a decrease in growth and reduction in fruit pigment at concentrations greater than 50 mg kg^{-1} dry weight soil.

Roychowdhury *et al.* (2002) conducted an experiment in As affected areas of the Murshidabad district, West Bengal, India. They reported that the shallow, large-diameter tube-wells installed for agricultural irrigation contain an appreciable amount of As (0.085 mg L^{-1}). They found that the individual food composites and group foods contained the highest As levels (μg g^{-1}) were potato skin (0.293 and 0.104), leaf of vegetables (0.212 and 0.294), arum leaf (0.33 and 0.34), papaya (0.196 and 0.373), rice (0.226 and 0.245), wheat (0.007 and 0.362), cumin (0.478 and 0.209), turmeric powder (0.297 and 0.280), cereals and bakery goods (0.156 and 0.294), other vegetables (0.092 and 0.123), spices (0.092 and 0.207) for the Jalangi and Domkal blocks, respectively. As is absorbed by the skin of most of the vegetables. The As concentration in fleshy vegetable material is low (mean 0.272 μg g^{-1}). Higher levels of As were observed in cooked items compared with raw.

Tlustos *et al.* (2002) carried out a pot experiment and observed that radish, carrot and green beans accumulated higher amount of As in roots than in above ground portion.

Peryea (2001) reported that the distribution of As among various plant parts is highly variable, with seeds and fruits having lower As concentration than leaves, stems or roots. Roots and tubers generally have the highest As concentrations, with the skin having concentrations than the inner flesh.

Queirolo *et al.* (2000) sampled various vegetables (broad beans, corn, potato, alfalfa and onion) in northern Chile, Antofagasta Region. The amounts found in the mustard greens are similar to those given earlier for corn (1.8 mg kg^{-1}, fresh weight) and potatoes (0.9 mg kg^{-1} fresh weight) when grown in arsenic contaminated soils in Chile.

Cobb *et al.* (2000) conducted an experiment in mine wastes and in waste amended soils and found that radish roots accumulated fewer metals (As, Cd, Pb and Zn) compared with leaves. Radish roots accumulated significantly more than bean and tomato fruits.

Carbonell-Barrachina *et al.* (1999) found inner root and outer skin concentration of more than 1 mg As kg^{-1} (above permissible limit) in turnip (*Brassica napus* L.).

Helgesen and Larsen (1998) found total As in carrot peel was approximately two times greater than in the core of the carrot.

Simon *et al.* (1998) conducted a pot experiment with different concentration of As on Radish cv. Rampouch. Tolerance limits were about 150-300 mg As kg^{-1} soil for radish growth.

Smith *et al.* (1998) showed that rice, bean and oats can exhibit phytotoxic symptoms at 20 mg As kg^{-1} soil, while for maize and radish this figure is 100 mg As kg^{-1}.

Klose and Braun (1997) studied the As content of soil and uptake As by potatoes. The soil As content of all the soils tested was over 50.0 mg kg^{-1} soil. In potatoes, As content ranged from 0.04 to 1.31 mg kg^{-1} dry matter when grown on soil containing 60-362 mg As kg^{-1} soil.

Sanok *et al.* (1995) conducted an experiment to determine the remaining concentrations of arsenic in potato soils on Long Island. The total concentrations of arsenic was markedly higher in the soils sampled than in untreated control soils.

Smiled *et al.* (1982) carried out field experiments to determine the yield and As accumulation by radish, lettuce, carrot, potato and wheat on soils having As concentration between 35 and 108 mg As kg^{-1} on dredged soil of the river Rhine and Meuse, UK. The highest level of As accumulation in radish (concentration ranging from 0.8 to 21 mg As kg^{-1}). The order of decreasing As accumulation was radish> lettuce> carrot> potato> spring wheat grain.

2.2 Varietal effect

Kassim *et al.* (2014) found that reducing physiological functions of above ground part of potato plant (leaf area and total chlorophyll content), the number and the weight of tuber decreased, so the productivity of the plant decreased.

Abebe (2013) carried out an experiment at three distinct locations in the Amhara region of Ethiopia for evaluation of the specific gravity of 25 potato varieties. The pooled specific gravity values ranged from 1.058 to 1.102. The specific gravity of tubers of the improved variety Belete was the highest while that of Menagesha was the lowest. Furthermore, the specific gravity values for varieties grown at Debretabor were higher than those for the corresponding varieties grown at Adet and Merawi. He mentioned that specific gravity is the measure of choice for estimating dry matter and ultimately for determining the processing quality of potato varieties.

Behjati *et al.* (2013) conducted a field experiment to evaluate the yield and yield components on promising potato clones. Clone No. 397031-1, had the highest yield and Lady Rosetta variety had the lowest yield compared with other varieties. The lowest and highest average number of main stems per plant, related to Lady Rosetta and clone No. 397067-2. Lady Rosetta variety had the highest number of tube per plant and clone No. 397067-2 had the lowest number of tubers per plant. The lowest and highest average tuber weight per plant related to clone No. 397067-2 and Lady Rosetta variety respectively.

Hossain (2011) conducted three experiments with BARI released twelve potato varieties to determine the yield potentiality, natural storage behavior and degeneration rate for three consecutive years. He found that the highest emergence was observed in Granola at 34 DAP. At 50 DAP plant height (cm) of Diamant was (43.50), BARI TPS 1 (47.70), Felsina (52.00), Asterix (52.97), Granola (38.30), Cardinal (46.33). Foliage coverage (%) of Diamant was (83.33), BARI TPS 1 (85.56), Felsina (82.22), Asterix (89.44), Granola (85.56), Cardinal (81.67). No. of stems hill^{-1} of Diamant was (4.06), BARI TPS 1 (3.21), Felsina (3.14), Asterix (4.03), Granola (3.30), Cardinal (3.89). Tuber yield hill^{-1} (g) of Diamant was (244.2), BARI TPS 1 (227.9), Felsina (300.1), Asterix (276.9), Granola (277.0), Cardinal (316.9). Under the grade 28-40mm, the highest number (48.63%) of seed tubers was produced by Granola which was statistically identical with Asterix (46.43%). Under the same grade (28-40 mm), the highest weight (43.46%) of seed tubers was produced by Patrones followed by Asterix (37.16%), Granola (36.64%) and Multa (35.39%) among which there was no significant variation.

Karim *et al.* (2011) conducted an experiment with ten exotic potato varieties (var. All Blue, All Red, Cardinal, Diamant, Daisy, Granola, Green Mountain, Japanese Red, Pontiac and Summerset) to determine their yield potentiality. The highest total tuber weight per plant (344.60g) recorded in var. Diamant and total tuber weight plant^{-1} was the lowest (65.05 g) recorded in var. All red, all blue varieties showed the most potential yield in this experiment.

Anonymous (2009a) conducted an experiment with three potato varieties to observe their performance on yield under different soil moisture levels. The highest plant height (50.75 cm) was found in Cardinal which was similar to Diamant (48.88 cm). The lowest plant height was observed in Granola (38.50 cm). The highest foliage coverage (93.25%) was observed in Diamant followed by Cardinal (92.75%) and the lowest in Granola (90.33%). The highest no. of stems hill^{-1} (6.25) was observed in Cardinal which was similar to Diamant (5.42) and the lowest in Granola (4.75). The highest no. of tubers hill^{-1} (13.83) was observed in Granola which was similar to Cardinal (13.33) and the lowest in Diamant (11.92).

Anonymous (2009b) conducted an experiment with twenty five varieties were evaluated at six locations. They found that, plant height (cm) in case of Diamant (47.87), Sagitta (56.20), Quincy (95.40); No. of stem hill^{-1} in Diamant (3.66), Sagitta (2.53), Quincy (2.26); Foliage coverage at 60 DAP (%) in Diamant (73.33), Sagitta (93.67), Quincy (92.00); No of tuber hill^{-1} in Diamant (6.72), Sagitta (3.94), Quincy (9.95); Weight of tuber hill^{-1} (kg) in Diamant (0.30), Sagitta (0.34), Quincy (0.35); Dry matter (%) in case of Diamant (19.54), Sagitta (20.10), Quincy (18.70).

Anonymous (2009c) conducted an experiment with twelve varieties were evaluated at six locations in their third generation. They found that, plant height (cm) in case of Diamant (50.93), Granola (69.10), Sagitta (41.33), Quincy (65.87); No. of stem hill^{-1} in Diamant (5.66), Granola (3.20), Sagitta (3.46), Quincy (4.86); Foliage coverage at 60 DAP (%) in Diamant (92.00), Granola (91.00), Sagitta (89.33), Quincy (96.00); No. of tuber hill^{-1} in Diamant (7.24), Granola (6.82), Sagitta (5.23), Quincy (5.76); Weight of tuber hill^{-1} (kg) in Diamant (0.38), Granola (0.26), Sagitta (0.33), Quincy (0.35); Dry matter (%) in case of Diamant (20.80), Granola (20.45), Sagitta (19.80), Quincy (18.40).

Anonymous (2009d) conducted an experiment with twenty eight varieties were evaluated at five locations. They found that, plant height at 60 DAP (cm) in case of Diamant (54.13), Sagitta (47.27), Quincy (80.93); No. of stem hill^{-1} in Diamant (4.66), Sagitta (5.40), Quincy (5.80); Foliage coverage at 60 DAP (%) in Diamant (93.67), Sagitta (90.67), Quincy (97.00); No. of tubers hill^{-1} in Diamant (8.11), Sagitta (5.41), Quincy (6.95); Weight of tubers hill^{-1} (kg) in Diamant (0.28), Sagitta (0.37), Quincy (0.45); Dry matter (%) in case of Diamant (19.91), Sagitta (20.60), Quincy (18.34).

Anonymous (2009e) conducted an experiment with four exotic potato varieties along with check Diamant, Cardinal and Granola were evaluated at six locations in Regional Yield Trial. They found that plant height (cm) in case of Diamant (51.20), Cardinal (48.27), Meridian (48.33) and Laura (41.00); No. of stem hill^{-1} in Diamant (5.93), Cardinal (6.20), Meridian (5.67) and Laura (4.73); Foliage coverage (%) in Diamant (88.33), Cardinal (90.33), Meridian (95.67) and Laura (86.67); No. of tuber hill^{-1} in Diamant (9.48), Cardinal (9.81), Meridian (9.63) and Laura (7.50); Weight of tuber hill^{-1} (kg) in case of Diamant (0.313), Cardinal (0.377), Meridian (0.490) and Laura (0.430); Dry matter (%) in case of Diamant (22.69), Cardinal (21.03), Meridian (19.49) and Laura (20.22).

Anonymous (2009f) conducted an experiment with seven potato varieties were evaluated at MLT site. They found that plant height (cm) in case of Diamant (43.00), Lady Rosetta (37.00), and Courage (44.47); No of stem plant^{-1} in Diamant (3.57), Lady Rosetta (2.80), and Courage (3.67); No of tuber plant^{-1} in Diamant (8.07), Lady Rosetta (5.67), and Courage (6.70).

Anonymous (2009g) conducted adaptive trails with new potato varieties at eleven districts. The mean yield of varieties over locations arranged in order of descending as BARI TPS-1 (23.87 t ha^{-1}), Granola (23.68 t ha^{-1}), Diamant (23.63 t ha^{-1}), Asterix (20.83 t ha^{-1}) and Raja (18.28 t ha^{-1}).

Güler (2009) observed that first, second, third class tuber yields and total tuber yield, tuber number per plant, mean tuber weight and leaf chl were significantly influenced by potato cultivar. There were significant correlations between chl and yield and yield related characters. Total yield significantly correlated with leaf chl. Correlations between first class yield and total yield as well as total yield and tuber number per plant were highly significant.

Mahmud *et al.* (2009) assessed the yield of seed size tubers in five standard potato cultivars (Cardinal, Multa, Ailsa, Heera, and Dheera) in relation to dates of dehaulming (65, 70, and 80 days after planting) in a Seed Potato Production

Farm, Debijong, Panchagarh. The maximum seed tuber yield was recorded from Cardinal at 80 DAP followed by Heera and Cardinal at 70 DAP, Dheera and Ailsa at 75 DAP.

Haque (2007) conducted a field experiment with 12 exotic potato germplasm to determine their suitability as a variety in Bangladesh. He found that all the varieties gave more than 90% emergence at 20-35 DAP. He also observed that Plant height (cm) of Quincy was (87.8), Sagitta (65.8), Diamant (62.6); No. of stems hill^{-1} was counted in Diamant (7.2), Quincy (4.5), Sagitta (4.4); Plant diameter (cm) of Sagitta was (4.0), Quincy (3.7), Diamant (2.6) at 60 DAP; Foliage coverage (%) of Sagitta was (100.0), Diamant (98.3), Quincy (96.6); No. of tubers plant^{-1} of Diamant was (13.06), Sagitta (8.34), Quincy (6.71); Wt. of tubers plant^{-1} (kg) of Quincy was (0.64), Sagitta (0.63), Diamant (0.49); Dry matter (%) of Sagitta was (20.8), Diamant (20.1), Quincy (18.5).

Das (2006) carried out an experiment to study the physio-morphological characteristics and yield potentialities of potato varieties. He found that Foliage coverage (%) of Diamant was (93.3), Asterix (71.7), Granola (66.7), Quincy (90.0), Courage (63.3), Felsina (83.3), Lady Rosetta (83.3), Laura (78.3); No. of tubers hill^{-1} of Diamant (11.7), Asterix (8.00), Granola (11.3), Quincy (9.33), Courage (7.33), Felsina (8.00), Lady Rosetta (10.3), Laura (8.33); Tuber weight hill^{-1} (g) of Diamant (380), Asterix (285), Granola (275), Quincy (300), Courage (320), Felsina (333), Lady Rosetta (348), Laura (258); Dry matter (%) of Diamant (25), Asterix (17.5), Granola (23), Quincy (31), Courage (34.5), Felsina (22.5), Lady Rosetta (22.0), Laura (27.0); Regarding size grade distribution of tubers the varieties Courage, Espirit, Granola, Lady rosetta, Laura were found superior.

Anonymous (2005) evaluated twenty one varieties along with two standard checks Diamant and Granola at seven locations. The yields of the varieties varied from location to location as well as within location. Of all the stations, except Pahartoli, none crossed the check variety Diamant but comparatively higher yields were produced by the varieties Espirit, Courage, Innovator, Quincy, Matador, Markies, Laura and Lady Rosetta.

Kumar *et al.* (2005) determined under water weight, specific gravity, dry matter and starch content of potatoes grown at Modipuram, Uttar Pradesh. He found that there was a positive correlation between under water weight and specific gravity (r=0.99), under water weight and dry matter (r=0.92).

Mondol (2004) conducted an experiment to evaluate the performance of seven exotic (Dutch) varieties of potato. He found that plant height (cm) of Diamant was (18.07), Granola (13.47); No. of main stem hill^{-1} of Diamant (4.36), Granola (4.90); No. of tubers hill^{-1} of Diamant (12.00), Granola (10.93); Weight of tubers plant^{-1} (kg) of Diamant (0.57), Granola (0.39); Dry matter (%) of Diamant (17), Granola (16.30).

Alam *et al.* (2003) conducted a field experiment with fourteen exotic varieties of potato under Bangladesh condition. The highest emergence (91%) was observed from Cardinal which was statistically identical with most of the varieties except the variety Granola (63%). The highest number of stem per hill was recorded in Ailsa (4.59) followed by Cardinal (4.50). Significantly maximum number of leaves hill^{-1} was produced from the plants of the variety Ailsa (53.80), which was followed by Cardinal (49.75). The yields ranged of exotic varieties were 19.44 to 46.67 t ha^{-1}. Variety Ailsa produced the maximum yield (46.67 t ha^{-1}) which was followed by Cardinal (42.21 t ha^{-1}).

Hossain (2000) conducted an experiment to study the effects of different levels of nitrogen on the yield of seed tubers in four potato varieties. He found that the tallest plants were produced by the seedling tubers of BARI TPS-1 (74.51 cm) and the shortest plants came from the variety Diamant (58.63 cm); Foliage coverage (%) of Diamant at 75 DAP was (79.00), BARI TPS-1 (89.00); No. of stems hill^{-1} of Diamant was (3.50), BARI TPS-1 (2.71); No. of tubers hill^{-1} of Diamant was (7.85), BARI TPS-1 (9.55); Weight of tubers hill^{-1} of Diamant was (416.67), BARI TPS-1 (491.33); Dry matter of tuber (%) of Diamant was (19.71), BARI TPS-1 (18.18).

Rabbani and Rahman (1995) studied the performance of 16 Dutch potato varieties in their third generation. They reported that the height of the plants significantly varied among the varieties. The highest foliage coverage at maximum vegetative growth stage was found in the variety Cardinal (93.3%) followed by Diamant. The highest yield of tubers per hectare was obtained from Cardinal (35.19 t ha^{-1}) followed by Romano (30.09 t ha^{-1}) and the lowest from Stroma (11.11 t ha^{-1}).

Chapter 3

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experiments and methods are described below:

3.1 Experimental period

The experiment was conducted during the period from November 10, 2012 to February 18, 2013 in Rabi season.

3.2 Site description

3.2.1 Geographical location

The experimental area was situated at $23^{0}77'$N latitude and $90^{0}33'$E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004).

3.2.2 Agro-Ecological Region

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

3.2.3 Climate of the experimental site

Experimental site was located in the sub-tropical monsoon climatic zone, set aparted by winter during the months from November, 10 to February, 18 (Rabi season). Plenty of sunshine and moderately low temperature prevails during experimental period, which is suitable for potato growing in Bangladesh. The weather data during the study period at the experimental site are shown in Appendix II.

3.3 Details of the Experiment

3.3.1 Experimental treatments

The experiment consisted of two factors such as variety and arsenic (As) level. The treatments were as follows:

Factor A: Variety (14)

- V_1 – BARI Alu-7 (Diamant)
- V_2 – BARI Alu-8 (Cardinal)
- V_3 – BARI Alu-25 (Asterix)
- V_4 – BARI Alu-13 (Granola)
- V_5 – BARI Alu-28 (Lady Rosetta)
- V_6 – BARI Alu-29 (Courage)
- V_7 – BARI TPS-1
- V_8 – BARI Alu-30 (Meridian)
- V_9 – BARI Alu-26 (Felsina)
- V_{10} – BARI Alu-34 (Laura)
- V_{11} – BARI Alu-32 (Quincy)
- V_{12} – BARI Alu-31 (Sagitta)
- V_{13} – Rumana and
- V_{14} – Jam Alu

Factor B: Arsenic level (3)

- As_0 – 0 mg As kg^{-1} soil
- As_1 – 25 mg As kg^{-1} soil
- As_2 – 50 mg As kg^{-1} soil

Treatment combinations are as:

V_1As_0, V_1As_1, V_1As_2, V_2As_0, V_2As_1, V_2As_2, V_3As_0, V_3As_1, V_3As_2, V_4As_0, V_4As_1, V_4As_2, V_5As_0, V_5As_1, V_5As_2, V_6As_0, V_6As_1, V_6As_2, V_7As_0, V_7As_1, V_7As_2, V_8As_0, V_8As_1, V_8As_2, V_9As_0, V_9As_1, V_9As_2, $V_{10}As_0$, $V_{10}As_1$, $V_{10}As_2$, $V_{11}As_0$, $V_{11}As_1$, $V_{11}As_2$, $V_{12}As_0$, $V_{12}As_1$, $V_{12}As_2$, $V_{13}As_0$, $V_{13}As_1$, $V_{13}As_2$, $V_{14}As_0$, $V_{14}As_1$, $V_{14}As_2$

3.3.2 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications thus comprised 126 baskets. The size of each basket was 25 cm (10 inches) in diameter and 30 cm (12 inches) in height.

3.4 Planting material

The planting materials comprised the certified seed tubers of fourteen potato varieties. The varieties were Diamant (V_1), Cardinal (V_2), Asterix (V_3), Granola (V_4), Lady Rosetta (V_5), Courage (V_6), BARI TPS-1 (V_7), Meridian (V_8), Felsina (V_9), Laura (V_{10}), Quincy (V_{11}), Sagitta (V_{12}), Rumana (V_{13}) and Jam Alu (V_{14}).

3.5 Crop management

3.5.1 Collection of seed

All variety of seed potato (certified seed) was collected from, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur and from BARI sub-station, Debigonj, Panchagarh District., Bangladesh. Individual weight of seed potato was 60-70 g except Rumana (25 g) and Jam Alu (20 g).

3.5.2 Preparation of seed

Collected seed tubers were kept in room temperature to facilitate sprouting. Finally sprouted potato tubers were used as a planting material.

3.5.3 Soil and Baskets preparation

Soil was collected from farm of Sher-e-Bangla Agricultural University. The collected soil was sandy loam. Weeds and stubbles were completely removed from soil. Each basket was filled by 10 kg soil and which was mixed with well dried cow dung. Poly pack was used in lower portion of basket to control leaching loss of As by irrigation water. Baskets were filled up 7 days before planting on November 3, 2012.

3.5.4 Fertilizer application

The experimental soil of basket was fertilized with following dose of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate and boric acid.

Fertilizers	**Dose (kg ha^{-1})**	**Dose (g 10 kg soil^{-1})**
Urea	250	1.25
TSP	150	0.75
MoP	250	1.25
Gypsum	120	0.6
Zinc Sulphate	10	0.05
Boric Acid	10	0.05

Source: Mondal *et al.*, 2011

The entire amounts of triple superphosphate, muriate of potash, gypsum, zinc sulphate, boric acid and one third of urea were applied as basal dose at 7 days before potato planting. Rest of the urea was applied in two equal installments i.e., first was done at 30 days after planting (DAP) followed by first pouring the soil in pot for complete the earthing up in the field and second was at 50 DAP followed by pouring the soil in pot.

3.5.5 Arsenic treatment in soil

For the Arsenic treatment in soil, sodium meta arsenate ($Na_2HAsO_4.7H_2O$) was used as the source of As. As application was done by adding 0 mg kg^{-1} soil, 25 mg kg^{-1} soil and 50 mg kg^{-1} soil into baskets according to treatment.

3.5.6 Planting of seed tuber

The well sprouted healthy and uniform sized potato tubers were planted according to treatment and a whole potato was used for one basket. Seed potatoes were planted in such a way that potato does not go much under soil or does not remain in shallow. On an average, potatoes were planted at 4-5 cm depth in basket on November 10, 2012.

3.5.7 Intercultural operations

3.5.7.1 Weeding

Weeding was necessary to keep the plant free from weeds. The newly emerged weeds were uprooted carefully in all the baskets after complete emergence of sprouts and afterwards when necessary.

3.5.7.2 Watering

Frequency of watering was done upon moisture status of soil retained as requirement of plants. Excess water was not given, because it always harmful for potato plant.

3.5.7.3 Earthing up

Earthing up process was done by pouring the soil in the pot at two times, during crop growing period. First pouring was done at 45 DAP and second was at 60 DAP.

3.5.7.4 Plant protection measures

Dithane M-45 was applied at 30 DAP as a preventive measure for controlling fungal infection. Ridomil (0.25%) was sprayed at 45 DAP to protect the crop from the attack of late blight.

3.5.7.5 Haulm cutting

Haulm cutting was done at February 8, 2013 at 90 DAP, when 40-50% plants showed senescence and the tops started drying. After haulm cutting the tubers were kept under the soil for 7 days for skin hardening. The cut haulm was collected, bagged and tagged separately for further data collection.

3.5.7.6 Harvesting of potatoes

Harvesting of potato was done at February 15, 2013 at 7 days after haulm cutting. The potatoes of each basket were separately harvested, bagged and tagged and brought to the laboratory. The yield of potato plant^{-1} was determined in gram. Harvesting was done manually by hand.

3.5.8 Recording of data

Experimental data were recorded from 30 DAP and continued until harvest. Dry weights of different plant parts were collected after harvesting. The following data were collected during the experimentation.

A. Crop growth characters
   - i. Days to emergence
   - ii. Plant height at 30, 45, 60, 75 and 90 DAP
   - iii. Number of leaves plant^{-1} at 30, 45, 60, 75 and 90 DAP
   - iv. Number of stems hill^{-1} at 30, 45, 60, 75 and 90 DAP
   - v. Leaf area plant^{-1} at 30, 45, 60, 75 and 90 DAP
   - vi. Total chlorophyll content of leaves at 30, 45, 60, 75 and 90 DAP
   - vii. Stem diameter at 30, 45, 60, 75 and 90 DAP

viii. Above ground stem dry matter content (%)

B. Yield and yield components

ix. Number of tubers hill^{-1}

x. Yield of tuber plant^{-1}

xi. Average weight of tuber

xii. Grading of tubers (% by number)

xiii. Marketable yield plant^{-1}

xiv. Marketable yield (% by number)

xv. Marketable yield (% by weight)

xvi. Non- marketable yield plant^{-1}

xvii. Non- marketable yield (% by number)

xviii. Non- marketable yield (% by weight)

C. Quality characters

xix. Tuber flesh dry matter content (%)

xx. Tuber peel dry matter content (%)

xxi. Specific gravity

xxii. Total soluble solids (TSS)

xxiii. Arsenic content in tuber peel

xxiv. Arsenic content in tuber flesh

3.5.9 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

A. Crop growth characters

i. Days to emergence

After planting the potato tuber keenly observed the emergence twice in a day (morning and afternoon) until 100% emergence.

ii. Plant height (cm)

Plant height refers to the length of the plant from ground level to the tip of the tallest stem. It was measured at an interval of 15 days starting from 30 DAP till 90 DAP. The height of each plant of each basket was measured in cm with the help of a meter scale and mean was calculated.

iii. Number of leaves plant^{-1}

Number of leaves plant^{-1} was counted at an interval of 15 days starting from 30 DAP till 90 DAP. Leaves number plant^{-1} were recorded by counting all leaves from each plant of each basket and mean was calculated.

iv. Number of stems hill^{-1}

Number of stems hill^{-1} was counted at an interval of 15 days starting from 30 DAP till 90 DAP. Stem numbers hill^{-1} was recorded by counting all stem from each basket.

v. Leaf area plant^{-1} (cm^2)

Leaf area plant^{-1} was measured an interval of 15 days starting from 30 DAP till 90 DAP by non-destructive method using CL-202 Leaf Area Meter (USA). Mature leaf (from 4th node) were measured all time and expressed in cm^2. Three mature plant of each pot were measured and then average it after that mean was calculated.

vi. Chlorophyll content of leaves (SPAD value)

Chlorophyll content of leaves was measured at an interval of 15 days starting from 30 DAP till 90 DAP. Mature leaf (fourth leaves from top) were measured all time. Three mature plant of each pot were measured by using portable Chlorophyll Meter (SPAD-502, Minolta, Japan) and then calculated an average SPAD value for each pot at each sampling time. The chlorophyll meter Soil Plant Analysis Development (SPAD-502) is a simple and portable diagnostic tool that measures the greenness or the relative chlorophyll concentration of leaves (Kariya *et al.*, 1982; Torres-netto *et al.*, 2005). It provides instantaneous and non-destructive readings on plants based on the quantification of the intensity of absorbed light by the tissue sample using a red LED (wavelength peak is ~650 nm) as a source. An infrared LED, with a central wavelength emission of approximately 940 nm, acts simultaneously with the red LED to compensate for the leaf thickness (Minolta camera Co. Ltd., 1989).

vii. Stem diameter (cm)

Stem diameter was measured at an interval of 15 days starting from 30 DAP till 90 DAP. The stem diameter of each plant of each basket was measured in cm by using Slide Calipers and mean was calculated.

viii. Above ground stem dry matter content (%)

First the fresh weight of haulm was taken. Then the samples of stem were dried in oven at 72^0C for 72 hours. From which the dry matter percentage of above ground harvest was calculated with the following formula (Elfinesh *et al.,* 2011)-

$$\text{Dry matter content (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

B. Yield and yield components

ix. Number of tubers hill^{-1}

Number of tubers hill^{-1} was counted at harvest. Tuber numbers hill^{-1} was recorded by counting all tubers from each basket.

x. Yield of tuber plant^{-1} (g)

Tubers of each basket were collected separately from which yield of tuber hill^{-1} was recorded in gram.

xi. Average weight of tuber (g)

Average weight of tuber was measured by using the following formula-

$$\text{Average weight of tuber} = \frac{\text{Yield of tuber/plant}}{\text{Number of tubers/hill}}$$

xii. Grading of tuber (% by number)

Tubers harvested from each basket were graded by number on the basis of diameter into the >55mm, 45-55mm, 28-45mm and <28mm and converted to percentages (Hussain, 1995). A special type of frame (potato riddle) was used to grading of tuber.

xiii. Marketable tuber and non-marketable tuber

On the basis of weight, the tubers have been graded into marketable tuber (>20g) and non-marketable tuber (<20g).

C. Quality characters

xiv. Tuber flesh dry matter content (%)

The samples of tuber were collected from each treatment. After peel off the tubers the samples were dried in oven at 72^0C for 72 hours. From which the weights of tuber flesh dry matter content % were recorded.

xv. Tuber peel dry matter content (%)

The peel (skin of potato) of tubers of each sample were collected from each treatment and dried in oven at 72^0C for 72 hours. From which the weights of tuber peel dry matter content % were recorded.

xvi. Preparation for chemical analysis

Potatoes were harvested and packed with labeled polythene bag. These labeled packed tubers were immediately sent to Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka. After peel out the tuber; tuber sample and tuber peel sample separated in different labeled packed. Then the samples were sent to Analytical Laboratory where As was determined with Atomic Absorption Spectrophotometer (HG-AAS) following USEPA method 1632.

xvii. Specific Gravity (gcm^{-3})

It was measured by using the following formula (Gould, 1995)-

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in water at } 4^0 \text{ C}}$$

xviii. Total soluble solids (TSS)

TSS of harvested tubers was determined in a drop of potato juice by using Hand Sugar Refrectometer "ERMA" Japan, Range: 0-32% according to (AOAC, 1990) and expressed as °BRIX value.

3.5.10 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Duncan’s Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

Chapter 4

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of As on different potato varieties. The results obtained from the study have been presented, discussed and compared in this chapter through table(s), figures and appendices. The analysis of variance of data in respect of all the parameters have been shown in Appendix III-XII. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings.

4.1 Crop growth characters

4.1.1 Days to emergence (Visual observation)

4.1.1.1 Effect of varieties

Days to emergence was significantly influenced by the different potato varieties (Appendix III and Figure 1). Results revealed that the variety 'Jam Alu' took the maximum days (18 days) for emergence which was statistically similar (16 days) with 'Cardinal' whereas, the minimum days (10 days) was taken by 'Quincy' which was statistically similar (11 days) with 'Meridian'. This result showed that 'Quincy' was the early emergence variety whereas, 'Jam Alu' was the late one. This might be due to varietal characters.

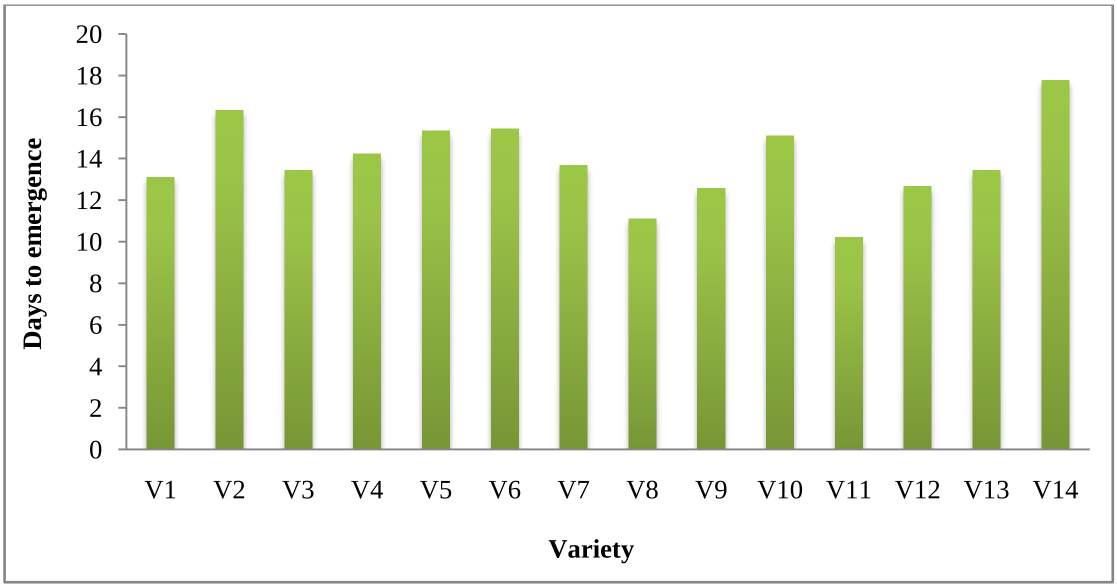

Figure 1. Effect of varieties on days to emergence of potato (SE value = 0.66)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.1.2 Effect of As levels

Significant variation of days to emergence was found due to different As levels (Appendix III and Figure 2). Figure 2 showed that duration of emergence increased with increasing As levels but As_0 and As_1 showed similar results. The minimum days to emergence (12 days) was required in As_0 (control) treatment which was statistically similar (13 days) with As_1 (25 mg As kg^{-1} soil) treatment and the maximum (17 days) was recorded in As_2 (50 mg As kg^{-1} soil). Similar trend of result was also found by Talukdar (2011), who observed that the mean value of germination percentage, germination index and relative germination rate decreased with concomitant increase of As levels in case of *Trigonella foenum-graecum* L. and *Lathyrus sativus* L. When plants were exposed to excess As either in soil or in solution culture, they exhibit toxicity symptoms such as inhibition of seed germination (Abedin and Meharg, 2002a).

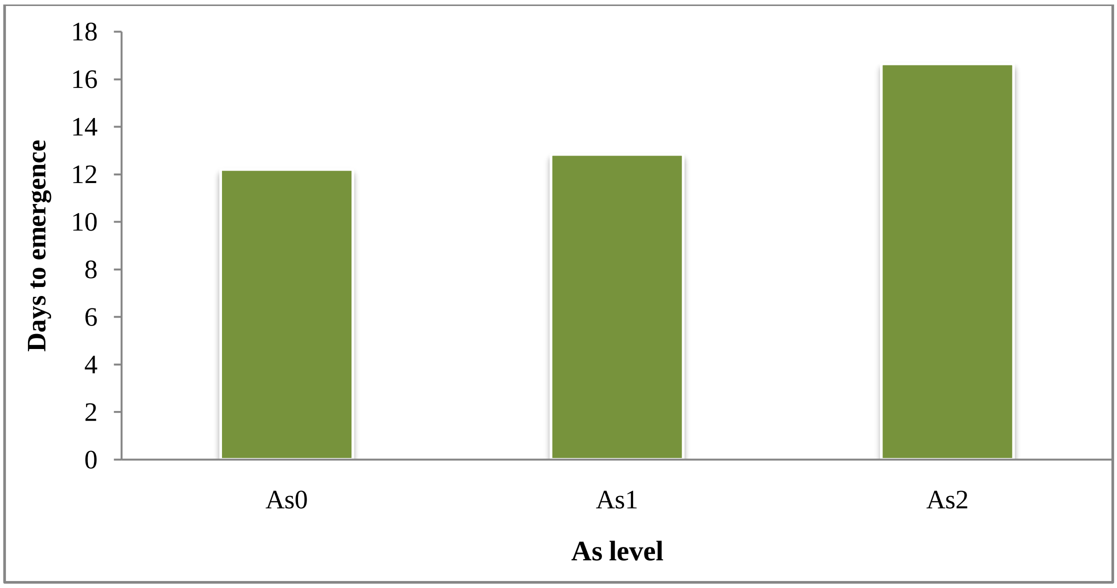

Figure 2. Effect of As levels on days to emergence of potato (SE value = 0.31)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.1.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the days taken to emergence of potato tubers (Appendix III and Table 1). The minimum duration for emergence (9 days) was recorded from the combination of 'Quincy' and control (As_0) treatment which was statistically similar with $V_{11}As_1$ (9 days), V_8As_0 (10 days) and V_8As_1 (10 days) whereas, the maximum duration (21 days) was recorded from the combination of 'Jam Alu' and 50 mg As kg^{-1} soil and it was statistically similar with V_2As_2 (20 days).

Table 1: Interaction effect of varieties and As levels on days to emergence of potato

Variety	Days to emergence		
	As level (mg kg^{-1})		
	As_0	As_1	As_2
V_1	11.67 m-p	12.00 l-o	15.67 f-i
V_2	14.33 g-k	15.00 f-j	19.67 ab
V_3	12.00 l-o	12.33 k-o	16.00 e-h
V_4	12.67 k-n	13.33 i-m	16.67 c-f
V_5	13.33 j-m	14.00 h-l	18.67 bc
V_6	13.67 i-m	14.33 g-k	18.33 b-d
V_7	12.00 l-o	12.67 k-n	16.33 d-g
V_8	9.67 pr	10.33 o-r	13.33 j-m
V_9	11.00 n-q	11.67 m-p	15.00 f-j
V_{10}	13.33 j-m	14.00 h-l	18.00 b-e
V_{11}	8.67 r	9.33 qr	12.67 k-n
V_{12}	11.00 n-q	11.67 m-p	15.33 f-j
V_{13}	11.67 m-p	12.33 k-o	16.33 d-g
V_{14}	15.67 f-i	16.67 c-f	21.00 a
SE value		0.66	
Level of significance		**	
CV (%)		8.26	

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability
** indicate 1% level of significance
Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.2 Plant height

4.1.2.1 Effect of varieties

The plant height of potato varieties were measured at 15, 30, 45, 60, 75 and 90 (at harvest) DAP. It was evident from Figure 3 and Appendix III that the height of plant was significantly influenced by variety at all the sampling dates. Figure 3 showed that plant height increased with advancing growing period irrespective of varieties, the potato height increased rapidly at the early stages of growth and rate of progression in height was slow at the later stages except 'Jam Alu'. At 30 DAP, 'Laura' showed the longest plant (28.91 cm) which was statistically similar with 'Felsina' (28.54 cm) and 'Sagitta' (26.97 cm) whereas, the shortest plant (11.80 cm) was found from the variety 'Jam Alu'.

At 45, 60, 75 and 90 DAP, 'BARI TPS-1' gave the highest plant height (46.68, 57.57, 61.63 and 64.28 cm, respectively) which was statistically similar with 'Laura' (44.66 cm) and 'Jam Alu' (58.43 and 63.36 cm) whereas, the lowest height was recorded from 'Lady Rosetta' (25.49 cm) and 'Diamant' (29.94, 32.60 and 33.97 cm) which was statistically similar with 'Diamant' (25.71 cm) and 'Lady Rosetta' (30.22, 33.40 and 34.99 cm). Present investigation referred, 'BARI TPS-1' exposed best in terms of plant height. The variations in the plant height among the varieties also recorded by Rabbani (1996) and Bashar (1978) in their experimental results. Plant height of a crop depends on the plant vigor, cultural practices, growing environment and the varietal characters. In the present experiment since all the varieties were grown in the same environment and were given same cultural practices, the variation in the plant height among the varieties might be due to the varietal character.

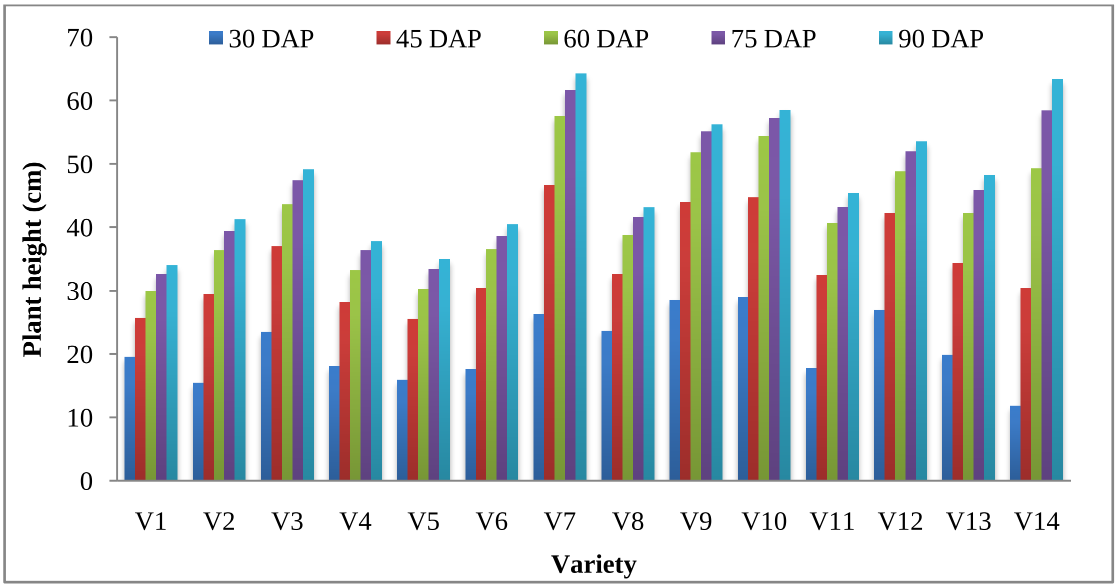

Figure 3. Effect of varieties on plant height (cm) of potato at different growth stages (SE value = 0.78, 0.80, 1.04, 1.14 and 0.82 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.2.2 Effect of As levels

Significant variation of plant height was found due to different As levels in all the studied durations (Appendix III and Figure 4). Plant height decreased with increasing As levels but As_0 and As_1 showed similar results (Figure 4). At 30, 45, 60, 75 DAP and at harvest, the tallest plant (23.22, 38.25, 47.09, 50.29 and 52.25 cm, respectively) was obtained from the control (As_0) which was statistically similar (22.21, 37.26, 45.86, 49.30 and 51.40 cm, respectively) with 25 mg As kg^{-1} soil (As_1) while the shortest plant (17.52, 28.10, 34.17, 38.12 and 39.93 cm, respectively) was obtained from the 50 mg As kg^{-1} soil (As_2) treatment. The phytotoxicity at lower soil As concentrations was not significant. Stimulation of growth by As additions has been, however, reported to increase growth of potatoes (Jacobs *et al.*, 1970). It is possible that displacement of soil phosphate by arsenate increased the availability of phosphate to the plant, which results in the increase of plant growth (Jacobs *et al.,* 1970; Duel and Swoboda, 1972). Thus, Kabata-Pendias and Pendias (1992) recommended the safe level of As in agricultural soil as 20 mg As kg^{-1}. At higher concentration, As is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through As induced phytotoxicity (Marin *et al.,* 1993). When plants are exposed to excess As either in soil or in solution culture, they exhibit toxicity symptoms such as decrease in plant height (Marin *et al.,* 1992; Carbonell-Barrachina *et al.,* 1995; Abedin *et al.,* 2002b; Jahan *et al.,* 2003).

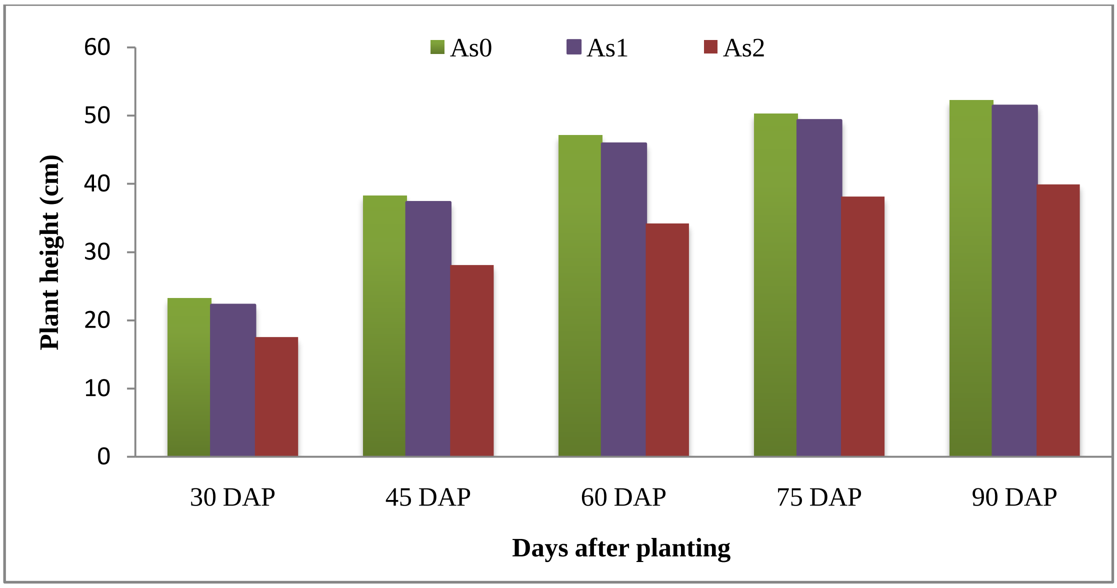

Figure 4. Effect of As levels on plant height (cm) of potato at different growth stages (SE value = 0.36, 0.37, 0.48, 0.53 and 0.38 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.2.3 Interaction effect of varieties and As levels

Significant interaction effect of varieties and As levels on plant height was observed at 30, 45, 60, 75 and 90 DAP (Appendix III and Table 2). Plant height increased with advancing growing period irrespective of varieties and As levels (Table 2). At 30 DAP, the tallest plant (31.00 cm) was obtained from the combination of 'Felsina' with control (As_0) which was statistically similar with V_9As_1 (30.57 cm), $V_{10}As_0$ (30.43 cm), $V_{10}As_1$ (29.73 cm), $V_{12}As_0$ (29.00 cm) and the shortest plant (9.07 cm) was obtained from the 'Jam Alu' with 50 mg As kg^{-1} soil. At 45, 60, 75 and 90 DAP, the highest plant height (49.60, 62.57, 66.03 and 69.43 cm, respectively) was observed from the 'BARI TPS-1' with control (As_0) treatment combination and it was statistically similar with V_7As_1 (48.60 cm), $V_{10}As_0$ (48.53 cm), V_9As_0 (48.27 cm), $V_{10}As_1$ (47.70 cm), V_9As_1 (47.07 cm) at 45 DAP, with V_7As_1 (60.93 cm), $V_{10}As_0$ (60.00 cm) at 60 DAP, 65.07 cm at 75 DAP and 68.77 cm at 90 DAP whereas, the smallest plant (17.77, 22.20, 24.87 and 26.63 cm, respectively) was obtained from the 'Lady Rosetta' with 50 mg As kg^{-1} which was statistically similar (18.67, 23.33, 25.60 and 26.77 cm, respectively) with V_1As_2. Such type of discontinuity in increasing plant height might have been caused by the variation between varieties in response to As or might be due to differences in crop growth pattern. The study disclosed that ‘BARI TPS-1’ variety treated with As_0 performed the best result in terms of plant height.

Table 2. Interaction effect of varieties and As levels on plant height of potato at different DAP

Variety× As level	Plant height (cm) at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_1 As_0	23.80 i-k	29.60 mn	33.80 rs	36.47 tu	37.93 uv
V_1 As_1	22.87 j-l	28.87 no	32.70 r-t	35.73 t-v	37.20 v
V_1 As_2	12.00 rs	18.67 s	23.33 w	25.60 x	26.77 y
V_2 As_0	18.10 n-p	33.50 g-j	41.50 m-o	44.33 m-p	45.50 o-q
V_2 As_1	17.27 p	32.27 i-l	40.53 no	43.23 n-q	44.43 pq
V_2 As_2	11.03 st	22.63 r	27.00 v	30.63 w	33.80 w
V_3 As_0	25.43 f-i	41.63 d	48.80 hi	52.03 f-i	53.60 g-i
V_3 As_1	24.30 h-j	40.53 d	47.80 h-j	51.17 g-j	52.90 g-j
V_3 As_2	20.70 l-n	28.63 n-p	34.20 q-s	38.87 r-t	40.80 st
V_4 As_0	20.03 m-o	31.77 j-m	37.27 pq	40.20 q-s	41.77 rs
V_4 As_1	19.47 m-p	30.87 k-n	35.87 qr	39.00 r-t	40.73 st
V_4 As_2	14.60 q	21.80 r	26.40 v	29.73 w	30.80 x
V_5 As_0	18.50 n-p	29.80 l-n	34.67 qr	38.17 s-u	39.67 s-v
V_5 As_1	17.53 op	28.90 no	33.80 rs	37.17 s-u	38.67 t-v
V_5 As_2	11.67 rs	17.77 s	22.20 w	24.87 x	26.63 y
V_6 As_0	19.40 m-p	34.77 f-i	41.30 m-o	43.10 o-q	44.60 pq
V_6 As_1	18.57 n-p	33.87 g-j	39.90 op	41.90 p-r	44.00 qr
V_6 As_2	14.77 q	22.67 r	28.30 uv	30.80 w	32.63 wx
V_7 As_0	28.07 b-e	49.60 a	62.57 a	66.03 a	69.43 a
V_7 As_1	27.03 d-g	48.60 a	60.93 ab	65.07 ab	68.77 ab
V_7 As_2	23.70 i-k	41.83 d	49.20 g-i	53.80 e-g	54.63 f-h
V_8 As_0	25.80 e-i	36.80 ef	43.60 k-n	46.47 k-o	47.73 m-o
V_8 As_1	24.63 g-j	35.23 e-h	42.47 l-o	45.57 l-o	46.90 n-p
V_8 As_2	20.53 l-n	25.80 q	30.33 tu	32.73 vw	34.67 w
V_9 As_0	31.00 a	48.27 ab	57.73 cd	59.83 c	60.73 cd
V_9 As_1	30.57 a	47.07 a-c	55.80 de	58.80 cd	59.87 d
V_9 As_2	24.07 h-k	36.73 ef	41.83 l-o	46.57 k-o	47.90 m-o
V_{10} As_0	30.43 ab	48.53 a	60.00 a-c	61.83 c	63.00 c
V_{10} As_1	29.73 a-c	47.70 ab	58.80 b-d	61.10 c	62.07 cd
V_{10} As_2	26.57 e-h	37.73 e	44.33 k-m	48.77 i-l	50.47 j-l
V_{11} As_0	19.80 m-p	35.70 e-g	46.00 i-k	47.93 j-m	49.63 k-m
V_{11} As_1	18.87 n-p	34.90 f-h	44.97 j-l	46.83 k-n	48.77 l-n
V_{11} As_2	14.57 q	26.70 o-q	31.03 s-u	34.70 uv	37.80 v
V_{12} As_0	29.00 a-d	46.00 bc	53.67 ef	56.00 de	57.50 e
V_{12} As_1	27.40 c-f	45.13 c	52.63 f	54.97 ef	56.87 ef
V_{12} As_2	24.50 h-j	35.63 e-g	40.00 op	44.87 m-p	46.30 n-q

Table 2 (Cont'd).

Variety× As level	Plant height (cm) at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_{13} As_0	21.77 k-m	36.80 ef	46.27 i-k	49.97 h-k	52.63 h-j
V_{13} As_1	20.33 mn	35.80 e-g	45.00 j-l	48.93 i-l	51.57 i-k
V_{13} As_2	17.57 op	30.53 k-n	35.37 qr	38.80 r-t	40.43 s-u
V_{14} As_0	13.97 qr	32.80 h-k	52.03 fg	61.73 bc	67.80 ab
V_{14} As_1	12.37 q-s	31.87 j-m	50.90 f-h	60.67 c	66.87 b
V_{14} As_2	9.07 t	26.33 pq	44.90 j-l	52.90 e-h	55.40 e-g
SE value	0.78	0.80	1.04	1.14	0.82
Level of significance	**	*	*	**	**
CV (%)	6.41	4.02	4.27	4.30	2.98

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

**, * indicate 1% and 5% level of significance, respectively

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.3 Number of leaves plant^{-1}

4.1.3.1 Effect of varieties

Different varieties exhibited significant variation in respect of number of leaves plant^{-1} of potato at 30, 45, 60, 75 and 90 DAP (Appendix IV and Figure 5). Number of leaves plant^{-1} increased with advancing growing period up to 75 DAP irrespective of varieties and thereafter decreased due to senescence of leaves (Figure 5). At 30 DAP, the maximum leaves number plant^{-1} (70.22) was observed from the variety 'Asterix' and the minimum number (15.11) was observed from 'Jam Alu'. At 45 DAP, the maximum leaves number plant^{-1} (88.11) was obtained from the 'Diamant' which was statistically similar (87.00) with 'Asterix' whereas, the minimum (25.78) was from 'Jam Alu'. At 60, 75 DAP and at harvest, the maximum number of leaves (158.8, 174.0 and 157.8, respectively) was counted from 'Jam Alu' whereas, the minimum (34.00, 38.44 and 33.00, respectively) was counted from the variety 'Courage' which was statistically similar (38.56, 40.44 and 37.56, respectively) with 'Granola'. The study referred that 'Jam Alu' variety produced maximum number of leaf.

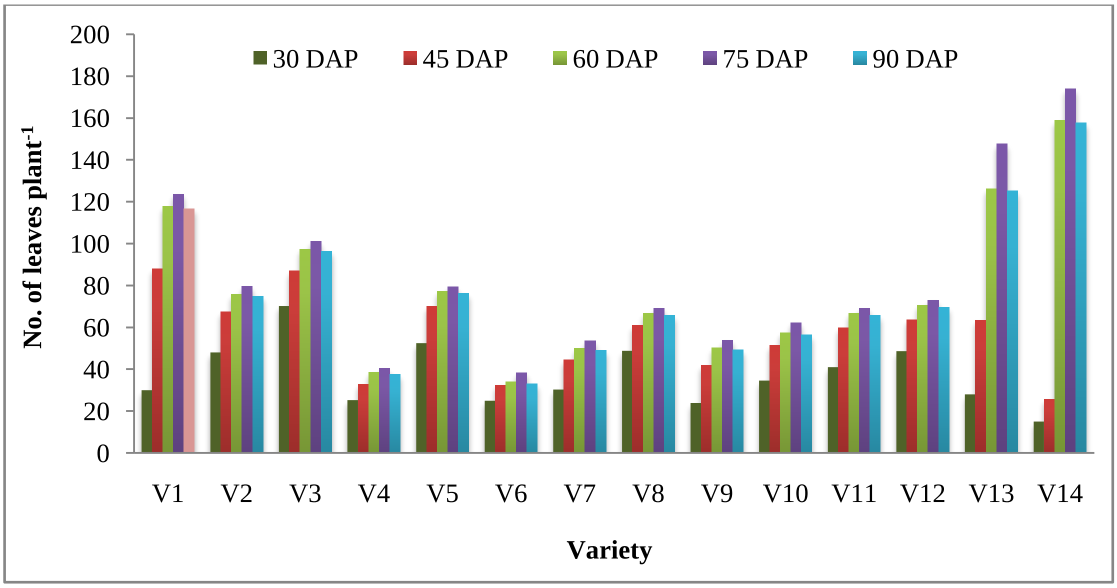

Figure 5. Effect of varieties on number of leaves plant^{-1} of potato at different growth stages (SE value = 1.54, 1.75, 1.97, 2.01 and 1.97 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.3.2 Effect of As levels

The number of leaves plant^{-1} was significantly influenced by different As levels at 30, 45, 60, 75 and 90 DAP (Appendix IV and Figure 6). Number of leaves plant^{-1} increased with the advancement of plant age up to 75 DAP irrespective of As levels and thereafter decreased due to senescence of leaves (Figure 6). At 30, 45, 60, 75 DAP and at harvest, the maximum leaves number plant^{-1} (38.60, 61.71, 84.29, 90.14 and 83.29, respectively) was observed from the As_0 (control) treatment which was statistically similar (37.57, 60.69, 83.21, 89.14 and 82.21, respectively) with 25 mg As kg^{-1} soil (As_1) and the minimum number plant^{-1} (35.55, 46.81, 65.62, 70.40 and 64.62, respectively) was counted from the 50 mg As kg^{-1} soil (As_2) treatment. Present study showed that number of leaves plant^{-1} was not statistically affected up to 25 mg As kg^{-1} soil treatment compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) treatment significantly decreased number of leaves plant^{-1}.

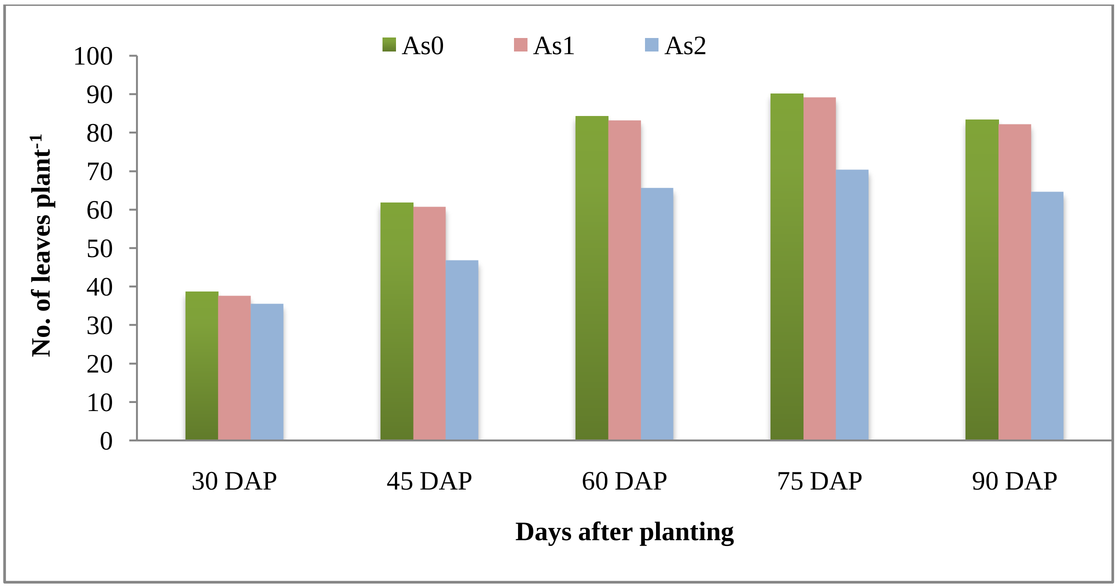

Figure 6. Effect of As levels on number of leaves plant^{-1} of potato at different growth stages (SE value = 0.71, 0.81, 0.91, 0.93 and 0.91 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.3.3 Interaction effect of varieties and As levels

There was significant variation among the interaction of varieties and As levels on the total numbers of leaves plant^{-1} at 30, 45, 60, 75 and 90 DAP (Appendix IV and Table 3). Number of leaves plant^{-1} increased with advancing growing period up to 75 DAP irrespective of varieties and As levels and thereafter decreased (Table 3). At 30 DAP, the maximum number of leaves plant^{-1} (71.67) was recorded from the combination of 'Asterix' with As_0 treatment which was statistically similar with V_3As_1 (70.67), V_3As_2 (68.33) and the minimum (13.67) was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil which was statistically similar with $V_{14}As_1$ (15.33) and $V_{14}As_0$ (16.33). At 45 DAP, the maximum number of leaves plant^{-1} (96.33) was counted from the combination of 'Diamant' with As_0 treatment and it was statistically similar with V_1As_1 (95.33), V_3As_0 (91.33) whereas, the minimum (18.33) was counted from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil. At 60, 75 DAP and at harvest, the maximum leaves number (168.3, 187.7 and 167.3, respectively) was obtained from the 'Jam Alu' with As_0

combination treatment which was statistically similar (167.3, 186.7 and 166.3, respectively) with $V_{14}As_1$. At 60 DAP and at harvest, the minimum number of leaves plant^{-1} (27.67 and 26.67, respectively) was recorded from the combination of ‘Courage’ with 50 mg As kg^{-1} soil which was statistically similar (31.33 and 30.33, respectively) with V_4As_2. At 75 DAP, the minimum number of leaves (33.00) was recorded from the combination of ‘Granola’ with 50 mg As kg^{-1} soil which was statistically similar with V_6As_2 (34.33), V_7As_2 (38.33).

Table 3. Interaction effect of varieties and As levels on number of leaves plant^{-1} of potato at different DAP

Variety× As level	Number of leaves plant^{-1} at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_1 As_0	31.33 h-l	96.33 a	125.7 d	130.7 d	124.7 d
V_1 As_1	30.33 i-n	95.33 ab	123.7 d	129.7 d	122.7 d
V_1 As_2	28.33 j-q	72.67 d-g	104.0 f	110.7 e	103.0 f
V_2 As_0	49.33 b-d	73.33 d-f	82.67 gh	85.67 fg	81.67 gh
V_2 As_1	48.33 cd	72.33 d-g	81.67 g-i	84.67 f-h	80.67 g-i
V_2 As_2	46.33 de	57.00 j	63.33 l	68.67 jk	62.33 l
V_3 As_0	71.67 a	91.33 ab	103.7 f	107.3 e	102.7 f
V_3 As_1	70.67 a	90.33 b	102.7 f	106.3 e	101.7 f
V_3 As_2	68.33 a	79.33 c	86.00 g	89.67 f	85.00 g
V_4 As_0	26.67 k-r	36.00 p	42.67 n-p	44.67 n-p	41.67 n-p
V_4 As_1	25.67 m-r	35.00 pq	41.67 n-p	43.67 o-q	40.67 n-p
V_4 As_2	23.67 p-r	27.67 s	31.33 qr	33.00 s	30.33 qr
V_5 As_0	54.00 b	76.67 cd	85.33 g	87.33 f	84.33 g
V_5 As_1	53.00 bc	75.67 c-e	84.33 g	86.33 f	83.33 g
V_5 As_2	50.33 b-d	58.00 j	62.33 l	64.67 kl	61.33 l
V_6 As_0	26.33 l-r	34.67 pq	37.67 op	41.00 pq	36.67 op
V_6 As_1	25.33 n-r	33.67 p-r	36.67 pq	40.00 p-r	35.67 pq
V_6 As_2	23.33 qr	29.00 rs	27.67 r	34.33 rs	26.67 r
V_7 As_0	31.67 h-k	50.67 k-m	57.00 lm	61.67 lm	56.00 lm
V_7 As_1	30.67 i-m	49.33 l-n	56.00 m	60.67 lm	55.00 m
V_7 As_2	28.67 j-p	33.67 p-r	37.00 o-q	38.33 q-s	36.00 o-q
V_8 As_0	50.33 b-d	64.67 hi	71.00 jk	73.33 ij	70.00 jk
V_8 As_1	49.00 b-d	63.67 i	70.00 k	72.33 j	69.00 k
V_8 As_2	47.00 de	54.67 j-l	59.33 lm	61.67 lm	58.33 lm
V_9 As_0	25.00 o-r	46.00 m-o	54.33 m	57.33 m	53.33 m
V_9 As_1	24.00 p-r	45.00 no	53.33 m	56.33 m	52.33 m
V_9 As_2	22.67 r	35.00 pq	43.00 no	47.67 no	42.00 no
V_{10} As_0	36.00 gh	57.00 j	63.33 l	69.00 jk	62.33 l
V_{10} As_1	35.00 g-i	56.00 jk	62.33 l	68.00 jk	61.33 l
V_{10} As_2	32.67 h-j	41.33 o	46.67 n	50.00 n	45.67 n

Table 3 (Cont'd).

Variety× As level	Number of leaves plant^{-1} at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_{11} As_0	42.33 ef	68.33 f-i	77.00 h-j	80.00 gh	76.00 h-j
V_{11} As_1	41.33 f	67.33 g-i	76.00 ij	79.00 hi	75.00 ij
V_{11} As_2	39.33 fg	43.67 o	47.33 n	48.67 no	46.33 n
V_{12} As_0	50.00 b-d	68.67 f-i	77.33 hi	80.00 gh	76.33 hi
V_{12} As_1	49.00 cd	67.67 f-i	76.33 ij	79.00 hi	75.33 ij
V_{12} As_2	47.00 de	54.33 j-l	58.33 lm	59.67 lm	57.33 lm
V_{13} As_0	29.33 j-o	70.33 e-g	134.0 c	156.3 b	133.0 c
V_{13} As_1	28.33 j-q	69.33 f-h	133.0 c	155.3 b	132.0 c
V_{13} As_2	26.33 l-r	50.67 k-m	111.7 e	131.0 d	110.7 e
V_{14} As_0	16.33 s	30.00 q-s	168.3 a	187.7 a	167.3 a
V_{14} As_1	15.33 s	29.00 rs	167.3 a	186.7 a	166.3 a
V_{14} As_2	13.67 s	18.33 t	140.7 b	147.7 c	139.7 b
SE value	1.54	1.75	1.97	2.01	1.97
Level of significance	**	**	**	**	**
CV (%)	7.17	5.38	4.40	4.18	4.46

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.4 Number of stems hill^{-1}

4.1.4.1 Effect of Varieties

The number of stems hill^{-1} was significantly varied among the varieties at 30, 45, 60, 75 and 90 DAP (Appendix V and Figure 7). Number of stems hill^{-1} increased with advancing growing period up to 60 DAP irrespective of varieties and thereafter remained constant (Figure 7). At 30 DAP, the maximum stem numbers hill^{-1} (6.44) was obtained from the variety 'Felsina' and the minimum (1.67) was obtained from the 'Jam Alu' which was statistically similar with 'Quincy' (1.78) and 'Rumana' (2.22). At 45 DAP, the maximum number of stems hill^{-1} (7.11) was recorded from the variety 'Felsina' which was statistically similar with 'Diamant' (6.44) and 'Asterix' (5.89) whereas, the minimum (2.22) number was from the variety 'Jam Alu' and it was statistically similar with 'Quincy' (2.33) and 'Rumana' (2.67). At 60, 75 DAP and at harvest, the maximum (7.67) number of stems hill^{-1} was counted from the variety 'Felsina' which was statistically similar with 'Diamant', (7.11) 'Asterix' (6.11) and the minimum number (2.56) was counted from the variety 'Jam Alu' which was statistically similar with 'Quincy', (2.67) 'Rumana', (3.00) 'Granola' (4.22) and 'BARI TPS-1' (4.22). The study referred that 'Felsina' variety produced maximum number of stem hill^{-1}. This might be due to varietal characters.

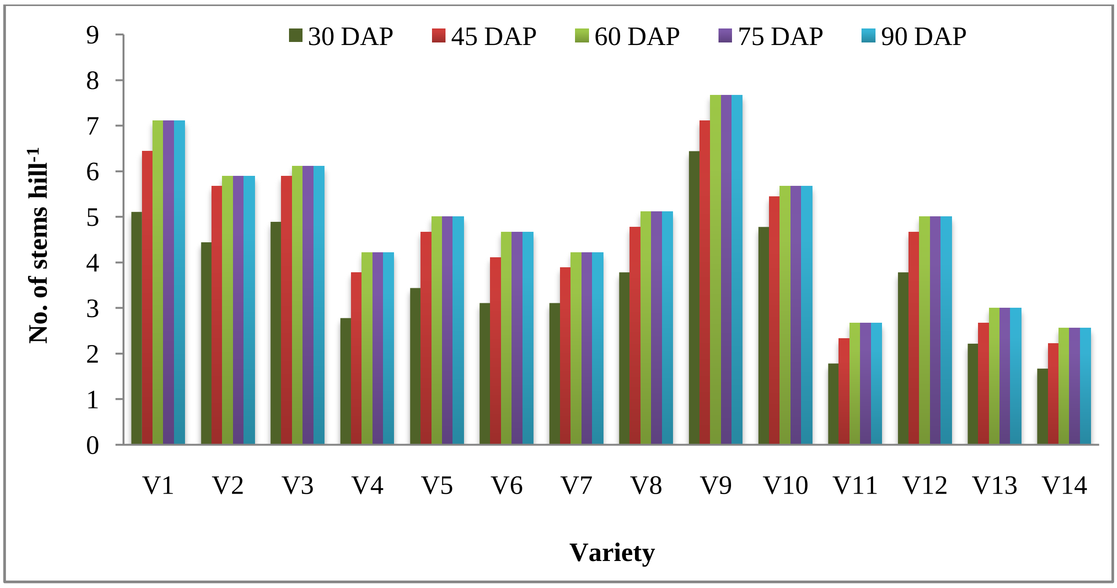

Figure 7. Effect of varieties on number of stems hill^{-1} of potato at different growth stages (SE value = 0.32, 0.43, 0.55, 0.55 and 0.55 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.4.2 Effect of As levels

Different As levels significantly affected the number of stems hill^{-1} of potato varieties at 30, 45, 60, 75 and 90 DAP (Appendix V and Figure 8). Number of stems hill^{-1} increased with advancement of age i.e. up to 60 DAP irrespective of As levels and thereafter remained constant (Figure 8). At 30, 45, 60, 75 DAP and at harvest, the maximum number of stems hill^{-1} (4.24, 5.26, 5.69, 5.69 and 5.69, respectively) was recorded from the control (As_0) treatment which was statistically similar (3.88, 4.93, 5.36, 5.36 and 5.36, respectively) with 25 mg As kg^{-1} soil (As_1) and the minimum stem numbers hill^{-1} (2.88, 3.45, 3.71, 3.71 and 3.71, respectively) was counted from the 50 mg As kg^{-1} soil (As_2). Present study showed that number of stems was not statistically affected up to 25 mg As kg^{-1} soil treatment compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) number of stems $hill^{-1}$ significantly decreased.

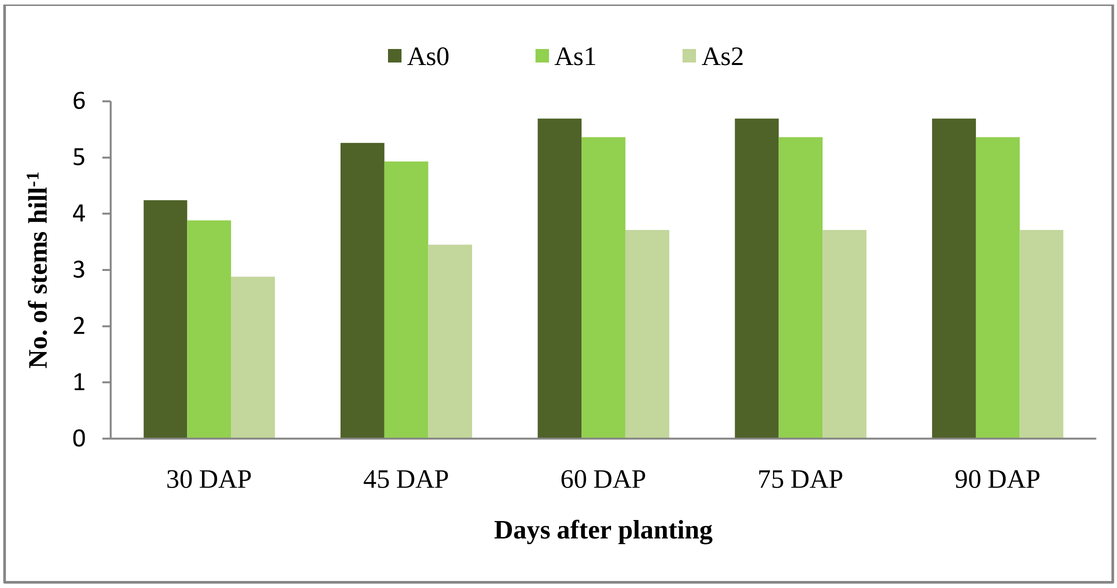

Figure 8. Effect of As levels on number of stems $hill^{-1}$ of potato at different growth stages (SE value = 0.15, 0.2, 0.25, 0.25 and 0.25 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.4.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the stem numbers $hill^{-1}$ (Appendix V and Table 4). At 30 DAP, the maximum number of stems $hill^{-1}$ (7.00) was recorded from the combination of 'Felsina' with control (As_0) treatment which was statistically similar with V_9As_1 (6.67) and the minimum number (1.00) of stems $hill^{-1}$ was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil which was statistically identical with $V_{11}As_2$ (1.00) and statistically similar with $V_{13}As_2$ (1.33), $V_{14}As_1$ (2.00), $V_{11}As_1$ (2.00), $V_{14}As_0$ (2.00). At 45 DAP, the maximum number (7.67) of stems $hill^{-1}$ was counted from the combination of 'Felsina' with As_0 treatment which was statistically similar with V_9As_1 (7.33), V_1As_0 (7.33), V_3As_0 (7.00), V_1As_1 (7.00), V_3As_1 (6.67), V_2As_0 (6.33), $V_{10}As_0$ (6.33), V_9As_2 (6.33) whereas, the minimum number (1.33) was counted from the combination of 'Quincy' with 50 mg As kg^{-1} soil which was statistically similar with $V_{14}As_2$ (1.67), $V_{13}As_2$ (1.67),

$V_{14}As_1$ (2.33), V_7As_2 (2.67), $V_{11}As_1$ (2.67), $V_{14}As_0$ (2.67). At 60, 75 DAP and at harvest, the maximum number of stems hill^{-1} (8.33) was obtained from the combination of 'Felsina' with control (As_0) treatment which was statistically similar with V_1As_0 (8.00), V_9As_1 (8.00), V_1As_1 (7.67), V_3As_0 (7.33), V_3As_1 (7.00), V_2As_0 (6.67), $V_{10}As_0$ (6.67), V_9As_2 (6.67) and the minimum (1.67) was recorded from the combination of 'Quincy' with 50 mg As kg^{-1} soil which was statistically similar with $V_{14}As_2$ (2.00), $V_{13}As_2$ (2.00), $V_{14}As_1$ (2.67), V_4As_2 (3.00), V_7As_2 (3.00), $V_{14}As_0$ (3.00), $V_{11}As_0$ (3.00), $V_{13}As_1$ (3.33) and $V_{11}As_0$ (3.33) treatments.

Table 4. Interaction effect of varieties and As levels on number of stems hill^{-1} of potato at different DAP

Variety× As level	Number of stems hill^{-1} at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_1 As_0	5.67 b	7.33 ab	8.00 ab	8.00 ab	8.00 ab
V_1 As_1	5.33 bc	7.00 a-c	7.67 a-c	7.67 a-c	7.67 a-c
V_1 As_2	4.33 c-f	5.00 e-i	5.67 d-h	5.67 d-h	5.67 d-h
V_2 As_0	5.00 b-d	6.33 a-e	6.67 a-f	6.67 a-f	6.67 a-f
V_2 As_1	4.67 b-e	6.00 b-f	6.33 b-g	6.33 b-g	6.33 b-g
V_2 As_2	3.67 e-h	4.67 f-j	4.67 g-k	4.67 g-k	4.67 g-k
V_3 As_0	5.67 b	7.00 a-c	7.33 a-d	7.33 a-d	7.33 a-d
V_3 As_1	5.00 b-d	6.67 a-d	7.00 a-e	7.00 a-e	7.00 a-e
V_3 As_2	4.00 d-g	4.00 h-l	4.00 h-l	4.00 h-l	4.00 h-l
V_4 As_0	3.33 f-i	4.33 g-k	5.00 f-j	5.00 f-j	5.00 f-j
V_4 As_1	3.00 g-j	4.00 h-l	4.67 g-k	4.67 g-k	4.67 g-k
V_4 As_2	2.00 j-l	3.00 k-n	3.00 k-n	3.00 k-n	3.00 k-n
V_5 As_0	4.00 d-g	5.33 d-h	5.67 d-h	5.67 d-h	5.67 d-h
V_5 As_1	3.67 e-h	5.00 e-i	5.33 e-i	5.33 e-i	5.33 e-i
V_5 As_2	2.67 h-j	3.67 i-m	4.00 h-l	4.00 h-l	4.00 h-l
V_6 As_0	3.67 e-h	4.67 f-j	5.33 e-i	5.33 e-i	5.33 e-i
V_6 As_1	3.33 f-i	4.33 g-k	5.00 f-j	5.00 f-j	5.00 f-j
V_6 As_2	2.33 i-k	3.33 j-m	3.67 i-m	3.67 i-m	3.67 i-m
V_7 As_0	3.67 e-h	4.67 f-j	5.00 f-j	5.00 f-j	5.00 f-j
V_7 As_1	3.33 f-i	4.33 g-k	4.67 g-k	4.67 g-k	4.67 g-k
V_7 As_2	2.33 i-k	2.67 l-o	3.00 k-n	3.00 k-n	3.00 k-n
V_8 As_0	4.33 c-f	5.67 c-g	6.00 c-g	6.00 c-g	6.00 c-g
V_8 As_1	4.00 d-g	5.33 d-h	5.67 d-h	5.67 d-h	5.67 d-h
V_8 As_2	3.00 g-j	3.33 j-m	3.67 i-m	3.67 i-m	3.67 i-m
V_9 As_0	7.00 a	7.67 a	8.33 a	8.33 a	8.33 a
V_9 As_1	6.67 a	7.33 ab	8.00 ab	8.00 ab	8.00 ab
V_9 As_2	5.67 b	6.33 a-e	6.67 a-f	6.67 a-f	6.67 a-f

Table 4 (Cont'd).

Variety× As level	Number of stems hill^{-1} at				
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**
V_{10} As_0	5.33 bc	6.33 a-e	6.67 a-f	6.67 a-f	6.67 a-f
V_{10} As_1	5.00 b-d	6.00 b-f	6.33 b-g	6.33 b-g	6.33 b-g
V_{10} As_2	4.00 d-g	4.00 h-l	4.00 h-l	4.00 h-l	4.00 h-l
V_{11} As_0	2.33 i-k	3.00 k-n	3.33 j-n	3.33 j-n	3.33 j-n
V_{11} As_1	2.00 j-l	2.67 l-o	3.00 k-n	3.00 k-n	3.00 k-n
V_{11} As_2	1.00 l	1.33 o	1.67 n	1.67 n	1.67 n
V_{12} As_0	4.33 c-f	5.33 d-h	5.67 d-h	5.67 d-h	5.67 d-h
V_{12} As_1	4.00 d-g	5.00 e-i	5.33 e-i	5.33 e-i	5.33 e-i
V_{12} As_2	3.00 g-j	3.67 i-m	4.00 h-l	4.00 h-l	4.00 h-l
V_{13} As_0	3.00 g-j	3.33 j-m	3.67 i-m	3.67 i-m	3.67 i-m
V_{13} As_1	2.33 i-k	3.00 k-n	3.33 j-n	3.33 j-n	3.33 j-n
V_{13} As_2	1.33 kl	1.67 no	2.00 mn	2.00 mn	2.00 mn
V_{14} As_0	2.00 j-l	2.67 l-o	3.00 k-n	3.00 k-n	3.00 k-n
V_{14} As_1	2.00 j-l	2.33 m-o	2.67 l-n	2.67 l-n	2.67 l-n
V_{14} As_2	1.00 l	1.67 no	2.00 mn	2.00 mn	2.00 mn
SE value	0.32	0.43	0.55	0.55	0.55
Level of significance	**	**	**	**	**
CV (%)	15.06	16.32	19.33	19.33	19.33

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.5 Leaf area plant^{-1}

4.1.5.1 Effect of varieties

Varietal effect significantly influenced leaf area of potato at 30, 45, 60, 75 and 90 DAP (Appendix VI and Figure 9). Leaf area increased with advancing growing period up to 75 DAP irrespective of varieties and thereafter decreased due to senescence of plant (Figure 9). At 30 DAP, the highest leaf area plant^{-1} (37.09 cm^2) was found in the variety 'Felsina' which was statistically similar with 'Diamant', (36.19 cm^2) 'Asterix', (35.88 cm^2) 'Cardinal' (34.70 cm^2) and the lowest (8.62 cm^2) was found in the 'Jam Alu'. At 45 DAP, the highest (50.80 cm^2) leaf area plant^{-1} was recorded from the variety 'Felsina' which was statistically similar with 'Diamant', (49.81 cm^2) 'Asterix' (48.46 cm^2) whereas, the lowest leaf area plant^{-1} (14.14 cm^2) was from the variety 'Jam Alu'. At 60, 75 DAP and at harvest, the highest leaf area (61.93, 65.77 and 68.80 cm^2, respectively) was obtained from the variety 'Felsina' and it was statistically similar (59.94, 63.79 and 62.63 cm^2, respectively) with 'Diamant' and the lowest (20.74, 24.70 and 23.36 cm^2, respectively) was obtained from the variety 'Jam Alu'. Study referred that the potato variety 'Felsina' exposed best result in terms of leaf area plant^{-1}.

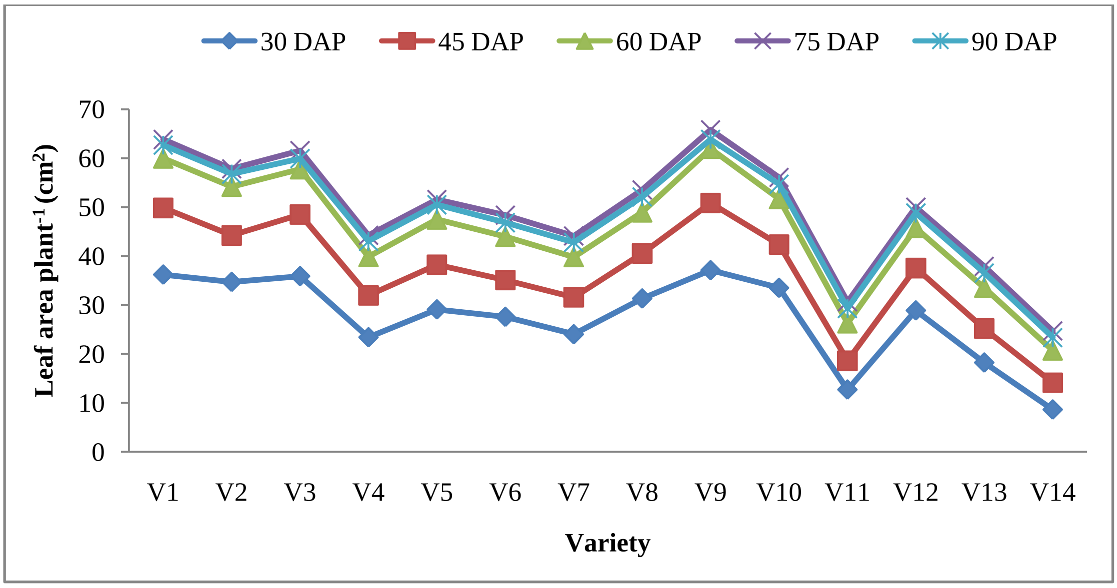

Figure 9. Effect of varieties on leaf area plant^{-1} (cm^2) of potato at different growth stages (SE value = 0.94, 0.92, 0.84, 0.9 and 1.0 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.5.2 Effect of As levels

Arsenic (As) levels significantly influenced leaf area plant^{-1} of potato at 30, 45, 60, 75 and 90 DAP (Appendix VI and Figure 10). Leaf area increased with advancing growing period up to 75 DAP irrespective of As levels and thereafter decreased due to senescence of plant (Figure 10). At 30, 45, 60, 75 DAP and at harvest, the highest leaf area plant^{-1} (30.44, 39.78, 48.41, 52.46 and 51.27 cm^2, respectively) was recorded from the control (As_0) treatment which was statistically similar (30.28, 39.59, 48.22, 52.28 and 51.12 cm^2, respectively) with 25 mg As kg^{-1} soil (As_1) and the lowest (20.94, 29.59, 38.76, 43.09 and 41.35 cm^2, respectively) was counted from the 50 mg As kg^{-1} soil

(As_2). Juzl and Stefl (2002) reported that leaf area index of potato plants decreased significantly with the increasing levels of As in irrigated water and soil but the present study showed that leaf area was not statistically affected up to 25 mg As kg^{-1} soil compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) treatment significantly decreased leaf area $plant^{-1}$.

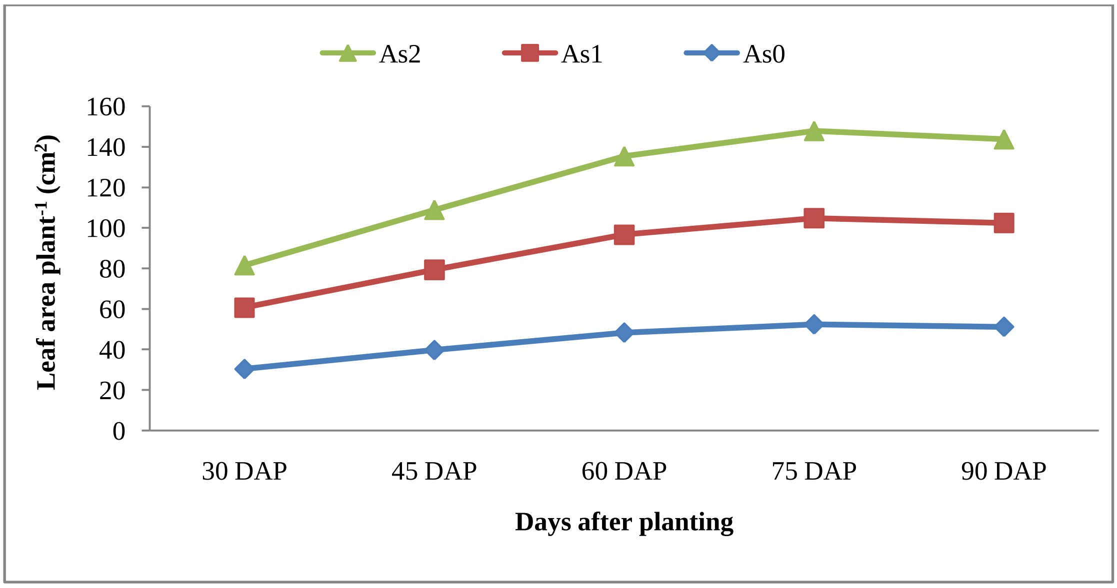

Figure 10. Effect of As levels on leaf area $plant^{-1}$ (cm^2) of potato at different growth stages (SE value = 0.44, 0.43, 0.39, 0.42 and 0.46 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.5.3 Interaction effect of varieties and As levels

Leaf area of potato significantly influenced by the interaction effect of varieties and As levels at 30, 45, 60, 75 and 90 DAP (Appendix VI and Table 5). At 30 DAP, the highest leaf area $plant^{-1}$ (40.19 cm^2) was recorded from the combination of 'Felsina' with As_0 treatment which was statistically similar with V_9As_1 (40.00 cm^2), V_1As_0 (39.25 cm^2), V_1As_1 (39.14 cm^2), V_3As_0 (38.97 cm^2), V_3As_1 (38.80 cm^2), V_2As_0 (37.81 cm^2), V_2As_1 (37.64 cm^2) and the lowest (5.58 cm^2) leaf area was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil which was statistically similar with $V_{11}As_2$ (8.18 cm^2). At 45 DAP, the highest (54.22 cm^2) leaf area was found from the combination of 'Felsina' with As_0 treatment and it was statistically similar with V_9As_1 (54.05 cm^2), V_1As_0 (53.24 cm^2), V_1As_1 (53.02 cm^2), V_3As_0 (51.94 cm^2), V_3As_1 (51.73

cm^2) whereas, the lowest (10.14 cm^2) was found from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil. At 60, 75 DAP and at harvest, the highest leaf area (65.01, 69.24 and 67.11 cm^2, respectively) was obtained from the combination of 'Felsina' with As_0 treatment which was statistically similar with V_9As_1 (64.80 cm^2), V_1As_0 (63.03 cm^2), V_1As_1 (62.80 cm^2), V_9As_1 (69.08 cm^2), V_1As_0 (67.25 cm^2), V_1As_1 (67.07 cm^2), V_9As_1 (66.95 cm^2), V_1As_0 (66.03 cm^2), V_1As_1 (65.89 cm^2) and the lowest (16.31, 20.19 and 18.12 cm^2, respectively) was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil. The study indicated that potato variety 'Felsina' cultivated with 25 mg As kg^{-1} (As_1) soil showed better and in control (As_0) performed best in terms of leaf area plant^{-1}.

Table 5. Interaction effect of varieties and As levels on leaf area plant^{-1} of potato at different DAP

Variety× As level	Leaf area plant^{-1} (cm^2) at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_1 As_0	39.25 a-c	53.24 a	63.03 ab	67.25 ab	66.03 ab
V_1 As_1	39.14 a-c	53.02 a	62.80 ab	67.07 ab	65.89 a-c
V_1 As_2	30.17 f-h	43.17 de	53.99 d-f	57.04 de	55.97 fg
V_2 As_0	37.81 a-c	47.68 b	57.29 c	61.27 c	60.17 de
V_2 As_1	37.64 a-c	47.48 b	57.06 c	61.06 c	59.97 de
V_2 As_2	28.64 g-j	37.42 gh	48.19 ij	51.13 gh	50.07 ij
V_3 As_0	38.97 a-c	51.94 a	60.94 b	65.04 b	63.14 bc
V_3 As_1	38.80 a-c	51.73 a	60.63 b	64.87 b	62.93 cd
V_3 As_2	29.87 f-i	41.72 ef	51.65 f-h	54.68 ef	53.64 gh
V_4 As_0	27.05 i-k	34.99 hi	42.88 l-n	46.91 j	45.91 kl
V_4 As_1	26.91 i-k	34.76 hi	42.66 l-n	46.74 j	45.74 kl
V_4 As_2	16.20 m	26.14 mn	33.97 q	39.06 lm	37.34 op
V_5 As_0	32.83 ef	41.59 ef	50.57 g-i	54.33 f	53.72 gh
V_5 As_1	32.56 ef	41.41 ef	50.35 hi	54.14 f	53.52 gh
V_5 As_2	21.84 l	31.62 jk	41.52 mn	46.12 j	44.13 lm
V_6 As_0	31.25 fg	39.18 fg	47.40 jk	51.34 gh	50.21 ij
V_6 As_1	31.12 fg	38.99 fg	47.20 jk	51.20 gh	50.04 ij
V_6 As_2	20.31 l	27.11 lm	37.27 p	42.45 k	40.16 no
V_7 As_0	27.87 h-j	35.64 hi	43.53 lm	47.52 ij	46.53 kl
V_7 As_1	27.39 h-k	35.47 hi	43.36 lm	47.33 ij	46.43 kl
V_7 As_2	16.73 m	23.63 no	32.55 q	37.41 m	35.39 p
V_8 As_0	34.72 de	44.27 c-e	53.14 ef	57.29 de	56.12 fg
V_8 As_1	34.58 de	44.04 c-e	52.97 e-g	57.13 de	55.93 fg
V_8 As_2	24.63 k	33.24 ij	40.68 no	46.14 j	44.16 lm
V_9 As_0	40.19 a	54.22 a	65.01 a	69.24 a	67.11 a
V_9 As_1	40.00 ab	54.05 a	64.80 a	69.08 a	66.95 a
V_9 As_2	31.08 fg	44.14 c-e	55.98 cd	58.98 cd	57.34 ef

Table 5 (Cont'd).

Variety× As level	Leaf area plant^{-1} (cm^2) at				
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**
V_{10} As_0	36.92 b-d	46.13 bc	55.10 c-e	59.19 cd	57.95 ef
V_{10} As_1	36.77 cd	45.94 b-d	54.94 c-e	59.05 cd	57.81 ef
V_{10} As_2	26.74 jk	34.88 hi	44.96 kl	49.90 hi	48.26 jk
V_{11} As_0	14.98 m	21.07 o	29.07 r	33.17 n	32.05 q
V_{11} As_1	14.93 n	20.90 o	28.89 r	33.00 n	31.92 q
V_{11} As_2	8.18 op	13.88 q	20.86 t	25.74 o	23.86 s
V_{12} As_0	32.52 ef	41.48 ef	49.54 h-j	53.43 fg	52.50 hi
V_{12} As_1	32.38 ef	41.26 ef	49.32 h-j	53.24 fg	52.41 hi
V_{12} As_2	21.70 l	29.87 kl	38.42 op	43.29 k	41.41 mn
V_{13} As_0	21.62 l	29.22 kl	37.27 p	41.37 kl	40.34 no
V_{13} As_1	21.54 l	29.06 kl	37.12 p	41.21 kl	40.27 no
V_{13} As_2	11.49 n	17.30 p	26.30 s	31.09 n	29.02 r
V_{14} As_0	10.16 no	16.20 pq	23.02 t	27.04 o	26.04 s
V_{14} As_1	10.11 no	16.09 pq	22.90 t	26.86 o	25.91 s
V_{14} As_2	5.58 p	10.14 r	16.31 u	20.19 p	18.12 t
SE value	0.94	0.92	0.84	0.90	1.00
Level of significance	**	**	**	**	**
CV (%)	5.99	4.41	3.21	3.16	3.62

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability
** indicate 1% level of significance
Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}-Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.6 Chlorophyll content of leaves (SPAD value)

4.1.6.1 Effect of varieties

Chlorophyll content of potato leaves were significantly affected by the varieties at 30, 45, 60, 75 and 90 DAP (Appendix VII and Figure 11). Chlorophyll content (SPAD value) increased with the advancement of plant age i.e., up to 60 DAP irrespective of varieties and thereafter decreased due to yellowing of leaves (Figure 11). At 30 DAP, the maximum chlorophyll content (SPAD value) (47.90) was recorded from 'Felsina' (V_9) which was statistically similar with 'Diamant', (46.37) 'Asterix', (44.95) 'Cardinal', (44.78) 'Jam Alu', (43.49) 'Meridian', (43.22) 'Lady Rosetta' (42.86) and the minimum (27.69) was recorded from the variety 'Quincy'. At 45, 60 and 75 DAP, the highest chlorophyll content (SPAD value) (49.78, 54.36 and 51.75, respectively) was recorded from 'Felsina' (V_9) which was statistically similar with 'Diamant', ‘Asterix’, ‘Cardinal’, ‘Jam Alu’, ‘Meridian’ and the lowest (29.47, 34.16 and 31.21, respectively) was recorded from ‘Quincy’ (V_{11}). At harvest, the maximum chlorophyll content (SPAD value) (35.15) was recorded from ‘Felsina’ (V_9) which was statistically similar with ‘Diamant’ (33.52), ‘Asterix’ (32.21), ‘Cardinal’ (31.81), ‘Jam Alu’ (30.96), and the minimum (18.21) was recorded from the variety ‘Quincy’. Potato varieties used in the study differed in chlorophyll content reading like observed by many other workers (Bavec and Bavec, 2001; Güler *et al.* 2006).

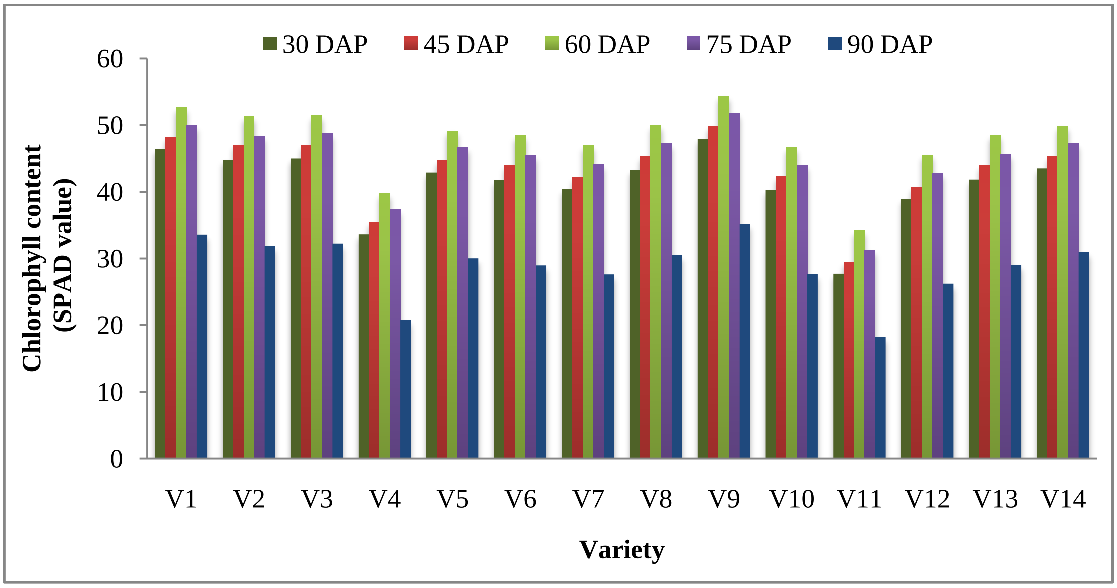

Figure 11. Effect of varieties on chlorophyll content of potato leaves (SPAD value) at different growth stages (SE value = 1.56, 1.55, 1.45, 1.45 and 1.46 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.1.6.2 Effect of As levels

Chlorophyll content of potato varieties showed statistically significant variation among the different As levels at 30, 45, 60, 75 and 90 DAP (Appendix VII and Figure 12). Chlorophyll content (SPAD value) increased with increasing growing period up to 60 DAP irrespective of As levels and thereafter decreased due to yellowing of leaves (Figure 12). At 30, 45, 60, 75 DAP and at harvest, the highest chlorophyll content (SPAD value) (45.33, 47.44, 51.90, 49.24 and

33.02, respectively) was recorded from the control (As_0) which was statistically similar (44.09, 46.20, 50.66, 48.00 and 31.79, respectively) with 25 mg As kg^{-1} soil (As_1) and the lowest chlorophyll content (34.41, 35.98, 40.64, 37.77 and 21.43, respectively) was found from the 50 mg As kg^{-1} soil (As_2). Nitrogen is the core component of chlorophyll molecule and thus, its content in leaf is directly correlated with chlorophyll content. Higher soil As concentrations decrease the nitrogen content in garden pea (Paivoke, 1983) and Silver bet (Merry *et al.*, 1986). Miteva and Merakchiyska (2002) reported that As concentrations of 25 mg kg^{-1} soil did not have negative effect on the photosynthetic process in bean plants (*Phaseolus vulgaris* L.), while the higher doses (50 and 100 mg of As kg^{-1} soil) inhibit the photosynthesis by 42 and 32%, respectively. Increased As concentrations caused an alternation of the chloroplast shape, manifested in its rounding and shortening of the longitudinal axis of plant cell. Other manifestations are concaving membrane, bending and partial destruction as well as changes in the accumulation and flow of assimilates which results in the decrease of chlorophyll content in potato leaf. Thus, it is expected that the higher soil As concentrations may also decrease nitrogen content in potato plant which may also cause the decrease of chlorophyll content. The results of the present experiment revealed that chlorophyll content of potato leaves were not statistically affected up to 25 mg As kg^{-1} soil treatment compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) treatment chlorophyll content significantly decreased.

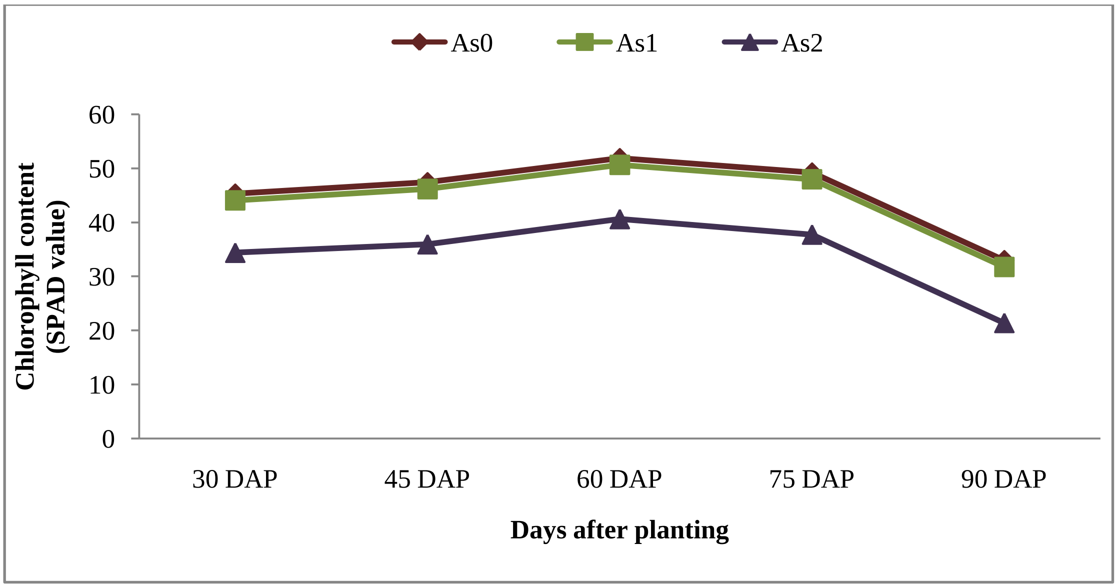

Figure 12. Effect of As levels on chlorophyll content of potato leaves (SPAD value) at different growth stages (SE value = 0.72, 0.72, 0.67, 0.67 and 0.68 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.6.3 Interaction effect of varieties and As levels

Interaction effect of different potato varieties and different As levels in terms of Chlorophyll content also exposed significant variation at 30, 45, 60, 75 and 90 DAP (Appendix VII and Table 6). Chlorophyll content (SPAD value) increased with advancing growing period up to 60 DAP irrespective of varieties and As levels and thereafter decreased due to yellowing of leaves (Table 6). At 30 and 45 DAP, the maximum chlorophyll content (SPAD value) (52.01 and 54.12, respectively) was recorded from the combination of 'Felsina' with control which was statistically similar with V_9As_1, V_1As_0, V_1As_1, V_2As_0, V_3As_0, V_8As_0, V_2As_1, $V_{14}As_0$, V_3As_1, V_5As_0 and the minimum (20.92, 22.02, respectively) was recorded from the variety 'Quincy' with 50 mg As kg^{-1} soil. At 60 and 75 DAP, the highest chlorophyll content (58.58 and 55.92, respectively) was recorded from the 'Felsina' with control (As_0) which was statistically similar with V_9As_1, V_1As_0, V_2As_0, V_3As_0, V_1As_1, V_3As_1, $V_{14}As_0$, V_2As_1, V_8As_0 whereas, the lowest (27.18 and 23.64, respectively) was recorded from the combination of 'Quincy' with 50 mg As kg^{-1} soil. At harvest, the maximum chlorophyll content (SPAD value) (39.48) was recorded from the 'Felsina' with control treatment which was statistically similar with V_9As_1

(38.24), V_1As_0 (37.73), V_1As_1 (36.50), V_3As_0 (36.42), V_2As_0 (36.13), V_3As_1 (35.19), $V_{14}As_0$ (35.06), V_2As_1 (34.90), V_8As_0 (34.80) and the minimum (18.21) was recorded from the combination of 'Quincy' with 50 mg As kg^{-1} soil. The variation in total chlorophyll content may be a good indicator of stress in plants that have been caused by environmental factors (Hendry and Price, 1993; Kara and Mujdeci, 2010).

Table 6. Interaction effect of varieties and As levels on chlorophyll content of potato leaf at different DAP

Variety× As level	Chlorophyll content of leaves (SPAD value) at				
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**
V_1 As_0	50.27 ab	52.38 ab	56.84 a-c	54.18 a-c	37.73 a-c
V_1 As_1	49.03 a-c	51.14 a-c	55.60 a-d	52.94 a-d	36.50 a-d
V_1 As_2	39.82 g-k	40.92 g-j	45.41 h-k	42.55 h-k	26.33 h-k
V_2 As_0	48.67 a-c	50.78 a-c	55.24 a-d	52.58 a-d	36.13 a-d
V_2 As_1	47.44 a-d	49.55 a-d	54.01 a-e	51.35 a-e	34.90 a-e
V_2 As_2	38.24 h-l	40.66 g-j	44.48 i-l	40.95 j-m	24.40 j-l
V_3 As_0	48.96 a-c	51.07 a-c	55.53 a-d	52.87 a-d	36.42 a-d
V_3 As_1	47.72 a-d	49.83 a-d	54.29 a-e	51.63 a-e	35.19 a-e
V_3 As_2	38.18 h-l	39.95 h-k	44.44 i-l	41.57 i-k	25.02 i-l
V_4 As_0	37.58 i-l	39.69 h-k	44.15 i-l	41.49 i-l	25.04 i-l
V_4 As_1	36.35 j-m	38.46 i-l	42.92 j-m	40.26 j-n	23.81 j-l
V_4 As_2	26.80 o	28.24 n	32.06 p	30.19 p	13.31 n
V_5 As_0	46.87 a-e	48.98 a-e	53.44 b-e	50.78 b-e	34.33 b-e
V_5 As_1	45.63 b-f	47.74 b-e	52.20 c-f	49.54 c-f	33.10 c-f
V_5 As_2	36.09 j-m	37.21 i-m	41.68 k-o	39.48 k-n	22.59 k-m
V_6 As_0	45.81 b-f	47.92 b-e	52.38 c-f	49.72 c-f	33.27 b-f
V_6 As_1	44.57 c-g	46.68 c-f	51.14 d-g	48.48 d-g	32.04 d-g
V_6 As_2	34.70 k-n	37.13 j-m	41.62 k-o	38.09 k-o	21.53 k-m
V_7 As_0	44.46 c-g	46.57 c-f	51.03 d-g	48.37 d-g	31.92 d-g
V_7 As_1	43.22 d-h	45.33 d-g	49.79 e-h	47.13 e-h	30.69 e-h
V_7 As_2	33.35 l-n	34.45 lm	39.94 l-o	36.74 l-o	20.18 lm
V_8 As_0	47.34 a-d	49.45 a-d	53.91 a-e	51.25 a-e	34.80 a-e
V_8 As_1	46.10 b-f	48.21 b-e	52.67 b-f	50.01 b-f	33.57 b-f
V_8 As_2	36.23 j-m	38.33 i-l	43.15 j-m	40.28 j-n	23.06 j-m
V_9 As_0	52.01 a	54.12 a	58.58 a	55.92 a	39.48 a
V_9 As_1	50.78 ab	52.89 ab	57.35 ab	54.69 ab	38.24 ab
V_9 As_2	40.90 f-j	42.34 f-i	47.16 g-j	44.63 g-j	27.74 g-j
V_{10} As_0	44.37 c-g	46.48 c-f	50.94 d-g	48.28 d-g	31.83 d-g
V_{10} As_1	43.13 d-h	45.24 d-g	49.70 e-h	47.04 e-h	30.60 e-h
V_{10} As_2	33.26 l-n	35.02 k-m	39.18 m-o	36.65 m-o	20.43 lm
V_{11} As_0	31.70 mn	33.81 lm	38.27 no	35.61 no	22.43 k-m
V_{11} As_1	30.46 no	32.57 mn	37.03 o	34.37 o	21.19 lm
V_{11} As_2	20.92 p	22.02 o	27.18 q	23.64 q	11.02 n

Table 6 (Cont'd).

Variety× As level	Chlorophyll content of leaves (SPAD value) at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_{12} As_0	43.04 d-h	45.15 d-g	49.61 e-h	46.95 e-h	30.51 e-h
V_{12} As_1	41.81 e-i	43.92 e-h	48.38 f-i	45.72 f-i	29.27 f-i
V_{12} As_2	31.93 mn	33.03 m	38.52 m-o	35.66 no	18.77 m
V_{13} As_0	45.89 b-f	48.00 b-e	52.46 b-f	49.80 b-f	33.35 b-f
V_{13} As_1	44.66 c-g	46.77 c-f	51.23 d-g	48.57 d-g	32.12 d-g
V_{13} As_2	34.78 k-n	36.88 j-m	41.70 k-o	38.50 k-o	21.62 k-m
V_{14} As_0	47.60 a-d	49.71 a-d	54.17 a-e	51.51 a-e	35.06 a-e
V_{14} As_1	46.37 b-e	48.48 b-e	52.94 b-f	50.28 b-f	33.83 b-f
V_{14} As_2	36.49 j-m	37.59 i-m	42.41 k-n	39.88 j-n	23.99 j-l
SE value	1.56	1.55	1.45	1.45	1.46
Level of significance	**	**	**	**	**
CV (%)	6.56	6.23	5.26	5.59	8.82

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.7 Stem diameter

4.1.7.1 Effect of varieties

Significant variation was recorded for stem diameter due to different varieties of potato at 30, 45, 60, 75 and 90 DAP (Appendix VIII and Figure 13). Stem diameter increased with advancing growing period up to 75 DAP irrespective of varieties and thereafter decreased (Figure 13). In vegetative stage, potato stems were fleshy and succulent and at later (harvesting) stage it becomes hard and slender due to senescence of plant. At 30, 45, 60, 75 DAP and at harvest, the widest stem diameter (0.72, 0.83, 0.87, 0.89 and 0.85 cm, respectively) was recorded from 'Felsina' whereas, the narrowest (0.28, 0.36, 0.43, 0.45 and 0.40 cm, respectively) was recorded from 'Jam Alu'.

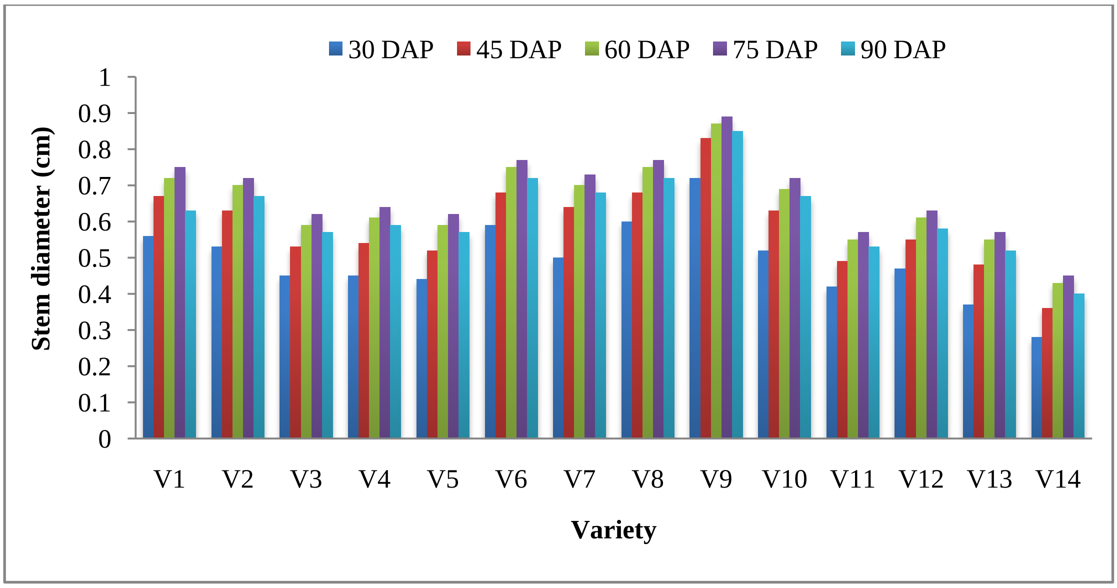

Figure 13. Effect of varieties on stem diameter (cm) of potato at different growth stages (SE value = 0.02, 0.02, 0.02, 0.02 and 0.02 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.1.7.2 Effect of As levels

Stem diameter showed significant variation with different As levels at 30, 45, 60, 75 and 90 DAP (Appendix VIII and Figure 14). Stem diameter increased with increasing different growing stages up to 75 DAP irrespective of As levels and thereafter decreased (Figure 14). In vegetative stage potato stems were fleshy and succulent and at later (harvesting) stage it becomes hard and slender due to senescence of plant. At 30, 45, 60, 75 DAP and at harvest, the maximum stem diameter (0.55, 0.64, 0.71, 0.73 and 0.68 cm, respectively) was recorded from the control (As_0) which was statistically similar (0.53, 0.62, 0.68, 0.70 and 0.66 cm, respectively) with 25 mg As kg^{-1} soil (As_1) and the minimum (0.40, 0.50, 0.56, 0.59 and 0.52 cm, respectively) was recorded from the 50 mg As kg^{-1} soil (As_2). In present study 25 mg As kg^{-1} soil (As_1) showed wider and in control (As_0) treatment performed widest result in terms of diameter of stem.

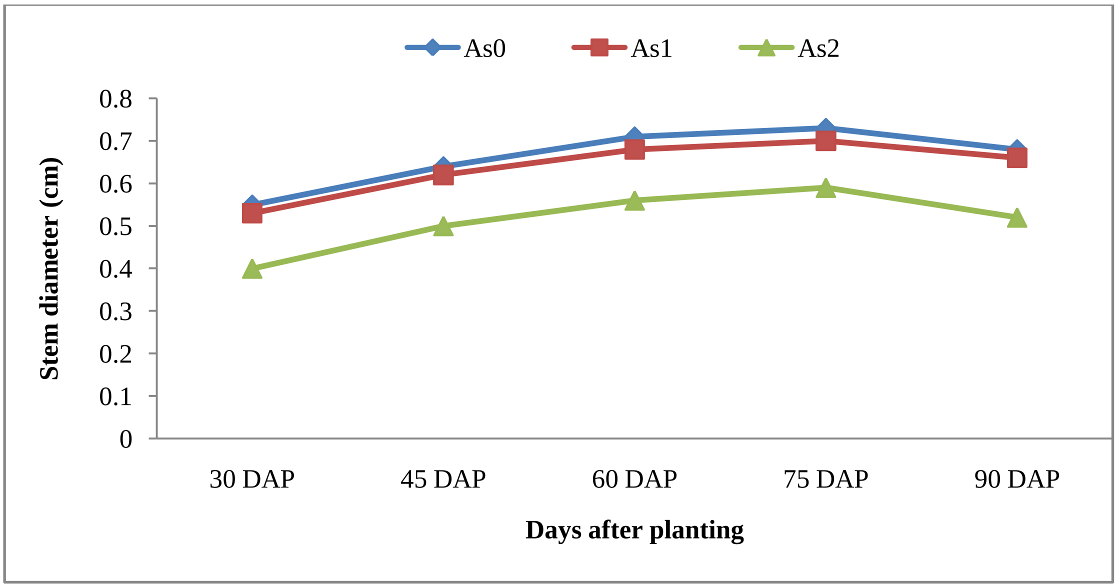

Figure 14. Effect of As levels on stem diameter (cm) of potato at different growth stages (SE value = 0.01, 0.01, 0.01, 0.01 and 0.01 at 30, 45, 60, 75 and 90 DAP, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.7.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels was significant in respect of stem diameter at 30, 45, 60, 75 and 90 DAP (Appendix VIII and Table 7). Stem diameter increased with increasing advancing growing period up to 75 DAP irrespective of As levels and thereafter decreased due to senescence of plant (Table 7). At 30, 45, 60, 75 DAP and at harvest, the widest stem diameter (0.78, 0.88, 0.94, 0.96 and 0.92 cm, respectively) was recorded from the combination of 'Felsina' and control (As_0) treatment which was statistically similar (0.76, 0.86, 0.91, 0.93 and 0.89 cm, respectively) with V_9As_1 and the narrowest (0.20, 0.28, 0.34, 0.37 and 0.31 cm, respectively) was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil.

Table 7. Interaction effect of varieties and As levels on stem diameter of potato at different DAP

Variety× As level	Stem diameter (cm) at				
	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
V_1 As_0	0.62 b-e	0.73 b-d	0.78 bc	0.80 b-d	0.69 e-h
V_1 As_1	0.60 c-e	0.71 b-e	0.76 bc	0.78 b-d	0.67 f-i
V_1 As_2	0.45 l-o	0.56 g-l	0.64 e-g	0.67 g-i	0.54 pq
V_2 As_0	0.59 c-f	0.70 b-e	0.74 bc	0.76 b-d	0.72 c-f
V_2 As_1	0.57 d-g	0.67 de	0.72 cd	0.74 d-f	0.70 d-g
V_2 As_2	0.43 m-p	0.54 i-l	0.62 e-g	0.65 g-k	0.59 j-p
V_3 As_0	0.51 h-l	0.60 g-i	0.65 ef	0.67 g-i	0.63 i-m
V_3 As_1	0.48 i-m	0.58 g-k	0.63 e-g	0.65 g-k	0.61 i-o
V_3 As_2	0.35 r-t	0.43 no	0.50 h	0.53 m-o	0.47 rs
V_4 As_0	0.51 i-l	0.61 fg	0.67 de	0.69 f-h	0.65 g-j
V_4 As_1	0.49 i-m	0.58 g-j	0.65 ef	0.67 g-i	0.63 i-m
V_4 As_2	0.35 q-s	0.44 no	0.52 h	0.55 lm	0.49 qr
V_5 As_0	0.50 i-l	0.58 g-j	0.65 ef	0.67 g-i	0.63 i-m
V_5 As_1	0.47 j-n	0.56 g-l	0.63 e-g	0.65 g-k	0.61 j-o
V_5 As_2	0.34 r-t	0.43 no	0.51 h	0.54 mn	0.48 rs
V_6 As_0	0.65 bc	0.74 bc	0.80 b	0.82 bc	0.78 bc
V_6 As_1	0.63 b-d	0.72 b-e	0.77 bc	0.79 b-d	0.75 b-d
V_6 As_2	0.49 i-l	0.58 g-k	0.67 de	0.70 e-g	0.64 h-l
V_7 As_0	0.54 f-i	0.69 b-e	0.76 bc	0.78 b-d	0.74 b-e
V_7 As_1	0.52 g-k	0.67 de	0.73 c	0.76 cd	0.71 d-f
V_7 As_2	0.46 k-o	0.56 g-l	0.61 e-g	0.64 g-k	0.58 k-p
V_8 As_0	0.67 b	0.73 bc	0.80 b	0.82 b	0.78 b
V_8 As_1	0.65 bc	0.71 b-e	0.78 bc	0.80 b-d	0.76 b-d
V_8 As_2	0.48 i-n	0.61 fg	0.65 ef	0.68 gh	0.62 i-m
V_9 As_0	0.78 a	0.88 a	0.94 a	0.96 a	0.92 a
V_9 As_1	0.76 a	0.86 a	0.91 a	0.93 a	0.89 a
V_9 As_2	0.62 b-e	0.75 b	0.76 bc	0.79 b-d	0.73 b-e
V_{10} As_0	0.59 d-f	0.68 c-e	0.75 bc	0.77 b-d	0.73 b-e
V_{10} As_1	0.57 e-h	0.66 ef	0.73 c	0.75 de	0.71 d-f
V_{10} As_2	0.42 n-p	0.54 h-l	0.60 fg	0.63 h-k	0.57 m-p
V_{11} As_0	0.48 i-n	0.54 h-l	0.60 fg	0.62 i-k	0.58 l-p
V_{11} As_1	0.46 k-o	0.52 k-m	0.58 g	0.60 j-l	0.56 n-p
V_{11} As_2	0.33 r-t	0.41 o	0.47 h	0.49 m-o	0.44 rs
V_{12} As_0	0.53 g-j	0.60 gh	0.66 e	0.68 gh	0.64 g-k
V_{12} As_1	0.51 i-l	0.58 g-k	0.64 e-g	0.66 g-j	0.62 i-n
V_{12} As_2	0.38 p-r	0.47 mn	0.52 h	0.55 l-n	0.49 rs
V_{13} As_0	0.43 m-p	0.53 j-l	0.61 e-g	0.62 i-k	0.58 l-p
V_{13} As_1	0.40 o-q	0.51 lm	0.58 g	0.60 kl	0.56 op
V_{13} As_2	0.29 t	0.40 o	0.46 h	0.49 no	0.43 s
V_{14} As_0	0.33 r-t	0.41 no	0.48 h	0.50 m-o	0.46 rs
V_{14} As_1	0.30 st	0.39 o	0.46 h	0.48 o	0.44 rs
V_{14} As_2	0.20 u	0.28 p	0.34 i	0.37 p	0.31 t
SE value	0.018	0.018	0.018	0.018	0.018
Level of significance	**	**	**	**	**
CV (%)	7.45	4.30	4.54	4.54	3.94

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.8 Above ground stem dry matter content (%)

4.1.8.1 Effect of varieties

Above ground stem dry matter content (%) significantly influenced by the varieties (Appendix IX and Figure 15). ‘Lady Rosetta’ produced higher stem dry matter content (19.87 %) which was statistically similar (19.00 %) with ‘Courage’ whereas, the minimum (13.22 %) was recorded from the variety ‘Granola’ followed by ‘Asterix’ (13.97 %) and ‘Laura’ (14.14 %). This might be due to varietal characters.

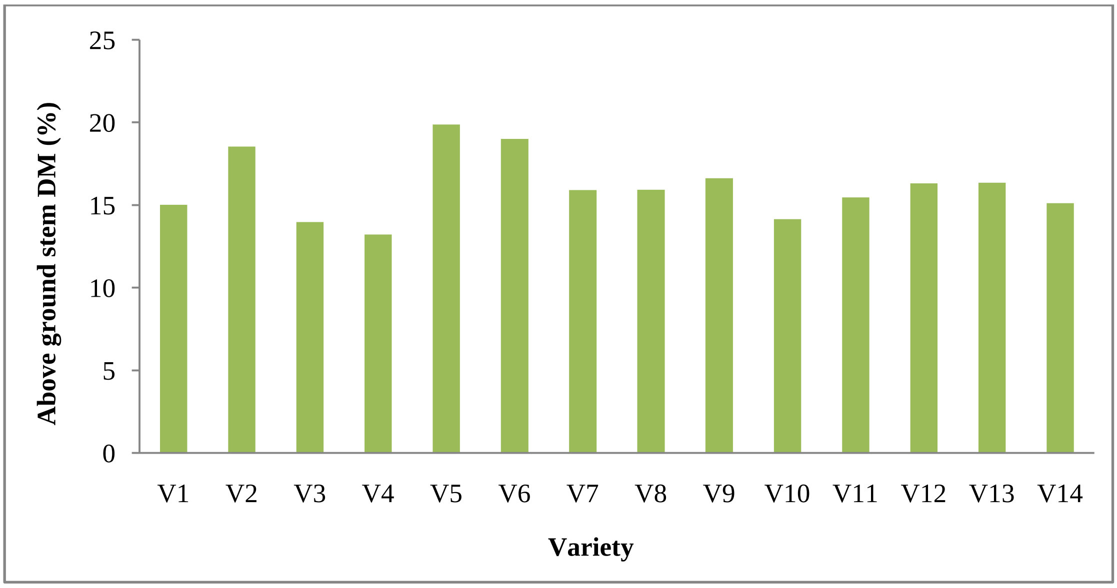

Figure 15. Effect of varieties on above ground stem dry matter content (%) of potato (SE value = 0.35)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.1.8.2 Effect of As levels

Dry matter content of above ground stem varied significantly with different As levels (Appendix IX and Figure 16). Above ground stem dry matter content decreased with increasing As levels though As_0 and As_1 showed similar results (Figure 16). The maximum stem dry matter content (18.51 %) was produced from the control (As_0) treatment which was statistically similar (18.09 %) with 25 mg As kg^{-1} soil (As_1) while, the minimum (11.72 %) was found from the 50 mg As kg^{-1} soil (As_2). Carbonell-Barrachina *et al.* (1997) stated that root, stem and leaf dry biomass production of tomato and bean plants were increased with increasing As (III) levels in the nutrient solution. Present experiment showed that shoot dry matter content (%) of potato stem was not statistically affected up to 25 mg As kg^{-1} soil compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) treatment significantly decreased.

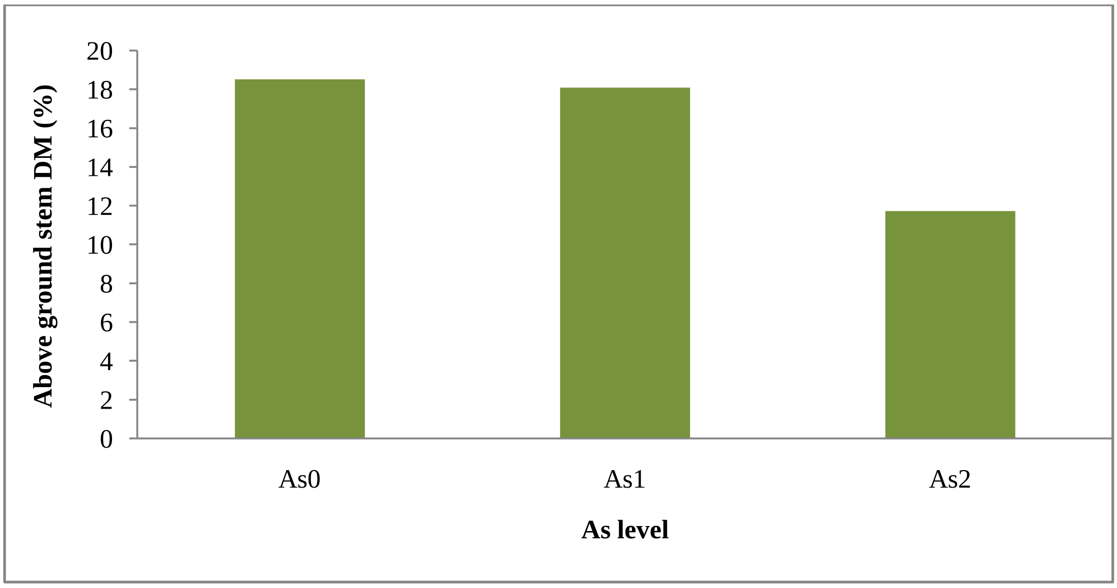

Figure 16. Effect of As levels on above ground stem dry matter content (%) of potato (SE value = 0.16)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.1.8.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels influenced the above ground stem dry matter content (Appendix IX and Table 8). It was observed that the maximum dry matter content of above ground stem (22.10%) was obtained from the combination of 'Lady Rosetta' with control which was statistically similar (21.65 and 21.16 %, respectively) with V_5As_1 ('Lady Rosetta' and 25 mg As kg^{-1} soil) and V_6As_0 ('Courage' and control) whereas, the minimum (8.90%) was recorded from the $\mathbf{V}_4As_2$ ('Granola' and 50 mg As kg^{-1} soil) and it was statistically similar (9.49 and 9.62 %, respectively) with V_3As_2 ('Asterix' and 50 mg As kg^{-1} soil) and $V_{10}As_2$ ('Laura' and 50 mg As kg^{-1} soil).

Table 8. Interaction effect of varieties and As levels on dry matter production at different parts of potato

Variety× As level	Above ground stem dry matter content (%)	Tuber flesh dry matter content (%)	Tuber peel dry matter content (%)
V_1 As_0	17.16 e-h	17.83 fg	12.63 f-j
V_1 As_1	16.75 f-j	17.75 fg	12.55 g-j
V_1 As_2	11.14 no	11.32 no	9.73 no
V_2 As_0	20.87 b	21.04 b	15.84 b
V_2 As_1	20.77 b	20.94 b	15.74 b
V_2 As_2	13.98 m	14.13 m	12.54 g-j
V_3 As_0	16.43 h-k	16.77 h-j	11.57 i-l
V_3 As_1	15.99 i-l	16.54 i-k	11.34 j-m
V_3 As_2	9.49 p	9.59 p	8.00 pq
V_4 As_0	15.60 kl	15.87 j-l	10.67 k-n
V_4 As_1	15.17 l	15.74 kl	10.54 k-n
V_4 As_2	8.90 p	8.99 p	7.73 q
V_5 As_0	22.10 a	22.98 a	17.78 a
V_5 As_1	21.65 ab	22.83 a	17.63 a
V_5 As_2	15.87 j-l	15.96 i-l	14.37 c
V_6 As_0	21.16 ab	21.69 b	16.49 b
V_6 As_1	20.71 b	21.60 b	16.40 b
V_6 As_2	15.14 l	15.25 l	13.66 c-g
V_7 As_0	18.23 c-e	18.42 d-f	13.22 c-g
V_7 As_1	17.78 d-f	18.29 ef	13.09 c-g
V_7 As_2	11.69 no	11.82 n	10.23 m-o
V_8 As_0	18.14 c-e	18.37 d-f	13.17 c-g
V_8 As_1	17.72 d-g	18.10 f	12.90 d-h
V_8 As_2	11.89 n	11.98 n	10.39 l-o
V_9 As_0	19.09 c	19.45 c	14.25 cd
V_9 As_1	18.61 cd	19.22 c-e	14.02 c-e
V_9 As_2	12.18 n	12.27 n	10.68 k-n
V_{10} As_0	16.61 g-k	16.92 g-i	11.72 h-k
V_{10} As_1	16.17 h-l	16.56 i-k	11.36 j-m
V_{10} As_2	9.62 p	9.70 p	8.11 pq
V_{11} As_0	18.09 c-e	18.33 ef	13.13 c-g
V_{11} As_1	17.67 d-g	18.12 f	12.92 d-h
V_{11} As_2	10.61 o	10.69 o	9.10 op
V_{12} As_0	19.01 c	19.36 cd	14.16 cd
V_{12} As_1	18.53 cd	19.14 c-e	13.94 c-f
V_{12} As_2	11.42 no	11.50 no	9.91 no
V_{13} As_0	19.07 c	19.44 c	14.24 cd
V_{13} As_1	18.57 cd	19.16 c-e	13.96 c-f
V_{13} As_2	11.44 no	11.60 no	10.01 no
V_{14} As_0	17.56 d-g	17.91 fg	12.71 e-i
V_{14} As_1	17.10 e-i	17.67 f-h	12.47 g-j
V_{14} As_2	10.68 o	10.82 o	9.23 op
SE value	0.35	0.32	0.40
Level of significance	**	**	**
CV (%)	3.77	3.33	5.61

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7- BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2 Yield and yield components

4.2.1 Number of tubers hill^{-1}

4.2.1.1 Effect of varieties

Number of tubers hill^{-1} significantly influenced by the potato varieties (Appendix IX and Figure 17). The maximum number of tubers hill^{-1} (55.44) was recorded from the 'Jam Alu' and the minimum (8.78) was found from the 'Courage' which was statistically similar with 'Laura' (9.89), 'Quincy' (9.89), 'Felsina' (10.67) and 'Lady Rosetta' (11.11).

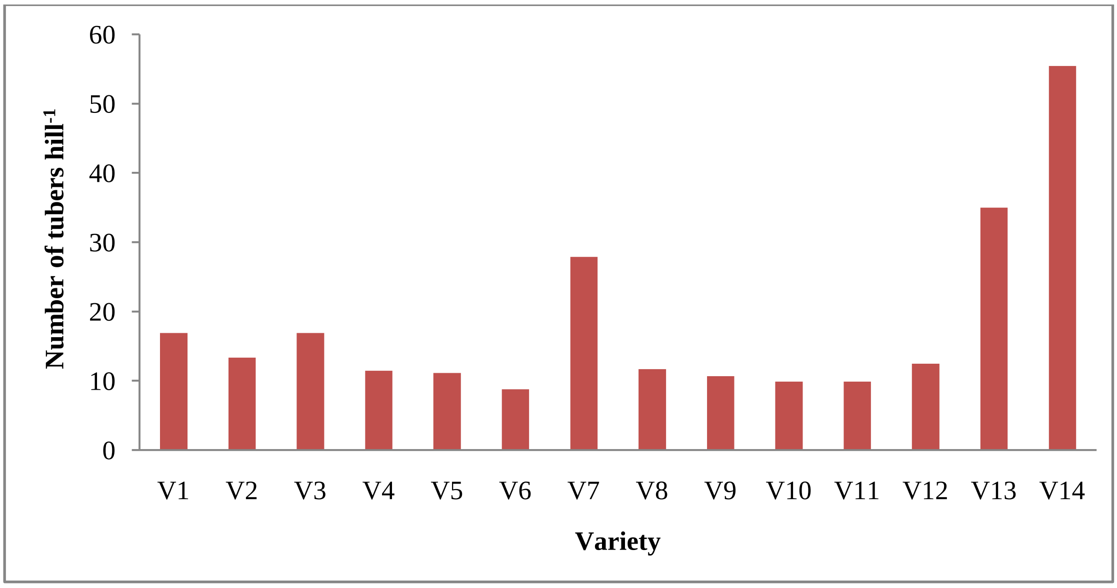

Figure 17. Effect of varieties on number of tubers hill^{-1} (SE value = 0.79)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu.

4.2.1.2 Effect of As levels

Number of tubers hill^{-1} significantly influenced by different As levels (Appendix IX and Figure 18). Figure 18 exhibited that number of tubers hill^{-1} increased with increasing As levels though As_0 and As_1 showed similar results. The maximum number of tubers hill^{-1} (20.90) was produced from the 50 mg As kg^{-1} soil (As_2) whereas, the minimum (16.19) was counted from the control (As_0) which was statistically similar (16.76) with 25 mg As kg^{-1} soil (As_1).

Present study showed that tuber numbers increased with increasing As levels but drastically reduced the size of tuber. Thus the reduced sized tuber hampered on total yield of tuber. This variation might be due to genetical characters of different potato varieties.

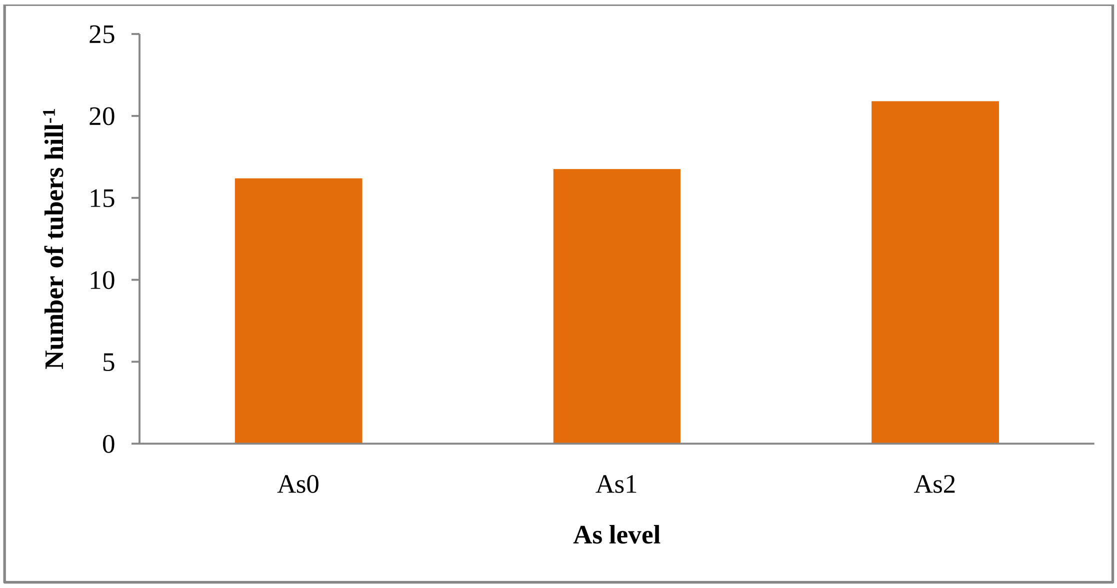

Figure 18. Effect of As levels on number of tubers hill^{-1} (SE value = 0.37)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.1.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels showed significant variation in respect of number of tubers hill^{-1} (Appendix IX and Table 9). The maximum number of tubers hill^{-1} (60.00) was recorded from the combination of 'Jam Alu' and 50 mg As kg^{-1} soil whereas, the minimum (7.00) was recorded from the combination of 'Courage' and control (As_0) which was statistically similar (, , , , 9.00 and 9.33, respectively) with V_6As_1 (7.67), $V_{11}As_0$ (8.00), $V_{11}As_1$ (8.67), $V_{10}As_0$ (8.67), $V_{10}As_1$ (9.00), V_4As_0 (9.33) and V_5As_0 (9.33).

Table 9. Interaction effect of varieties and As levels on yield of tuber, number of tuber hill^{-1} and average weight of tuber

Variety× As level	Yield of tuber plant^{-1} (g)	Number of tubers hill^{-1}	Average tuber weight (g)
V_1 As_0	442.1 a-c	15.67 g	28.40 g-i
V_1 As_1	436.1a-d	16.00 g	27.53 hi
V_1 As_2	346.0 i-l	19.00 f	18.24 k
V_2 As_0	405.9 b-g	12.00 j-n	33.87 ef
V_2 As_1	399.0 c-h	12.33 j-m	32.78 e-g
V_2 As_2	305.0 l-o	15.67 g	19.65 k
V_3 As_0	426.0 a-e	15.67 g	27.35 hi
V_3 As_1	421.4 a-f	16.00 g	26.39 i
V_3 As_2	336.4 k-n	19.00 f	17.81 k
V_4 As_0	292.2 n-q	9.33 n-s	31.17 f-h
V_4 As_1	286.2 o-q	10.00 m-r	28.49 g-i
V_4 As_2	196.8 tu	15.00 g-i	13.11 l
V_5 As_0	365.3 g-k	9.33 n-s	39.71 cd
V_5 As_1	359.4 g-k	10.00 m-r	36.80 de
V_5 As_2	284.6 o-r	14.00 g-k	20.36 k
V_6 As_0	340.3 j-m	7.00 s	48.94 a
V_6 As_1	334.8 k-n	7.67 rs	44.41 b
V_6 As_2	254.3 p-r	11.67 k-o	21.86 jk
V_7 As_0	295.0 m-p	25.67 e	11.51 lm
V_7 As_1	290.8 n-q	26.33 e	11.08 lm
V_7 As_2	202.5 s-u	31.67 d	6.397 n
V_8 As_0	392.2 d-i	10.00 m-r	39.29 d
V_8 As_1	386.3 e-j	10.67 l-q	36.34 de
V_8 As_2	300.5 l-p	14.33 g-j	21.00 jk
V_9 As_0	454.8 a	9.67 n-r	47.14 ab
V_9 As_1	448.8 ab	9.67 m-r	46.51 ab
V_9 As_2	374.9 f-k	12.67 i-l	29.62 f-i
V_{10} As_0	395.7 c-h	8.67 p-s	45.66 ab
V_{10} As_1	392.0 d-i	9.00 o-s	43.64 bc
V_{10} As_2	302.6 l-p	12.00 j-n	25.24 ij
V_{11} As_0	167.3 u	8.00 q-s	21.04 jk
V_{11} As_1	161.4 u	8.67 p-s	18.90 k
V_{11} As_2	86.01 v	13.00 h-l	6.610 n
V_{12} As_0	362.2 g-k	10.67 l-q	34.12 ef
V_{12} As_1	356.3 h-k	11.33 l-p	31.51 f-h
V_{12} As_2	274.1 o-r	15.33 gh	17.88 k
V_{13} As_0	245.0 q-s	32.33 d	7.577 mn
V_{13} As_1	239.2 r-t	33.33 d	7.177 mn
V_{13} As_2	163.9 u	39.33 c	4.163 no
V_{14} As_0	101.0 v	52.67 b	1.920 o
V_{14} As_1	95.90 v	53.67 b	1.787 o
V_{14} As_2	34.50 w	60.00 a	0.5733 o
SE value	14.69	0.79	1.45
Level of significance	**	**	**
CV (%)	8.38	7.67	10.19

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7- BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.2 Yield of tuber plant^{-1}

4.2.2.1 Effect of varieties

Variety had significant effect on the yield of tuber plant^{-1} (Appendix IX and Figure 19). The highest tuber yield plant^{-1} (426.2 g) was obtained from the variety 'Felsina' which was statistically similar with 'Diamant' (408.10 g) and 'Asterix' (394.60 g) while the minimum (77.15 g) was found from the 'Jam Alu'. The yields of different cultivars of potato were significantly different from each other reported by Kundu *et al.* (2012). Similar trend of yield performance was also reported by Hossain (2011), Dhar *et al.* (2009) and Das (2006). The probable reason for variation in yield due to the heredity of the variety, difference in agro-ecological condition and soils of the experimental site.

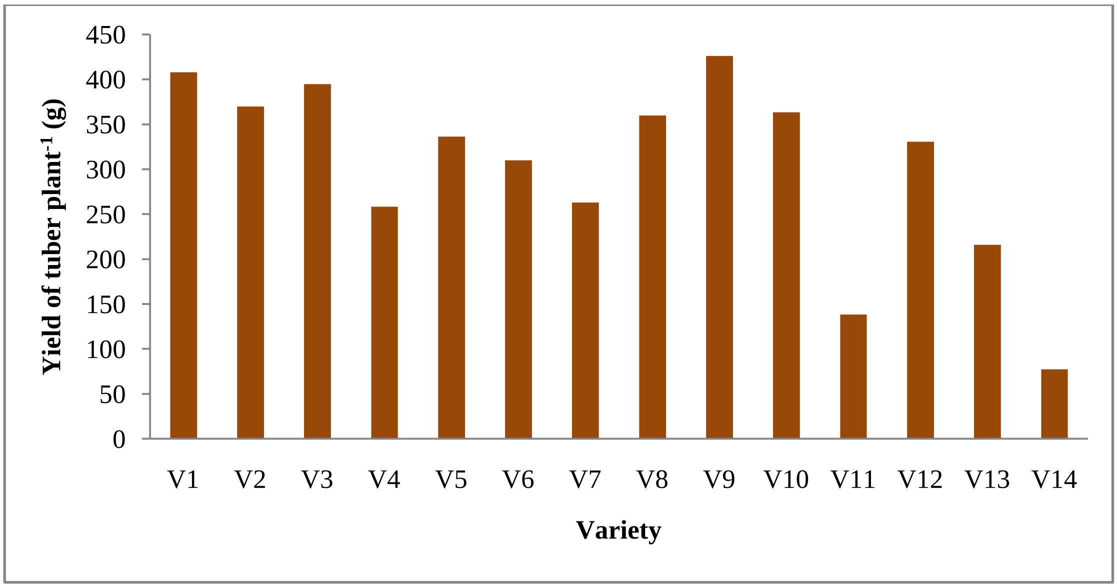

Figure 19. Effect of varieties on yield of tuber plant^{-1} (SE value = 14.69)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.2.2.2 Effect of As levels

Yield of tuber was significantly affected by different As levels (Appendix IX and Figure 20). Figure 20 exhibited that yield of tuber plant^{-1} decreased with increasing As levels though As_0 and As_1 showed similar results. The highest tuber yield plant^{-1} (334.60 g) was recorded from the control (As_0) which was statistically similar with 25 mg As kg^{-1} soil (As_1) (329.10 g) and the minimum (247.30 g) was recorded from the 50 mg As kg^{-1} soil (As_2). The decrease in yield was caused by increasing levels of heavy metals. This is in agreement with the finding of Ducsay (2000). He reported that phytotoxic effect of heavy metals on plants, which decrease their yields and quality. Carbonell-Barrachina *et al.* (1998) and Gulz (1999) observed that yield increases due to small additions of As for corn, potatoes, rye and wheat. Two possibilities exist for growth stimulation by As: first, stimulation of plant systems by small amount of As, since other pesticides, such as 2, 4-D, stimulate plant growth at sub-lethal dose levels (Woolson *et al*., 1971); second, displacement of phosphate ions from the soil by arsenate ions, with the resultant increase of phosphate availability (Jacobs *et al.,* 1970). In the present experiment, application of 25 mg As kg^{-1} soil did not show harmful effect on the most yield contributing characters compared to control.

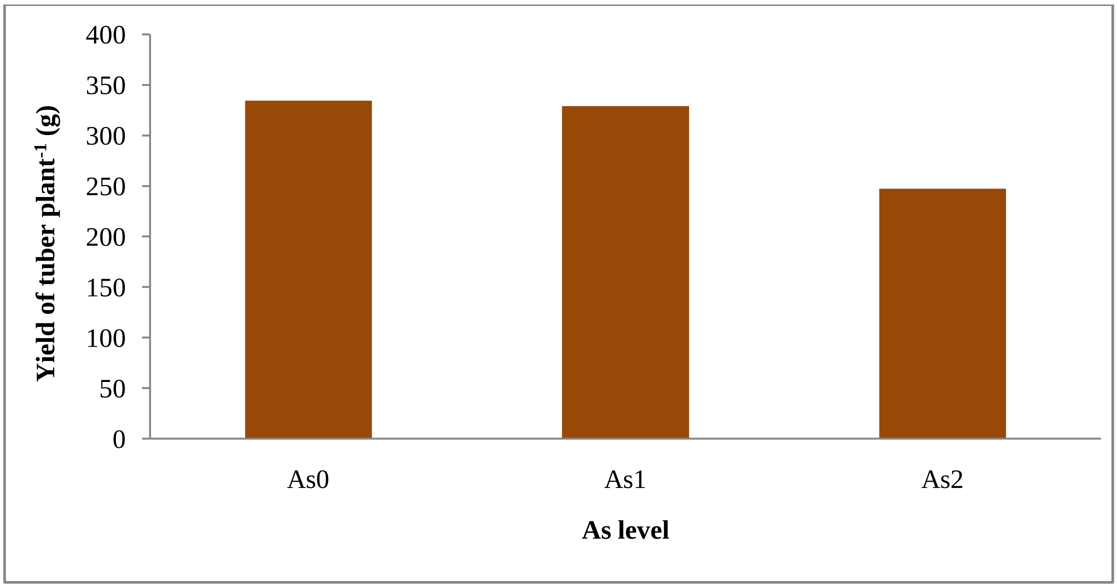

Figure 20. Effect of As levels on yield of tuber plant^{-1} (SE value = 6.80)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.2.3 Interaction effect of varieties and As levels

Interaction between varieties and As levels played an important role for promoting the yield. Yield of tuber plant^{-1} was significantly influenced by the interaction effect of varieties and As levels (Appendix IX and Table 9). Among the treatments, the highest yield of tuber plant^{-1} was observed in 'Felsina' with control (454.80 g), which was statistically similar (448.80, 442.10, 436.10, 426.00 and 421.40 g, respectively) with V_9As_1 ('Felsina' and 25 mg As kg^{-1} soil), V_1As_0 ('Diamant' and control), V_1As_1 ('Diamant' and 25 mg As kg^{-1} soil), V_3As_0 ('Asterix' and control) and V_3As_1 ('Asterix' and 25 mg As kg^{-1} soil) whereas, the minimum (34.50 g) was found from the 'Jam Alu' with 50 mg As kg^{-1} soil.

4.2.1 Average tuber weight (g)

4.2.1.1 Effect of varieties

The average tuber weight varied significantly due to different varieties (Appendix IX and Figure 21). The maximum average tuber weight (41.09 g) was recorded from the 'Felsina' variety which was statistically similar with 'Courage' (38.40 g) and 'Laura' (38.18 g) whereas, the minimum (1.427 g) was obtained from the 'Jam Alu' variety.

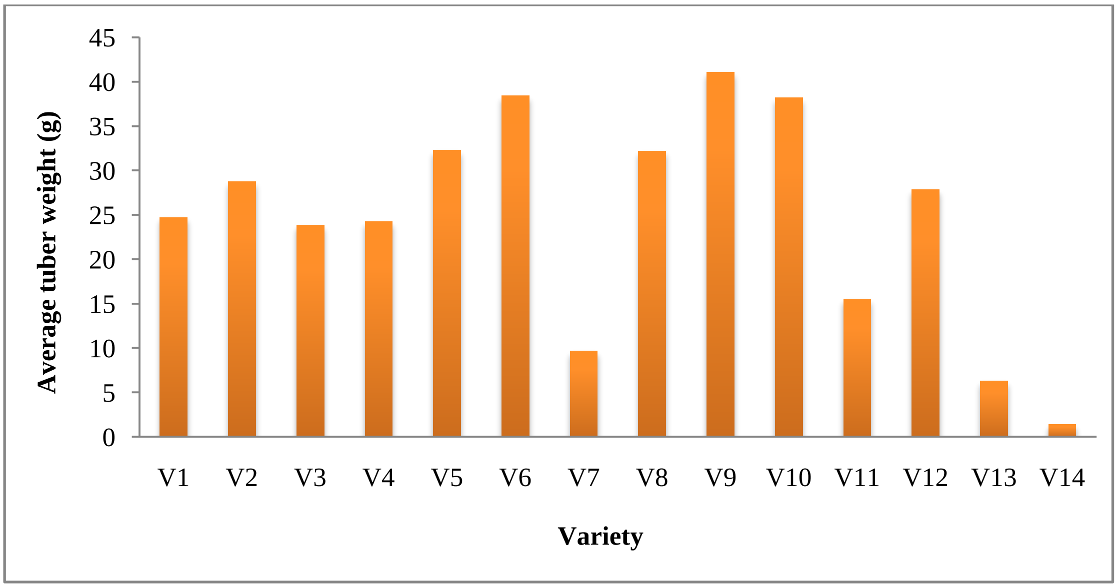

Figure 21. Effect of varieties on average weight of tuber (SE value = 1.45)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.2.3.2 Effect of As levels

The average tuber weight significantly affected by the different As levels (Appendix IX and Figure 22). Figure 22 exhibited that average tuber weight decreased with increasing As levels though As_0 and As_1 showed similar results. The highest average tuber weight (29.84 g) was recorded from the control (As_0) treatment and it was statistically similar (28.10 g) with treatment 25 mg As kg^{-1} soil (As_1) and the lowest (15.90 g) was recorded from the 50 mg As kg^{-1} soil (As_2).

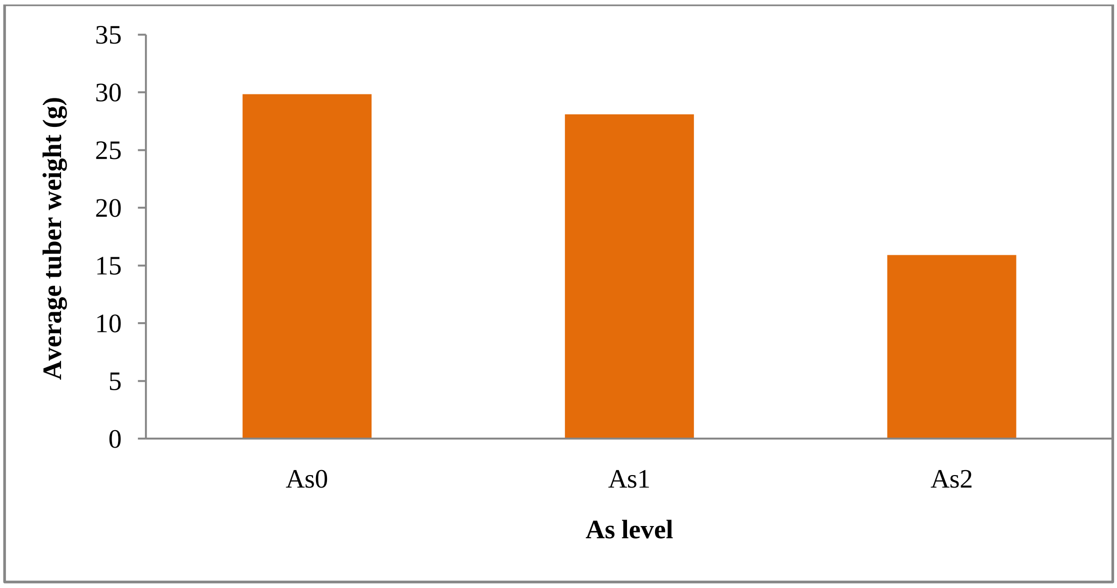

Figure 22. Effect of As levels on average weight of tuber (SE value = 0.67)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.3.3 Interaction effect of varieties and As levels

Interaction of varieties and As levels had significant effect on average tuber weight (Appendix IX and Table 9). The maximum average tuber weight (48.94 g) was recorded from the combination of 'Courage' with control (As_0) which was statistically similar with V_9As_0 (47.14 g), V_9As_1 (46.51 g) and $V_{10}As_0$ (45.66 g) whereas, the minimum (0.5733 g) was recorded from the combination of 'Jam Alu' with 50 mg As kg^{-1} soil and it was statistically similar with $V_{14}As_1$ (1.787 g), $V_{14}As_0$ (1.920 g) and $V_{13}As_2$ (4.163 g) treatment combinations.

4.2.4 Grading of tuber (% by number)

4.2.4.1 Effect of varieties

Variety had significant effect on grading of tuber (% by number) (Appendix X and Figure 23). ‘Laura’ produced the highest percentage (43.56) of large tubers (>55 mm) whereas, the lowest (2.346 %) were produced by ‘Quincy’ which was statistically similar with varieties ‘Granola’ (4.976 %), ‘Asterix’ (6.857 %), ‘Sagitta’ (9.373 %) and ‘Courage’ (9.806 %). Variety ‘Lady Rosetta’, ‘BARI TPS-1’, ‘Rumana’, ‘Jam Alu’ did not produce any large (>55 mm) tuber. In case of 45-55 mm, ‘Asterix’ produced the highest tuber number (41.27 %) which was statistically similar with ‘Lady Rosetta’ (40.48 %) and ‘Courage’ (31.07 %) whereas, the lowest (3.098 %) was produced by ‘BARI TPS-1’ which was statistically similar with ‘Laura’ (11.31 %). ‘Rumana’ and ‘Jam Alu’ did not produce any 45-55 mm size tuber. In case of 28-45 mm, the highest grade of tuber number (46.29 %) was produced by ‘Quincy’ which was statistically similar with ‘BARI TPS-1’ (44.11 %), ‘Lady Rosetta’ (38.94 %), ‘Granola’ (37.48 %) and ‘Diamant’ (34.35 %) while the ‘Jam Alu’ produced the lowest (4.346 %). In case of under sized tubers (<28 mm), ‘Jam Alu’ produced the highest grade of tuber number (95.65 %) and ‘Lady Rosetta’ produced the lowest grade of tuber number (20.58 %) which was statistically similar with ‘Diamant’ (23.43 %), ‘Meridian’ (24.47 %), ‘Laura’ (27.11 %), ‘Felsina’ (29.57 %), ‘Granola’ (29.82 %), ‘Courage’ (30.63 %) and ‘Asterix’ (32.18 %).

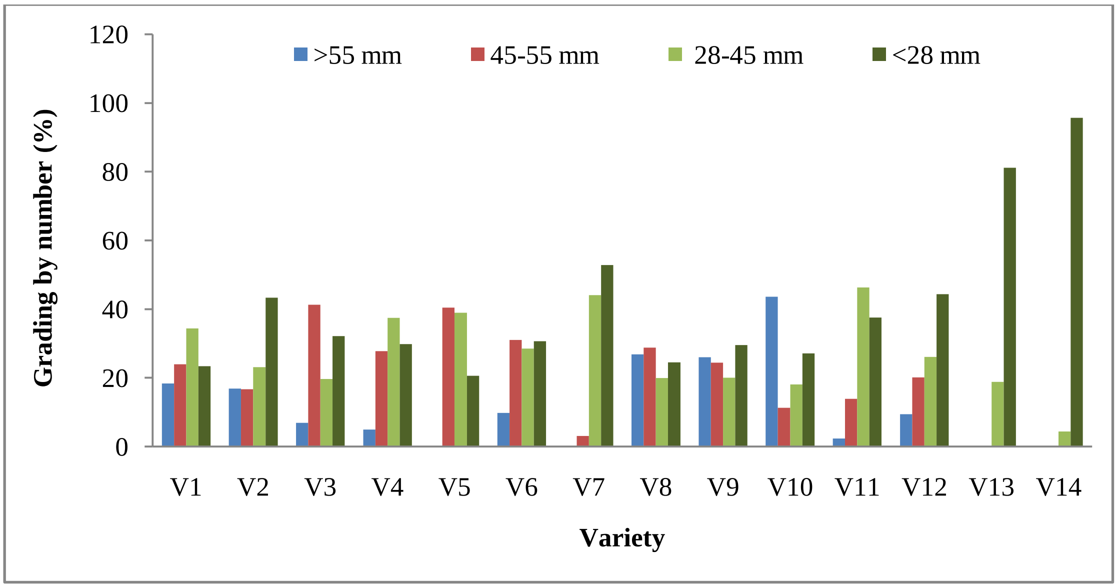

Figure 23. Effect of varieties on grading of tuber (% by number) (SE value = 3.30, 4.01, 4.80 and 4.67 at >55, 45-55, 28-45and <28 mm, respectively)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.2.4.2 Effect of As levels

Grading of tuber (% by number) was also influenced by different As levels (Appendix X and Figure 24). In case of >55 mm and 45-55 mm, the maximum grade of tuber number (14.83 and 23.69 %, respectively) was found from the control (As_0) treatment which was statistically similar (14.34 and 22.61 %, respectively) with 25 mg As kg^{-1} soil (As_1). In case of 28-45 mm, the highest percentage of tuber number (29.24) was produced by control (As_0) which was statistically similar (27.71 and 24.41 %, respectively) with 25 mg As kg^{-1} soil (As_1) and 50 mg As kg^{-1} soil (As_2). In case of under sized tubers (<28 mm), 50 mg As kg^{-1} soil (As_2) produced the maximum number of tuber (55.13 %) and the lowest (32.23 %) was produced by control (As_0) treatment which was followed by 25 mg As kg^{-1} soil (As_1) (35.34 %). Present experiment showed that tuber size decreases with increasing As level.

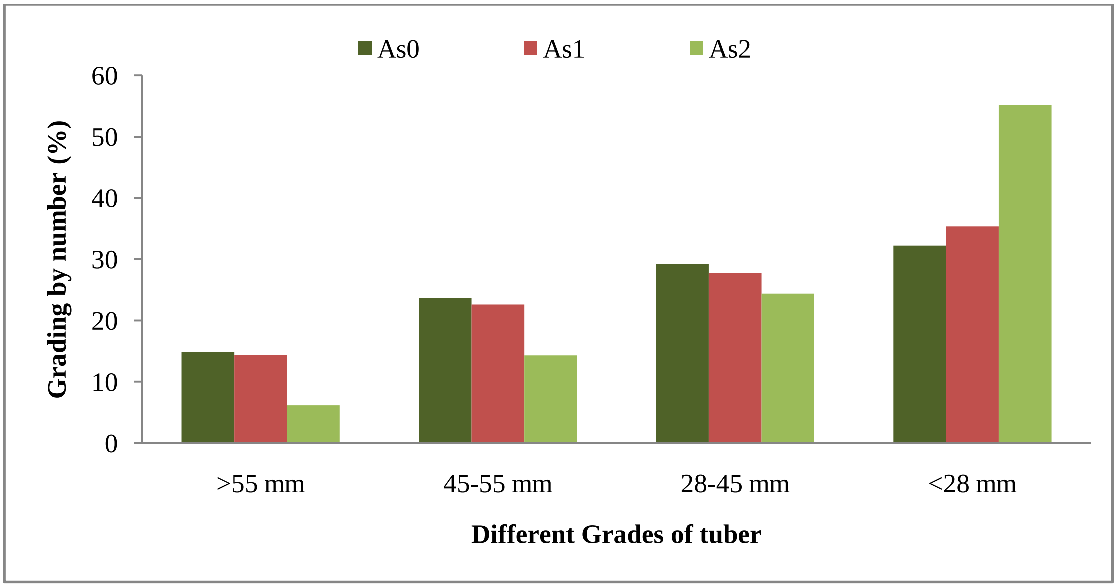

Figure 24. Effect of As levels on grading of tuber (% by number) (SE value = 1.53, 1.86, 2.22 and 2.16 at >55, 45-55, 28-45and <28 mm, respectively)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.4.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the grading of tuber (% by number) (Appendix X and Table 10). In case of large tuber (>55 mm), the highest grade of tuber number (53.71 %) was produced by combinations of 'Laura' with control which was statistically similar (51.85 %) with $V_{10}As_1$ and the lowest (2.083 %) from the combination of 'Granola' with 50 mg As kg^{-1} soil which was statistically similar with V_6As_2 (2.563 %), $V_{11}As_1$ (3.333 %), $V_{11}As_0$ (3.703 %), V_3As_2 (3.713 %), $V_{12}As_2$ (4.340 %), V_4As_1 (6.110 %), V_2As_2 (6.127 %), V_4As_0 (6.733 %), V_3As_1 (8.350 %) and V_3As_0 (8.507 %). Treatment combinations of V_5As_0, V_5As_1, V_5As_2, V_7As_0, V_7As_1, V_7As_2, $V_{11}As_2$, $V_{13}As_0$, $V_{13}As_1$, $V_{13}As_2$, $V_{14}As_0$, $V_{14}As_1$ and $V_{14}As_2$ did not produce any large (>55 mm) tuber. In case of 45-55 mm, the highest grade of tuber number (50.34 %) was produced by combinations of 'Lady Rosetta' with control which was statistically similar with V_5As_1 (47.22 %), V_3As_0 (46.64

%), V_3As_1 (45.69 %) and V_6As_0 (39.29 %) while treatment combination of 'BARI TPS-1' with 50 mg As kg^{-1} soil showed the lowest grade (2.020 %) of tuber number which was statistically similar with V_7As_1 (3.570 %), V_7As_0 (3.703 %), $V_{11}As_2$ (10.10 %), $V_{10}As_2$ (11.15 %), $V_{10}As_1$ (11.20 %), V_4As_2 (11.29 %), $V_{10}As_0$ (11.57 %). However, $V_{13}As_0$, $V_{13}As_1$ and $V_{13}As_2$, $V_{14}As_0$, $V_{14}As_1$ and $V_{14}As_2$ combinations did not produce any (45-55 mm) tuber. In case of 28-45 mm, the highest (54.69 %) of tuber number was produced by combinations of 'Quincy' with control (As_0) which was statistically similar with $V_{11}As_1$ (50.90 %), V_7As_0 (46.71 %), V_5As_0 (46.63 %), V_7As_1 (45.57 %), V_5As_1 (43.89 %), V_4As_0 (42.93 %), V_4As_1 (40.56 %) and V_7As_2 (40.04 %) while the combinations of 'Jam Alu' with 25 mg As kg^{-1} soil showed the lowest number of tuber (3.717 %) which was statistically similar with $V_{14}As_0$ (3.790 %), $V_{14}As_2$ (5.530 %), $V_{13}As_2$ (16.04 %), $V_{10}As_2$ (16.49 %), V_8As_1 (17.78 %), V_9As_2 (18.59 %), $V_{10}As_1$ (18.61 %), V_3As_1 (18.80 %), $V_{10}As_0$ (18.98 %), V_8As_0 (19.16 %), V_3As_0 (19.28 %) and $V_{13}As_1$ (19.96 %). In case of under sized tubers (<28 mm), the highest percentage of tuber number (96.28) was found from the combinations of 'Jam Alu' with 25 mg As kg^{-1} soil which was statistically similar with $V_{14}As_0$ (96.21 %), $V_{14}As_2$ (94.47 %) and $V_{13}As_2$ (83.96 %) whereas, the the lowest (3.030 %) was found from the combinations of 'Lady Rosetta' with control (As_0) followed by with V_5As_1 (8.890 %), V_4As_0 (13.47 %), V_6As_0 (13.89 %), V_8As_0 (14.07 %), $V_{10}As_0$ (15.74 %), V_1As_0 (16.90 %), V_4As_1 (18.33 %), $V_{10}As_1$ (18.33 %), V_1As_1 (18.42 %).

Table 10. Interaction effect of varieties and As levels on grading of tuber (% by number)

Variety× As level	Grading of tuber (%by number)			
	>55 mm	45-55 mm	28-45 mm	<28 mm
V_1 As_0	21.53 d-f	28.08 c-i	33.49 c-h	16.90 k-n
V_1 As_1	21.10 d-f	27.64 c-i	32.84 c-j	18.42 k-n
V_1 As_2	12.31 f-i	16.00 i-k	36.72 b-g	34.97 f-j
V_2 As_0	22.34 c-f	16.49 i-k	24.65 f-j	36.52 e-i
V_2 As_1	22.19 c-f	15.73 i-k	21.54 g-k	40.55 d-h
V_2 As_2	6.127 g-j	17.91 h-j	23.07 g-j	52.89 cd
V_3 As_0	8.507 g-j	46.64 ab	19.28 h-l	25.58 h-l
V_3 As_1	8.350 g-j	45.69 ab	18.80 h-l	27.16 h-l
V_3 As_2	3.713 h-j	31.48 c-g	21.01 g-k	43.80 c-g
V_4 As_0	6.733 g-j	36.87 b-d	42.93 a-e	13.47 l-n
V_4 As_1	6.110 g-j	35.00 b-e	40.56 a-f	18.33 k-n
V_4 As_2	2.083 j	11.29 j-m	28.97 e-j	57.66 c
V_5 As_0	-	50.34 a	46.63 a-c	3.030 n
V_5 As_1	-	47.22 ab	43.89 a-e	8.890 mn
V_5 As_2	-	23.88 d-j	26.29 f-j	49.83 c-f
V_6 As_0	13.89 f-h	39.29 a-c	32.94 c-i	13.89 l-n
V_6 As_1	12.96 f-i	36.57 b-d	29.63 d-j	20.83 j-m
V_6 As_2	2.563 ij	17.35 h-j	22.90 g-j	57.18 c
V_7 As_0	0.00	3.703 k-m	46.71 a-c	49.59 c-f
V_7 As_1	0.00	3.570 k-m	45.57 a-d	50.86 c-e
V_7 As_2	0.00	2.020 m	40.04 a-f	57.94 c
V_8 As_0	33.84 b	32.93 c-f	19.16 h-l	14.07 l-n
V_8 As_1	32.22 bc	30.56 c-h	17.78 h-l	19.44 k-m
V_8 As_2	14.35 f-h	22.87 e-j	22.87 g-j	39.90 d-i
V_9 As_0	31.11 b-d	27.41 c-i	20.74 g-k	20.74 j-m
V_9 As_1	31.11 b-d	27.41 c-i	20.74 g-k	20.74 j-m
V_9 As_2	15.81 e-g	18.38 g-j	18.59 h-l	47.22 c-f
V_{10} As_0	53.71 a	11.57 j-m	18.98 h-l	15.74 k-n
V_{10} As_1	51.85 a	11.20 j-m	18.61 h-l	18.33 k-n
V_{10} As_2	25.12 b-e	11.15 j-m	16.49 i-l	47.24 c-f
V_{11} As_0	3.703 h-j	16.34 i-k	54.69 a	25.26 i-l
V_{11} As_1	3.333 h-j	15.13 i-l	50.90 ab	30.63 g-k
V_{11} As_2	-	10.10 j-m	33.27 c-i	56.62 c
V_{12} As_0	12.29 f-i	22.05 e-j	24.83 f-j	40.82 d-h
V_{12} As_1	11.49 f-j	20.88 f-j	23.45 g-j	44.17 c-g
V_{12} As_2	4.340 h-j	17.57 h-j	30.02 d-j	48.07 c-f
V_{13} As_0	-	-	20.57 g-k	79.43 b
V_{13} As_1	-	-	19.96 h-l	80.05 b
V_{13} As_2	-	-	16.04 j-l	83.96 ab
V_{14} As_0	-	-	3.790 l	96.21 a
V_{14} As_1	-	-	3.717 l	96.28 a
V_{14} As_2	-	-	5.530 kl	94.47 a
SE value	3.30	4.00	4.80	4.67
Level of significance	*	*	**	**
CV (%)	48.57	34.37	30.66	19.76

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

**, * indicate 1% and 5% level of significance, respectively

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7- BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.5 Marketable yield plant^{-1}

4.2.5.1 Effect of varieties

Variety had significant effect on marketable yield of tuber plant^{-1} (Appendix XI and Table 11). Highest marketable yield plant^{-1} (381.5 g) was obtained from the 'Felsina' variety and the lowest (37.58 g) was obtained from 'Rumana'. 'Jam Alu' did not produce any marketable tuber.

Table 11. Effect of varieties on marketable yield plant^{-1}, marketable yield (% by number), marketable yield (% by weight), non-marketable yield plant^{-1}, non-marketable yield (% by number) and non-marketable yield (% by weight)

Variety	Marketable yield plant^{-1} (g)	Marketable yield		Non-marketable yield plant^{-1} (g)	Non-marketable yield	
		% by number	% by weight		% by number	% by weight
V_1	282.2 b-d	58.87 ab	68.19 de	125.9 b	41.13 de	31.81 de
V_2	247.0 d	55.31 ab	65.57 de	123.0 b	44.69 de	34.43 de
V_3	252.0 cd	58.56 ab	63.09 e	142.6 b	41.44 de	36.91 d
V_4	193.8 e	57.79 ab	72.32 cd	64.62 cd	42.21 de	27.68 ef
V_5	301.7 bc	55.63 ab	88.94 a	34.68 e	44.37 de	11.06 h
V_6	264.7 cd	50.11 b	84.43 ab	45.11 de	49.89 d	15.57 gh
V_7	89.70 f	13.92 d	31.45 f	173.1 a	86.08 b	68.55 c
V_8	282.7 b-d	53.47 ab	77.33 bc	76.95 c	46.53 de	22.67 fg
V_9	381.5 a	61.70 a	89.16 a	44.68 de	38.30 e	10.84 h
V_{10}	318.5 b	54.34 ab	86.93 a	44.93 de	45.66 de	13.07 h
V_{11}	92.28 f	40.12 c	62.71 e	45.95 de	59.88 c	37.29 d
V_{12}	287.9 b-d	59.65 ab	86.51 a	42.93 de	40.35 de	13.49 h
V_{13}	37.58 g	6.243 d	16.42 g	178.5 a	93.76 ab	83.58 b
V_{14}	-	-	-	77.06 c	100.0 a	100.0 a
SE value	15.81	8.93	2.65	7.84	3.18	2.65
Level of significance	**	**	**	**	**	**
CV (%)	12.65	12.31	7.20	15.58	9.94	12.68

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

** indicate 1% level of significance

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.2.5.2 Effect of As levels

Marketable yield plant^{-1} was also influenced by different As levels (Appendix XI and Table 12). Marketable yield of tuber plant^{-1} decreased with increasing As levels though As_0 and As_1 showed similar results. The maximum marketable yield plant^{-1} (256.8 g) was recorded from the control (As_0) treatment which was statistically similar (243.3 g) with 25 mg As kg^{-1} soil (As_1). The lowest marketable yield plant^{-1} (149.4 g) was recorded from the 50 mg As kg^{-1} soil (As_2) treatment.

Table 12. Effect of As levels on marketable yield plant^{-1}, marketable yield (% by number), marketable yield (% by weight), non-marketable yield plant^{-1}, non-marketable yield (% by number) and non-marketable yield (% by weight)

As level	Marketable yield plant^{-1} (g)	Marketable yield		Non-marketable yield plant^{-1} (g)	Non-marketable yield	
		% by number	% by weight		% by number	% by weight
As_0	256.8 a	58.37 a	70.85 a	77.78 b	41.63 b	29.15 b
As_1	243.3 a	55.85 a	67.90 a	85.78 b	44.15 b	32.10 b
As_2	149.4 b	19.86 b	52.62 b	97.87 a	80.14 a	47.38 a
SE value	7.318	1.470	1.227	3.629	1.470	1.227
Level of significance	**	**	**	**	**	**
CV (%)	12.65	12.31	7.20	15.58	9.94	12.68

In a column means having similar letter (s) are statistically similar and those having dissimilar letter (s) differ significantly by DMRT at 0.05 level of probability
** indicate 1% level of significance

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.5.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced to produce marketable yield plant^{-1} (Appendix XI and Table 13). The highest marketable yield plant^{-1} (422.3 g) was obtained from the combinations of 'Felsina' with control (As_0) which was statistically similar with V_9As_1 (410.5 g) whereas, the lowest (15.80 g) marketable yield plant^{-1} was obtained from the combination of 'Rumana' with 50 mg As kg^{-1} soil and it was statistically similar with V_7As_2 (17.82 g), $V_{11}As_2$ (35.96 g) and $V_{13}As_1$ (39.93 g). No marketable yield was obtained from the combinations of $V_{14}As_0$, $V_{14}As_1$ and $V_{14}As_2$.

Table 13. Interaction effect of varieties and As levels on marketable yield plant^{-1}, marketable yield (% by number), marketable yield (% by weight), non-marketable yield plant^{-1}, non-marketable yield (% by number) and non-marketable yield (% by weight)

Variety× As level	Marketable yield plant^{-1} (g)	Marketable yield		Non-marketable yield plant^{-1} (g)	Non-marketable yield	
		% by number	% by weight		% by number	% by weight
V_1 As_0	335.8 b-d	70.55 ab	75.87 f-i	106.3 h-j	29.45 ij	24.13 i-l
V_1 As_1	314.0 b-f	69.25 ab	71.90 h-j	122.1 g-i	30.75 ij	28.10 h-j
V_1 As_2	196.7 h-j	36.82 e	56.80 k	149.3 d-f	63.18 f	43.20 g
V_2 As_0	300.5 c-f	69.33 ab	74.03 g-j	105.3 h-j	30.67 ij	25.97 h-k
V_2 As_1	277.6 fg	68.69 ab	69.54 ij	121.4 g-i	31.31 ij	30.46 hi
V_2 As_2	162.7 j-l	27.91 e-g	53.12 k	142.3 e-g	72.09 d-f	46.88 g
V_3 As_0	300.4 c-f	70.26 ab	70.56 h-j	125.6 f-h	29.74 ij	29.44 h-j
V_3 As_1	280.9 e-g	68.67 ab	66.72 j	140.5 e-g	31.33 ij	33.28 h
V_3 As_2	174.6 jk	36.74 e	51.99 kl	161.8 c-e	63.26 f	48.01 fg
V_4 As_0	240.7 gh	78.20 a	81.50 e-g	51.49 l-q	21.80 j	18.50 k-m
V_4 As_1	229.2 hi	73.33 ab	79.16 f-h	56.98 l-p	26.67 ij	20.84 j-l
V_4 As_2	111.4 m	21.85 gh	56.32 k	85.38 jk	78.15 cd	43.68 g
V_5 As_0	345.5 b-d	75.17 ab	94.59 a	19.77 r	24.83 ij	5.410 q
V_5 As_1	333.8 b-e	70.56 ab	92.90 a	25.54 qr	29.44 ij	7.103 q
V_5 As_2	225.9 hi	21.16 gh	79.33 f-h	58.72 l-o	78.84 cd	20.67 j-l
V_6 As_0	308.9 c-f	71.03 ab	90.77 a-c	31.34 p-r	28.97 ij	9.227 o-q
V_6 As_1	298.0 d-f	65.28 bc	89.01 a-e	36.80 n-r	34.72 hi	10.99 m-q
V_6 As_2	187.1 ij	14.02 hi	73.51 g-j	67.18 kl	85.98 bc	26.49 h-k
V_7 As_0	133.6 k-m	19.53 gh	45.25 lm	161.5 c-e	80.47 cd	54.75 ef
V_7 As_1	117.7 lm	19.07 gh	40.45 m	173.1 b-d	80.93 cd	59.55 e
V_7 As_2	17.82 n	3.163 j	8.650 p	184.7 a-c	96.84 a	91.35 b
V_8 As_0	328.7 b-f	69.80 ab	83.61 b-f	63.50 k-m	30.20 ij	16.39 l-p
V_8 As_1	317.3 b-f	65.56 bc	81.91 d-g	68.98 kl	34.44 hi	18.09 k-n
V_8 As_2	202.2 h-j	25.07 fg	66.47 j	98.38 ij	74.93 de	33.53 h
V_9 As_0	422.3 a	75.56 ab	92.87 a	32.48 o-r	24.44 ij	7.133 q
V_9 As_1	410.5 a	75.56 ab	91.48 a-c	38.28 m-r	24.44 ij	8.523 o-q
V_9 As_2	311.7 b-f	33.97 ef	83.13 c-f	63.28 k-m	66.03 ef	16.87 l-o
V_{10} As_0	363.3 b	73.15 ab	91.78 a-c	32.43 o-r	26.85 ij	8.223 o-q
V_{10} As_1	353.3 bc	70.56 ab	90.11 a-d	38.64 m-r	29.44 ij	9.890 n-q
V_{10} As_2	238.9 gh	19.31 gh	78.91 f-h	63.71 k-m	80.69 cd	21.09 j-l
V_{11} As_0	127.0 k-m	58.40 cd	75.93 f-i	40.26 m-r	41.60 gh	24.07 i-l
V_{11} As_1	113.9 lm	54.23 d	70.55 h-j	47.54 l-q	45.77 g	29.45 h-j
V_{11} As_2	35.96 n	7.720 ij	41.63 m	50.06 l-q	92.28 ab	58.37 e
V_{12} As_0	332.0 b-e	77.95 a	91.94 ab	30.16 qr	22.05 j	8.063 pq
V_{12} As_1	320.4 b-f	73.22 ab	90.22 a-d	35.89 o-r	26.78 ij	9.783 n-q
V_{12} As_2	211.3 h-j	27.80 e-g	77.38 f-i	62.74 k-n	72.20 d-f	22.62 i-l
V_{13} As_0	57.00 n	8.217 ij	23.19 n	188.0 ab	91.79 ab	76.81 d
V_{13} As_1	39.93 n	7.970 ij	16.59 no	199.3 a	92.03 ab	83.41 cd
V_{13} As_2	15.80 n	2.543 j	9.480 op	148.1 ef	97.46 a	90.52 bc

Table 13 (Cont'd).

Variety× As level	Marketable yield (g)	Marketable yield		Non-marketable yield (g)	Non-marketable yield	
		% by number	% by weight		% by number	% by weight
V_{14} As_0	-	-	-	100.8 h-j	100.0 a	100.0 a
V_{14} As_1	-	-	-	95.90 j	100.0 a	100.0 a
V_{14} As_2	-	-	-	34.50 o-r	100.0 a	100.0 a
SE value	15.81	3.18	2.65	7.84	3.18	2.65
Level of significance	*	**	**	**	**	**
CV (%)	12.65	12.31	7.20	15.58	9.94	12.68

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

**, * indicate 1% and 5% level of significance, respectively

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.2.6 Marketable yield (% by number)

4.2.6.1 Effect of varieties

Marketable yield (% by number) significantly affected by different varieties (Appendix XI and Table 11). 'Felsina' produced the highest number of marketable tuber (61.70 %) which was statistically similar with 'Sagitta' (59.65 %), 'Diamant' (58.87 %), 'Asterix' (58.56 %), 'Granola' (57.79 %), 'Lady Rosetta' (55.63 %), 'Cardinal' (55.31 %), 'Laura' (54.34 %) and 'Meridian' (53.47 %) whereas, the lowest (6.243 %) was obtained from 'Rumana'. Variety 'Jam Alu' did not produce any marketable yield (% by number).

4.2.6.2 Effect of As levels

Marketable yield (% by number) was also influenced by different As levels (Appendix XI and Table 12). Marketable yield (% by number) decreased with increasing As levels though As_0 and As_1 showed similar results. The maximum number of marketable tuber (58.37 %) was obtained from the control (As_0) treatment which was statistically similar (55.85 %) with 25 mg As kg^{-1} soil (As_1) while, the minimum (19.86 %) was obtained from the 50 mg As kg^{-1} soil

(As_2). Present experiment showed that marketable tuber number (%) was not statistically affected up to 25 mg As kg^{-1} soil treatment compared to control (As_0) but at higher concentration (50 mg As kg^{-1} soil) it was significantly decreased.

4.2.6.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the marketable yield (% by number) (Appendix XI and Table 13). Results revealed that the combination of 'Granola' with control (As_0) produced the maximum marketable tuber number (78.20 %) which was statistically similar (77.95, 75.56, 75.56, 75.17, 73.33, 73.22, 73.15, 71.03, 70.56, 70.56, 70.55, 70.26, 69.80, 69.33, 69.25, 68.69 and 68.67 %, respectively) with $V_{12}As_0$, V_9As_0, V_9As_1, V_5As_0, V_4As_1, $V_{12}As_1$, $V_{10}As_0$, V_6As_0, V_5As_1, $V_{10}As_1$, V_1As_0, V_3As_0, V_8As_0, V_2As_0, V_1As_1, V_2As_1 and V_3As_1 combinations. The minimum (2.543 %) marketable yield (% by number) was recorded from the combinations of 'Rumana' with 50 mg As kg^{-1} soil which was statistically similar with V_7As_2 (3.163 %), $V_{11}As_2$ (7.720 %), $V_{13}As_1$ (7.970 %) and $V_{13}As_0$ (8.217 %). No marketable yield (% by number) was obtained from the combinations of $V_{14}As_0$, $V_{14}As_1$ and $V_{14}As_2$.

4.2.7 Marketable yield (% by weight)

4.2.7.1 Effect of varieties

Marketable yield (% by weight) was significantly affected by different varieties (Appendix XI and Table 11). The variety 'Felsina' produced the highest marketable tuber weight (89.16 %) of which was statistically similar with 'Lady Rosetta' (88.94 %), 'Laura' (86.93 %), 'Sagitta' (86.51 %) and 'Courage' (84.43 %). The lowest (16.42 %) marketable yield (% by weight) was obtained from 'Rumana'. Marketable yield (% by weight) was not found from 'Jam Alu'.

4.2.7.2 Effect of As levels

Marketable yield (% by weight) was also influenced by different As levels (Appendix XI and Table 12). Table 12 showed that marketable yield (% by weight) decreased with increasing As levels but As_0 and As_1 showed similar results. The highest marketable tuber weight (70.85 %) was found from the control (As_0) treatment which was statistically similar (67.90 %) with 25 mg As kg^{-1} soil (As_1) and the lowest (52.62 %) was recorded from the 50 mg As kg^{-1} soil (As_2) treatment.

4.2.7.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the marketable yield (% by weight) (Appendix XI and Table 13). The highest marketable tuber weight (94.59 %) was obtained from the combination of 'Lady Rosetta' with control which was statistically similar with V_5As_1 (92.90 %), V_9As_0 (92.87 %), $V_{12}As_0$ (91.94 %), $V_{10}As_0$ (91.78 %), V_9As_1 (91.48 %), V_6As_0 (90.77 %), $V_{12}As_1$ (90.22 %), $V_{10}As_1$ (90.11 %) and V_6As_1 (89.01 %) whereas, the lowest (8.650 %) was obtained from the combination of 'BARI TPS-1' with 50 mg As kg^{-1} soil and it was statistically similar with 'Rumana' with 50 mg As kg^{-1} soil (9.480 %). Marketable yield (% by weight) was not found from the combinations of $V_{14}As_0$, $V_{14}As_1$ and $V_{14}As_2$.

4.2.8 Non-marketable yield plant^{-1}

4.2.8.1 Effect of varieties

Variety had significant effect on non-marketable yield plant^{-1} (Appendix XI and Table 11). The highest non-marketable yield plant^{-1} (178.5 g) was produced by the variety 'Rumana' which was statistically similar (173.1 g) with 'BARI TPS-1'. On the contrary, 'Lady Rosetta' produced the lowest non-marketable yield plant^{-1} (34.68 g) and it was statistically similar with 'Sagitta' (42.93 g), 'Felsina' (44.68 g), 'Laura' (44.93 g), 'Courage' (45.11 g) and 'Quincy' (45.95 g).

4.2.8.2 Effect of As levels

Non-marketable yield $plant^{-1}$ was significantly influenced by different As levels (Appendix XI and Table 12). Non-marketable yield $plant^{-1}$ increased with increasing As levels though As_0 and As_1 showed similar results. The maximum non-marketable yield $plant^{-1}$ (97.87 g) was recorded from the 50 mg As kg^{-1} soil (As_2) treatment and the minimum (77.78 g) was counted from the control (As_0) treatment which was statistically similar (85.78 g) with 25 mg As kg^{-1} soil (As_1).

4.2.8.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the non-marketable yield $plant^{-1}$ (Appendix XI and Table 13). The highest non-marketable yield $plant^{-1}$ (199.3 g) was obtained from the combinations of 'Rumana' with 25 mg As kg^{-1} soil which was statistically similar with $V_{13}As_0$ (188.0 g) and V_7As_2 (184.7 g) whereas, the lowest (19.77 g) was obtained from the combination of 'Lady Rosetta' with control (As_0) which was statistically similar with V_5As_1 (25.54 g), $V_{12}As_0$ (30.16 g), V_6As_0 (31.34 g), $V_{10}As_0$ (32.43 g), V_9As_0 (32.48 g), $V_{14}As_2$ (34.50 g), $V_{12}As_1$ (35.89 g), V_6As_1 (36.80 g), V_9As_1 (38.28 g), $V_{10}As_1$ (38.64 g) and $V_{11}As_0$ (40.26 g) combinations.

4.2.9 Non-marketable yield (% by number)

4.2.9.1 Effect of varieties

Non-marketable yield (% by number) significantly influenced by the varieties (Appendix XI and Table 11). 'Jam Alu' produced the highest number of non-marketable tuber (100 %) which was statistically similar (93.76 %) with 'Rumana'. The minimum number of non-marketable tuber (38.30 %) was recorded from the variety 'Felsina' which was statistically similar with 'Sagitta' (40.35 %), 'Diamant' (41.13 %), 'Asterix' (41.44 %), 'Granola' (42.21 %), 'Lady Rosetta' (44.37 %), 'Cardinal' (44.69 %), 'Laura' (45.66 %) and 'Meridian' (46.53 %).

4.2.9.2 Effect of As levels

Non-marketable yield (% by number) varied significantly with different As levels (Appendix XI and Table 12). Table 11 showed that non-marketable yield (% by number) increased with increasing As levels but As_0 and As_1 showed similar results. The maximum non-marketable tuber number (80.14 %) was obtained from the 50 mg As kg^{-1} soil (As_2) while, the minimum (41.63 %) was produced from the control (As_0) treatment which was statistically similar (44.15 %) with 25 mg As kg^{-1} soil (As_1). Present experiment showed that % of non-marketable tuber number increases with increasing As levels.

4.2.9.3 Interaction effect of varieties and As levels

Different potato varieties and different As levels significantly influenced the non-marketable yield (% by number) (Appendix XI and Table 13). The highest % of non-marketable number (100 %) was counted from the combinations of $V_{14}As_0$ ('Jam Alu' and As_0), $V_{14}As_1$ ('Jam Alu' and 25 mg As kg^{-1} soil) and $V_{14}As_2$ ('Jam Alu' and 50 mg As kg^{-1} soil) which was statistically similar with $V_{13}As_2$ (97.46 %), V_7As_2 (96.84 %), $V_{11}As_2$ (92.28 %), $V_{13}As_1$ (92.03 %) and $V_{13}As_0$ (91.79 %) combinations. The minimum non-marketable number (21.80 %) was obtained from the 'Granola' with control (As_0) which was statistically similar with $V_{12}As_0$ (22.05 %), V_9As_0 (24.44%), V_9As_1 (24.44 %), V_5As_0 (24.83 %), V_4As_1 (26.67 %), $V_{12}As_1$ (26.78 %), $V_{10}As_0$ (26.85 %), V_6As_0 (28.97 %), $V_{10}As_1$ (29.44 %), V_5As_1 (29.44 %), V_1As_0 (29.45 %), V_3As_0 (29.74 %), V_8As_0 (30.20 %), V_2As_0 (30.67 %), V_1As_1 (30.75 %), V_2As_1 (31.31 %) and V_3As_1 (31.31 %).

4.2.10 Non-marketable yield (% by weight)

4.2.10.1 Effect of varieties

Non-marketable yield (% by weight) was significantly affected by the varieties (Appendix XI and Table 11). The highest (100 %) non-marketable tuber weight was produced by 'Jam Alu' whereas, the lowest (10.84 %) was obtained from the 'Felsina' which was statistically similar with 'Lady Rosetta' (11.06 %), 'Laura' (13.07 %), 'Sagitta' (13.49 %) and 'Courage' (15.57 %).

4.2.10.2 Effect of As levels

Non-marketable yield (% by weight) was also influenced by different As levels (Appendix XI and Table 12). Non-marketable yield (% by weight) increased with increasing As levels but As_0 and As_1 showed similar results. The highest non-marketable tuber weight (47.38 %) was found from the 50 mg As kg^{-1} soil (As_2) treatment and the lowest (29.15 %) was recorded from the control (As_0) which was statistically similar (32.10 %) with 25 mg As kg^{-1} soil (As_1).

4.2.10.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the non-marketable yield (% by weight) (Appendix XI and Table 13). The highest non-marketable tuber weight (100 %) was obtained from the combinations of $V_{14}As_0$ ('Jam Alu' and As_0), $V_{14}As_1$ ('Jam Alu' and 25 mg As kg^{-1} soil) and $V_{14}As_2$ ('Jam Alu' and 50 mg As kg^{-1} soil) whereas, the lowest (5.410 %) was obtained from the combinations of 'Lady Rosetta' with As_0 which was statistically similar with V_5As_1 (7.103 %), V_9As_0 (7.133 %), $V_{12}As_0$ (8.063 %), $V_{10}As_0$ (8.223 %), V_9As_1 (8.523 %), V_6As_0 (9.227 %), $V_{12}As_1$ (9.783 %), $V_{10}As_1$ (9.890 %) and V_6As_1 (10.99 %).

4.3 Quality characters

4.3.1 Tuber flesh dry matter content (%)

4.3.1.1 Effect of varieties

Tuber flesh dry matter content showed significant variations among the potato varieties (Appendix IX and Figure 25). The maximum dry matter content of tuber flesh (20.59 %) was recorded from the variety 'Lady Rosetta'. The minimum tuber flesh dry matter content (13.53%) was recorded from 'Granola' which was statistically similar with 'Asterix' (14.30 %) and 'Laura' (14.39 %,).

The variation in dry matter content among the potato varieties were also observed by Suyre *et al.* (1975), Lana *et al.* (1970) and Capezio (1987). Variation in tuber dry matter content may be attributed to cultivars inherent difference in the production of total solids. Burton (1966) reported that genetic differences among varieties play a role in their ability to produce high solids when grown on the same test plot. Dry matter content is subjected to the influence of both the environment and genotypes (Miller *et al.*, 1975; Tai and Coleman, 1999).

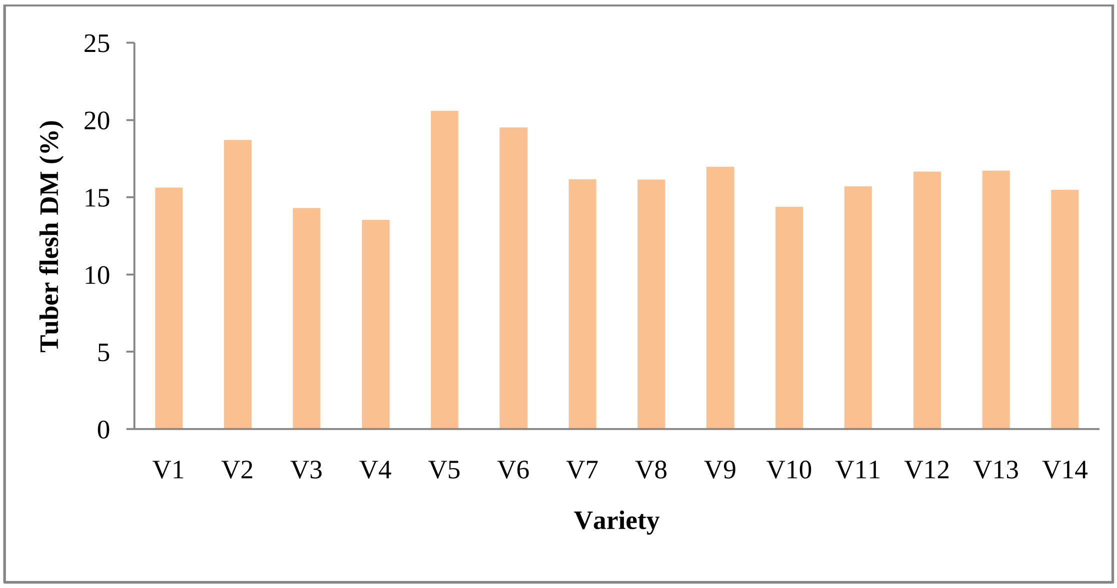

Figure 25. Effect of varieties on tuber flesh dry matter content (%) (SE value = 0.32)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.1.2 Effect of As levels

Dry matter content of tuber flesh varied significantly with different As levels (Appendix IX and Figure 26). Figure 26 exhibited that tuber flesh dry matter content decreased with increasing As levels but As_0 and As_1 showed similar results. The maximum dry matter content (18.88 %) was obtained from the control (As_0) treatment which was statistically similar (18.69 %) with 25 mg As kg^{-1} soil and the minimum (11.83 %) was found from the 50 mg As kg^{-1} soil.

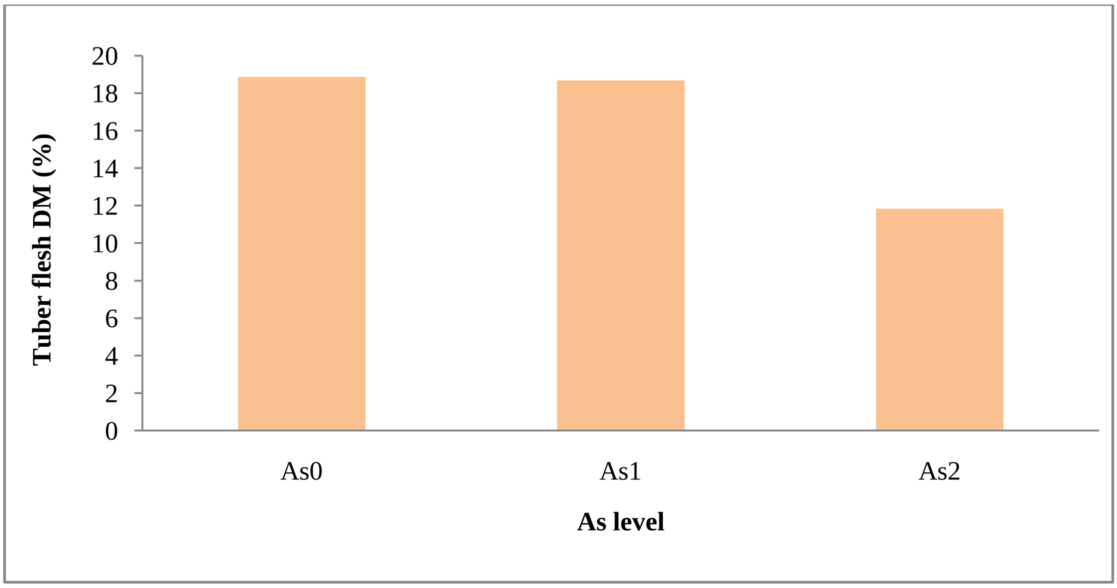

Figure 26. Effect of As levels on tuber flesh dry matter content (%) (SE value = 0.15)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.1.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the dry matter content (%) of tuber flesh (Appendix IX and Table 8). The maximum dry matter content of tuber flesh (22.98 %) was obtained from the combination of 'Lady Rosetta' with control (As_0) which was statistically similar (22.83 %) with V_5As_1 whereas, the minimum (8.99 %) was obtained from the combination of 'Granola' and 50 mg As kg^{-1} soil which was statistically similar (9.59 and 9.70 %, respectively) with V_3As_2, $V_{10}As_2$.

4.3.2 Tuber peel dry matter content (%)

4.3.2.1 Effect of varieties

Significant variation was recorded from the varietal performance in respect of tuber peel dry matter content (%) (Appendix IX and Figure 27). The highest dry matter content of tuber peel (16.59 %) was recorded from the variety 'Lady Rosetta' which was statistically similar (15.52 %) with 'Courage' and the minimum (9.83 %) was recorded from the ‘Granola’ and it was statistically similar with ‘Asterix’ (10.30 %) and ‘Laura’ (10.40 %,).

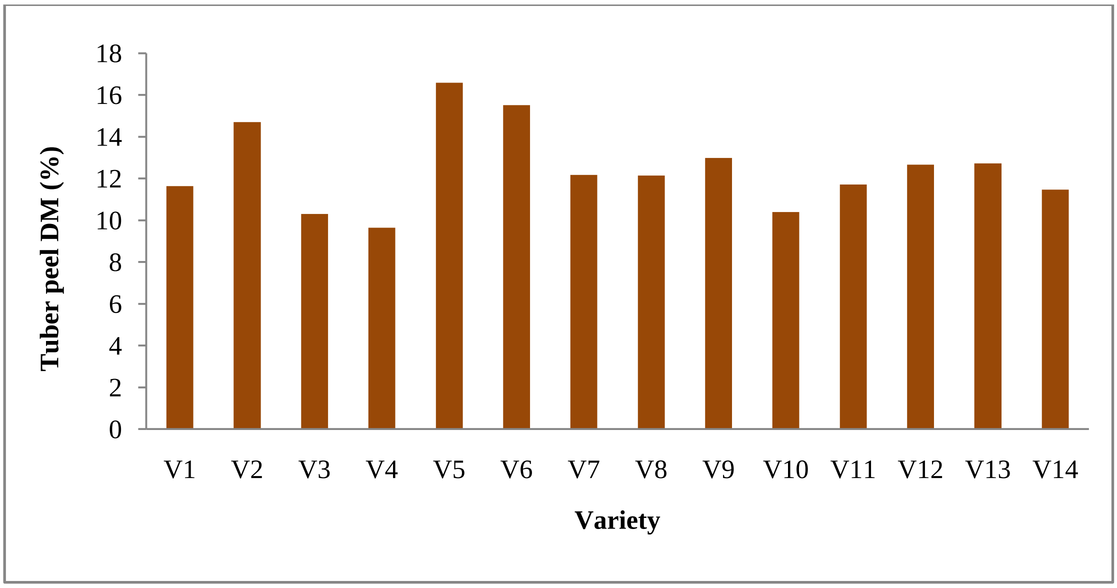

Figure 27. Effect of varieties on tuber peel dry matter content (%) (SE value = 0.40)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.2.2 Effect of As levels

Different levels of As influenced the dry matter content of tuber peel significantly (Appendix IX and Figure 28). Figure 28 exhibited that tuber peel dry matter content decreased with increasing As levels though As_0 and As_1 showed similar results. The maximum (13.68 %) dry matter content in tuber peel was recorded from the control (As_0) treatment which was statistically similar (13.49 %) with 25 mg As kg^{-1} soil (As_1) while, the minimum (10.26 %) was recorded from the 50 mg As kg^{-1} soil (As_2).

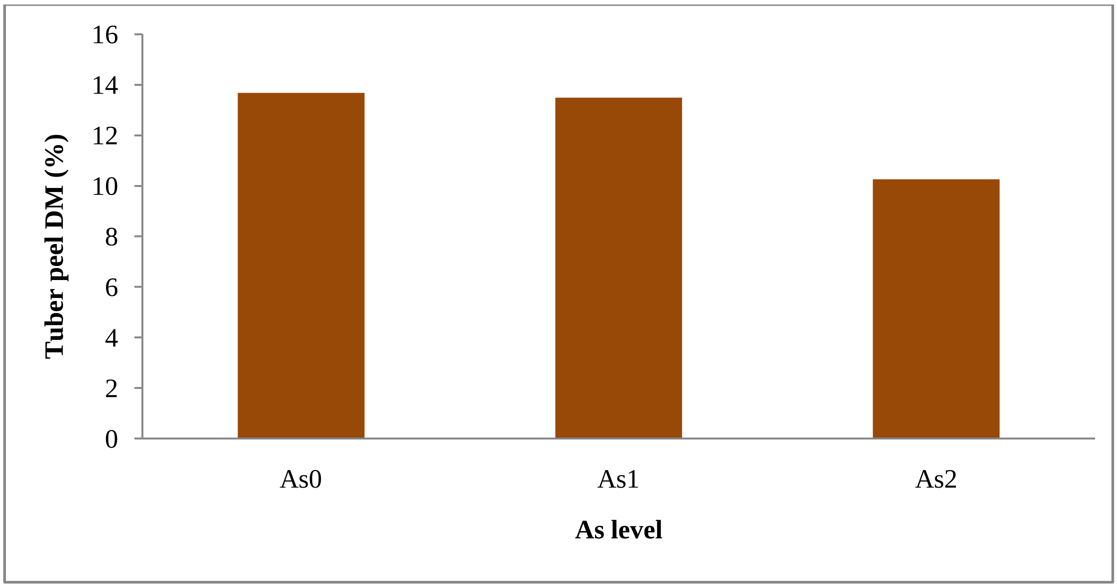

Figure 28. Effect of As levels on tuber peel dry matter content (%) (SE value = 0.19)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.2.3 Interaction effect of varieties and As levels

Significant interaction effect between the varieties and As levels was observed in case of dry matter content of tuber peel (Appendix IX and Table 8). It was observed that the maximum dry matter content of tuber peel (17.78 %) was recorded from the combination of 'Lady Rosetta' with control (As_0) which was statistically similar (17.63 %) with V_5As_1 whereas, the minimum (7.73 %) was recorded from the V_4As_2 which was statistically similar with V_3As_2 (8.00 %) and $V_{10}As_2$ (8.11 %).

4.3.3 Specific Gravity

4.3.3.1 Effect of varieties

In present study varieties had insignificant effect on specific gravity (Appendix XII and Figure 29). Numerically the highest specific gravity (1.07 g cm^{-3}) was obtained from the 'Cardinal', 'Lady Rosetta' and 'Courage' whereas, the lowest (1.02 g cm^{-3}) specific gravity was found from the 'Granola' variety. Asmamaw *et al.* (2010) and Elfnesh *et al.* (2011) reported a specific gravity ranging them 1.06 to 1.09 and 1.08 to 1.10, respectively in two separate experiments with nine potato varieties during evaluated their processing quality. Ekin (2011) also reported specific gravity values ranging from 1.07 to 1.08 from a study of eight potato varieties over two consecutive years.

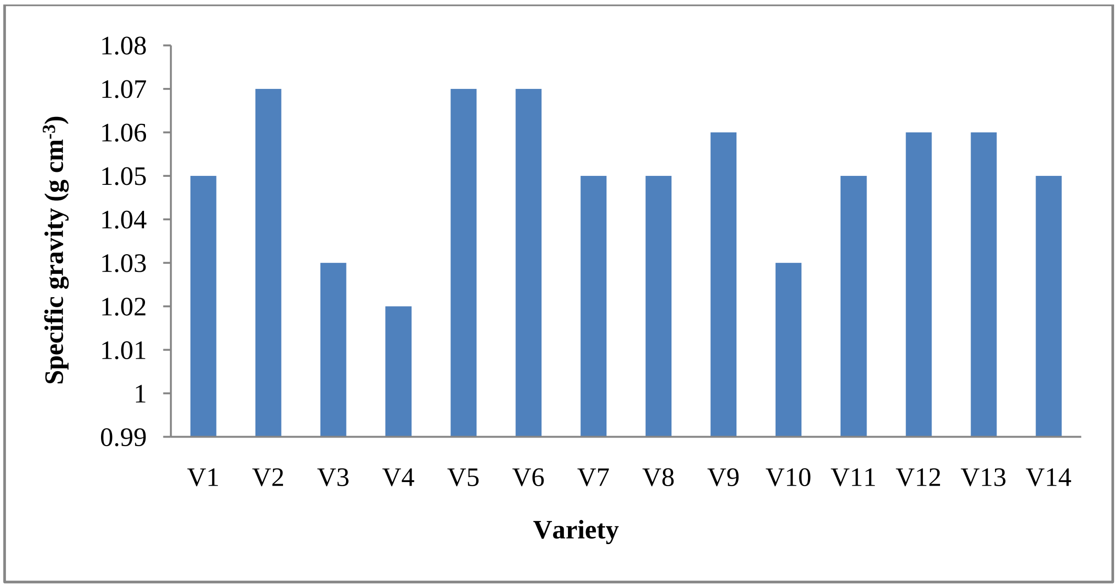

Figure 29. Effect of varieties on specific gravity of potato (SE value = 0.02)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.3.2 Effect of As levels

Different As levels showed significant effect on the specific gravity (Appendix XII and Figure 30). Figure 30 exhibited that specific gravity decreased with increasing As levels but As_0 and As_1 showed similar results. Highest specific gravity (1.06 g cm^{-3}) was found from the control (As_0) and 25 mg As kg^{-1} soil (As_1) treatments while the lowest (1.03 g cm^{-3}) was obtained from the 50 mg As kg^{-1} soil (As_2) treatment.

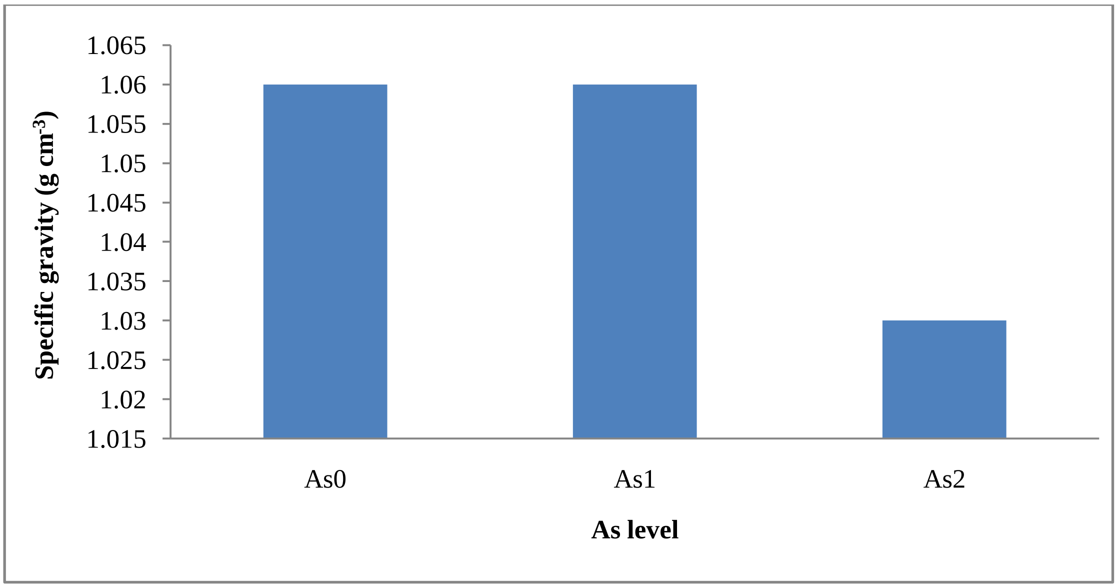

Figure 30. Effect of As levels on specific gravity of potato (SE value = 0.01)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.3.3 Interaction effect of varieties and As levels

Specific gravity differed significantly due to interaction effect of varieties and As levels (Appendix XII and Table 14). 'Lady Rosetta' with control (As_0) and 'Lady Rosetta' with 25 mg As kg^{-1} soil treatment combinations showed the maximum specific gravity (1.09 g cm^{-3}) which was statistically similar (1.08, 1.08, 1.08, 1.08, 1.06 and 1.06 g cm^{-3}, respectively) with V_2As_0, V_2As_1, V_6As_0, V_6As_1, V_7As_0 and V_7As_1 while the minimum (1.01 g cm^{-3}) was recorded from the combination of 'Granola' with 50 mg As kg^{-1} soil which was statistically similar (1.01 and 1.02 g cm^{-3}, respectively) with V_3As_2 and $V_{10}As_2$.

Table 14. Interaction effect of varieties and As levels on specific gravity, total soluble solids (TSS), As accumulation in peel and flesh of potato tuber

Variety× As level	Specific Gravity (gcm^{-3})	Total soluble solids	As content in tuber peel ($mg\ kg^{-1}$)	As content in total tuber flesh ($mg\ kg^{-1}$)
V_1 As_0	1.06 a-c	4.70 g-m	-	-
V_1 As_1	1.06 a-c	4.67 h-n	1.88 jk	0.130 kl
V_1 As_2	1.03 a-c	4.60 h-o	5.89 d-f	0.183 e-k
V_2 As_0	1.08 ab	5.07 e-h	-	-
V_2 As_1	1.08 ab	5.00 e-h	1.87 jk	0.120 l
V_2 As_2	1.05 a-c	4.97 e-i	5.89 ef	0.180 e-l
V_3 As_0	1.03 a-c	4.27 m-p	-	-
V_3 As_1	1.03 a-c	4.20 n-q	1.98 ij	0.160 g-l
V_3 As_2	1.01 bc	4.13 o-r	5.99 c-e	0.220 c-g
V_4 As_0	1.02 a-c	5.73 ab	-	-
V_4 As_1	1.02 a-c	5.67 ab	1.98 jk	0.157 h-l
V_4 As_2	1.01 c	5.63 a-c	5.99 c-e	0.217 c-h
V_5 As_0	1.09 a	4.93 e-i	-	-
V_5 As_1	1.09 a	4.90 e-j	1.89 jk	0.143 i-l
V_5 As_2	1.05 a-c	4.83 e-k	5.90 d-f	0.203 c-i
V_6 As_0	1.08 ab	5.27 b-e	-	-
V_6 As_1	1.08 ab	5.20 c-f	2.11 i	0.233 b-e
V_6 As_2	1.05 a-c	5.17 d-g	6.13 b	0.290 ab
V_7 As_0	1.06 ab	5.70 ab	-	-
V_7 As_1	1.06 ab	5.60 a-d	1.82 k	0.163 f-l
V_7 As_2	1.04 a-c	5.57 a-d	5.84 f	0.223 c-f
V_8 As_0	1.06 a-c	3.80 p-r	-	-
V_8 As_1	1.06 a-c	3.77 qr	1.98 ij	0.157 h-l
V_8 As_2	1.04 a-c	3.70 r	5.99 c-e	0.217 c-h
V_9 As_0	1.07 a-c	4.33 l-o	-	-
V_9 As_1	1.07 a-c	4.27 m-p	2.01 ij	0.193 c-j
V_9 As_2	1.04 a-c	4.20 n-q	6.02 b-d	0.247 b-d
V_{10} As_0	1.04 a-c	4.27 m-p	-	-
V_{10} As_1	1.04 a-c	4.23 m-q	2.04 i	0.233 b-e
V_{10} As_2	1.02 bc	4.17 o-q	6.06 bc	0.287 ab
V_{11} As_0	1.06 a-c	4.50 i-o	-	-
V_{11} As_1	1.06 a-c	4.43 j-o	1.98 ij	0.160 g-l
V_{11} As_2	1.03 a-c	4.40 k-o	5.99 c-e	0.217 c-h
V_{12} As_0	0.07 a-c	4.77 f-l	-	-
V_{12} As_1	1.07 a-c	4.77 f-l	2.38 h	0.250 b-d
V_{12} As_2	1.04 a-c	4.70 g-m	6.39 a	0.310 a
V_{13} As_0	1.07 a-c	5.80 a	-	-
V_{13} As_1	1.07 a-c	5.73 ab	2.41 h	0.253 bc
V_{13} As_2	1.04 a-c	5.70 ab	6.43 a	0.313 a
V_{14} As_0	1.06 a-c	5.97 a	-	-
V_{14} As_1	1.06 a-c	5.90 a	1.46 l	0.133 j-l
V_{14} As_2	1.03 a-c	5.87 a	5.47 g	0.190 d-k
SE value	0.01	0.14	0.04	0.01
Level of significance	**	*	**	**
CV (%)	2.26	5.12	2.82	16.29

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

**, * indicate 1% and 5% level of significance, respectively

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7- BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu. As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.3 Total soluble solids (TSS)

4.3.4.1 Effect of varieties

Varieties differed significantly between themselves regarding TSS (Appendix XII and Figure 31). The maximum TSS (5.91) was recorded from the variety 'Jam Alu' (V_{14}) which was statistically similar (5.74, 5.68 and 5.62, respectively) with 'Rumana', 'Granola' and 'BARI TPS-1' whereas, the minimum (3.76) was obtained from the variety 'Meridian'. Study referred that the variety 'Jam Alu' expressed best result in terms of TSS.

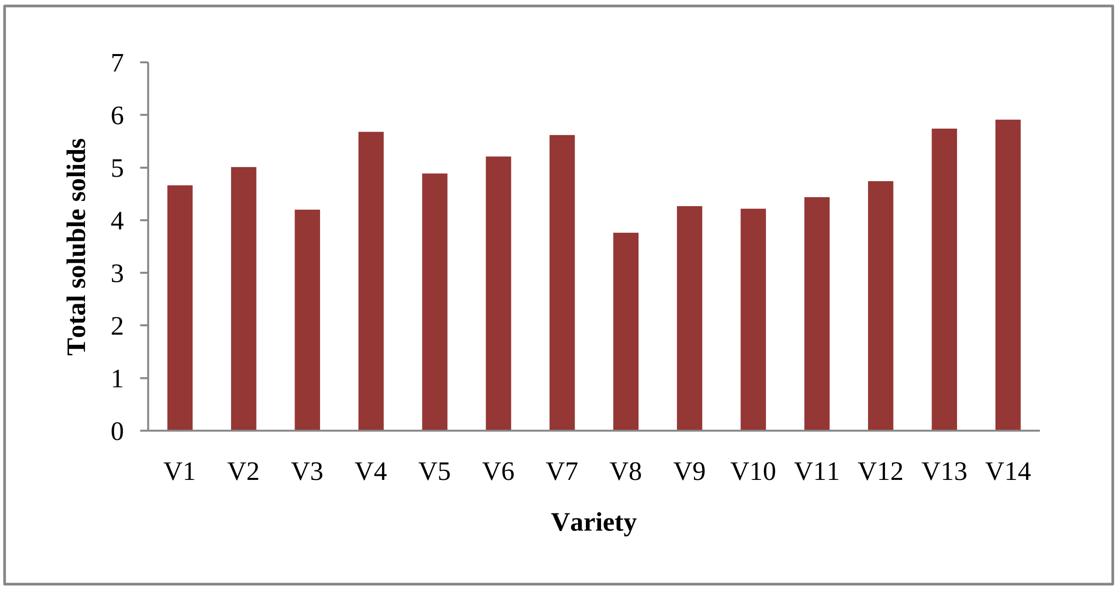

Figure 31. Effect of varieties on TSS of potato (SE value = 0.14)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.4.2 Effect of As levels

Different As levels had no significant effect on TSS of potato (Appendix XII and Figure 32). Numerically the maximum TSS (4.94) was found from the control (As_0) treatment and the minimum (4.83) was found from the 50 mg As kg^{-1} soil (As_2) treatment.

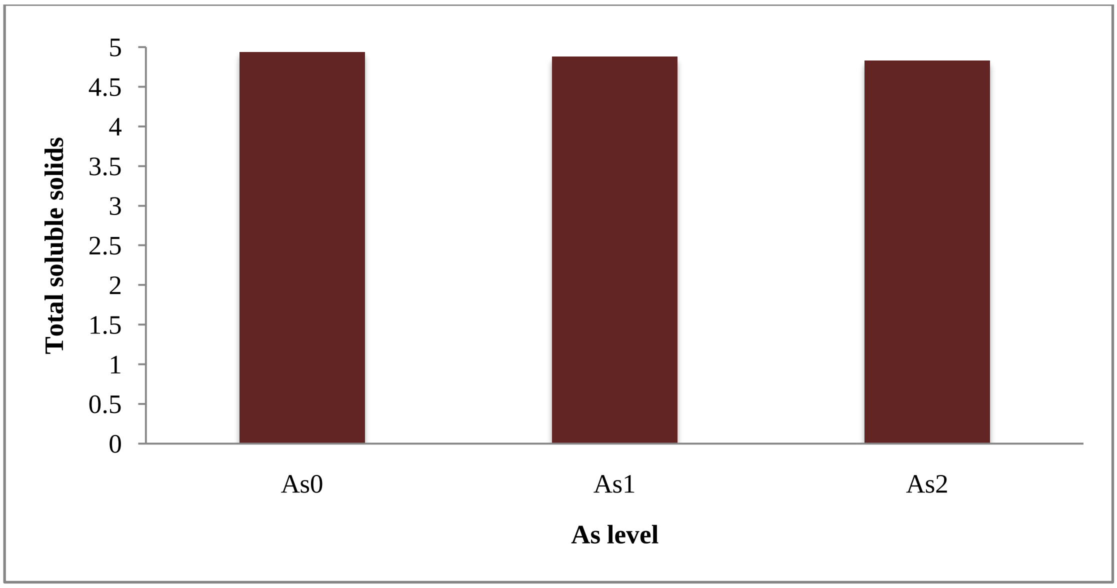

Figure 32. Effect of As levels on TSS of potato (SE value = 0.07)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.4.3 Interaction effect of varieties and As levels

It was found that TSS was affected significantly due to the interaction of varieties and As levels (Appendix XII and Table 14). The highest TSS (5.97) was recorded from the combination of 'Jam Alu' and control (As_0) which was statistically similar (5.90, 5.87, 5.80, 5.73, 5.73, 5.70, 5.70, 5.67, 5.63, 5.60 and 5.57, respectively) with the interaction of $V_{14}As_1$, $V_{14}As_2$, $V_{13}As_0$, $V_{13}As_1$, V_4As_0, $V_{13}As_2$, V_7As_0, V_4As_1, V_4As_2, V_7As_1 and V_7As_2 whereas, the minimum (3.70) was found from the combination of 'Meridian' and 50 mg As kg^{-1} soil which was statistically similar (3.77, 3.80 and 4.13, respectively) with V_8As_1, V_8As_0 and V_3As_2.

4.3.3 Arsenic content of tuber peel

4.3.3.1 Effect of varieties

Arsenic (As) content of tuber peel was significantly influenced by different varieties (Appendix XII and Figure 33). The maximum As accumulation of tuber peel was recorded from the variety Rumana (2.95 mg kg^{-1}) which was statistically similar with 'Sagitta' (2.92 mg kg^{-1}), whereas, the least amount of

As load in tuber peel was observed in the variety 'Jam Alu' (2.31 mg kg^{-1}). Rahman *et al.* (2007b) and Kundu *et al.* (2012) reported that As concentration appearing toxicity widely varied with plant genotypes probably due to varietal differences in As translocation and phyto-extraction or phyto-morphological potential of the varieties.

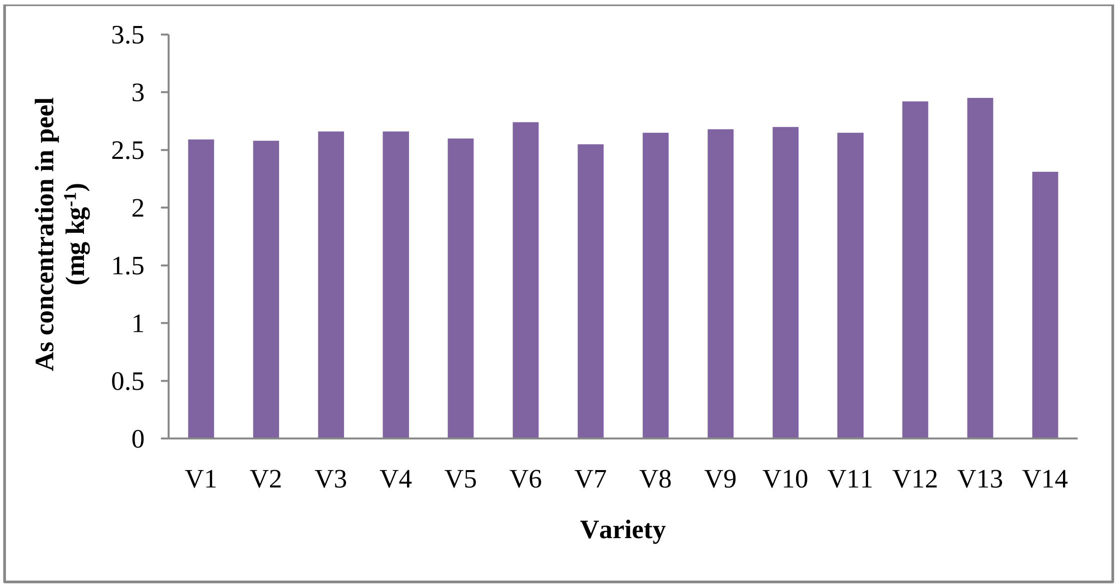

Figure 33. Effect of varieties on As concentration in tuber peel (SE value = 0.05)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.5.2 Effect of As levels

Arsenic (As) content of tuber peel showed significant variation with different As levels (Appendix XII and Figure 34). Figure 46 exhibited that As content of tuber peel increased with increasing As levels. The highest As accumulation in tuber peel (6.00 mg kg^{-1}) was recorded from the 50 mg As kg^{-1} soil (As_2) treatment whereas, the least (1.99 mg kg^{-1}) was accumulated with 25 mg As kg^{-1} soil (As_1). No As was found from the control (As_0) treatment. Pyles and Woolson (1982) found 3.00 mg As kg^{-1} in potato peel when soil was treated with 100 mg As kg^{-1}. 'As' appears to accumulate preferentially on the skin of potato (Roychowdhury *et al.*, 2002; Warren *et al.*, 2003), either because of tubers are able to absorb As from the surrounding soil or the soil particles adhered on the tuber surface have not been completely cleaned.

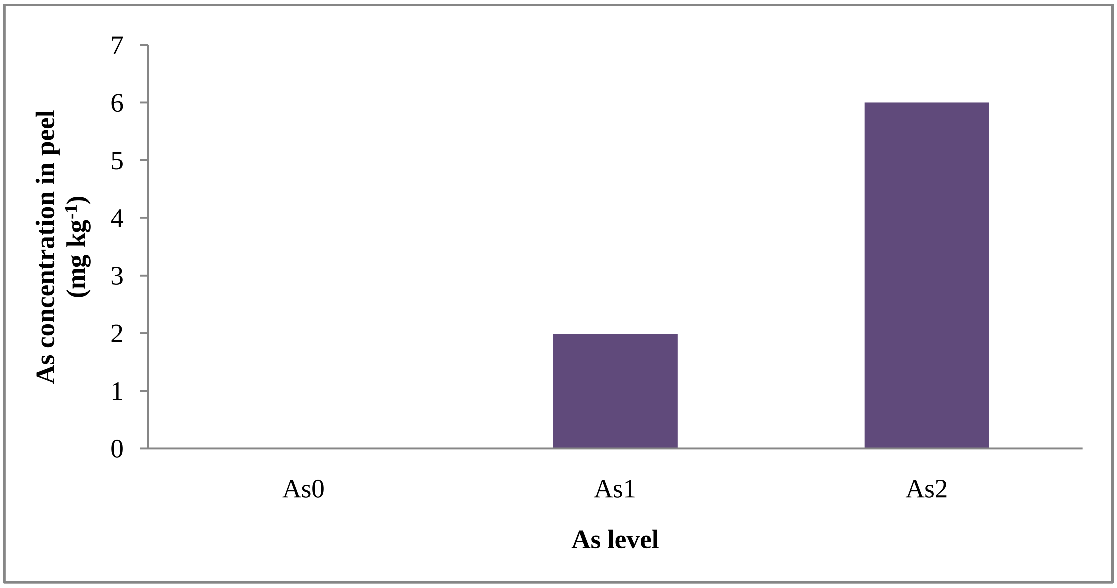

Figure 34. Effect of As levels on As concentration in tuber peel (SE value = 0.02)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.5.3 Interaction effect of varieties and As levels

Interaction effect of potato varieties and As levels significantly influenced the As content of potato peel (Appendix XII and Table 14). Results revealed that the maximum As accumulation in tuber peel (6.43 mg kg^{-1}) was recorded from the combination of 'Rumana' and 50 mg As kg^{-1} soil which was statistically similar (6.39 mg kg^{-1}) with combination of 'Sagitta' and 50 mg As kg^{-1} soil. The least accumulation (1.461 mg kg^{-1}) was noticed from the combination of 'Jam Alu' and 25 mg As kg^{-1} soil treatment. No As was found from the control (As_0) combination treatment.

4.3.4 Arsenic content of tuber flesh

4.3.6.1 Effect of varieties

Accumulation of As in tuber flesh differed significantly among the varieties (Appendix XII and Figure 35). The maximum As concentration (0.189 mg kg^{-1}) was recorded with 'Rumana' in the tuber flesh which was statistically similar

(0.187, 0.174, 0.173 and 0.147 mg kg^{-1}, respectively) with 'Sagitta', 'Courage', 'Laura' and 'Felsina' whereas, the least amount of As accumulation (0.100 mg kg^{-1}) was observed in the variety 'Cardinal' which was statistically similar (0.104 and 0.108 mg kg^{-1}, respectively) with Daimant and 'Jam Alu'. Different variety of potato tuber accumulated different amount of arsenic in its edible parts also reported by Kundu *et al.* (2012a).

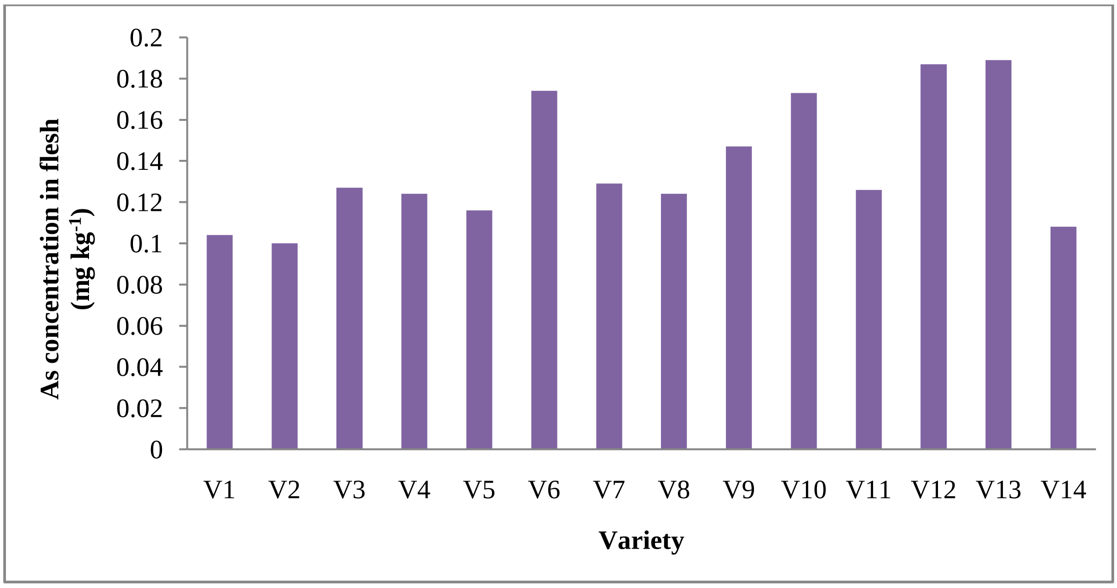

Figure 35. Effect of varieties on As content in tuber flesh (SE value = 0.02)

Note: V_1- Diamant, V_2- Cardinal, V_3- Asterix, V_4- Granola, V_5- Lady Rosetta, V_6- Courage, V_7-BARI TPS-1, V_8- Meridian, V_9- Felsina, V_{10}- Laura, V_{11}- Quincy, V_{12}- Sagitta, V_{13}- Rumana, V_{14}- Jam Alu

4.3.6.2 Effect of As levels

Arsenic (As) accumulation in tuber flesh showed statistically significant variation among the different As levels (Appendix XII and Figure 36). Figure 36 exhibited that As content of tuber flesh increased with increasing As levels. The maximum As concentration (0.236 mg kg^{-1}) was recorded from the 50 mg As kg^{-1} soil (As_2) and the lowest (0.178 mg kg^{-1}) from the 25 mg As kg^{-1} soil (As_1). No As was found from the control (As_0) treatment. Higher content of As in soils also causes higher absorption of this element by roots (Onken and Hossner, 1995).

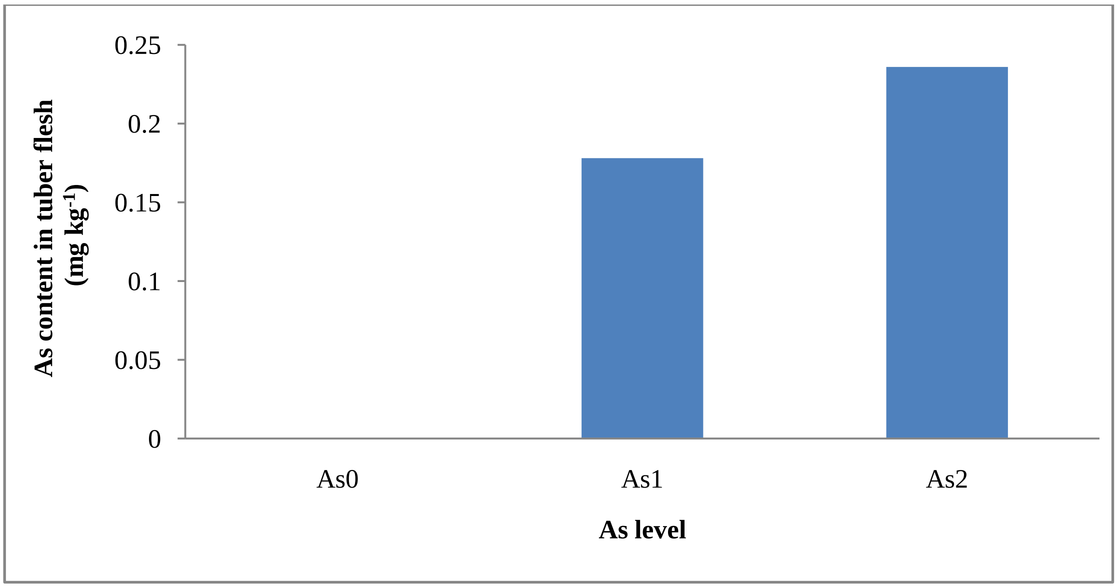

Figure 36. Effect of As levels on As content in tuber flesh (SE value = 0.01)

Note: As_0= 0 mg kg^{-1} soil, As_1= 25 mg kg^{-1} soil, As_2= 50 mg kg^{-1} soil

4.3.6.3 Interaction effect of varieties and As levels

Interaction effect of varieties and As levels significantly influenced the As accumulation of tuber flesh (Appendix XII and Table 14). The maximum As concentration (0.313 mg kg^{-1}) in tuber flesh was found from the combination of 'Rumana' and with 50 mg As kg^{-1} soil which was statistically similar with $V_{12}As_2$ (0.310 mg kg^{-1}), V_6As_2 (0.290 mg kg^{-1}) and $V_{10}As_2$ (0.287 mg kg^{-1}) whereas, the minimum (0.120 mg kg^{-1}) was recorded from the combinations of 'Cardinal' with 25 mg As kg^{-1} soil which were statistically similar with V_1As_1 (0.130 mg kg^{-1}), $V_{14}As_1$ (0.133 mg kg^{-1}), V_5As_1 (0.143 mg kg^{-1}), V_8As_1 (0.157 mg kg^{-1}), V_4As_1 (0.157 mg kg^{-1}), V_3As_1 (0.160 mg kg^{-1}), $V_{11}As_1$ (0.160 mg kg^{-1}), V_7As_1 (0.163 mg kg^{-1}) and V_2As_2 (0.180 mg kg^{-1}). No As was found from the control (As_0) combination treatments.

Chapter 5

Summary and conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Agronomy field laboratory of Sher-e-Bangla Agricultural University (SAU), Dhaka, during the period from November 10, 2012 to February 18, 2013 to investigate the growth, yield and quality of potato varieties under As contaminated soil under the Modhupur Tract (AEZ-28). Two factor experiment included 14 potato varieties viz. ‘Diamant’ (V_1), ‘Cardinal’ (V_2), ‘Asterix’ (V_3), ‘Granola’ (V_4), ‘Lady Rosetta’ (V_5), ‘Courage’ (V_6), ‘BARI TPS-1’ (V_7), ‘Meridian’ (V_8), ‘Felsina’ (V_9), ‘Laura’ (V_{10}), ‘Quincy’ (V_{11}), ‘Sagitta’ (V_{12}), ‘Rumana’ (V_{13}), ‘Jam Alu’ (V_{14}) and 3 Arsenic levels viz. As_0 (Control), As_1 (25 mg As kg^{-1} soil), As_2 (50 mg As kg^{-1} soil) was outlined in Randomized Complete Block Design (RCBD) with three replications.

The data on crop growth parameters like days to first emergence, plant height, number of leaves $plant^{-1}$, number of stems $hill^{-1}$, leaf area $plant^{-1}$, chlorophyll content of leaves (SPAD value) and stem diameter were recorded at different growth stages. Yield parameters like, number of tubers $hill^{-1}$, yield of tuber $plant^{-1}$, average weight of tuber, grading of tuber (% by number), marketable yield $plant^{-1}$, non-marketable yield $plant^{-1}$, tuber flesh dry matter content (%) and tuber peel dry matter content (%) were recorded after harvest. Quality character parameters like, specific gravity, total soluble solids (TSS), As content of tuber peel and tuber flesh were recorded after harvest. Data were analyzed using MSTAT package. The mean differences among the treatments were compared by Duncan’s Multiple Range Test (DMRT) at 5% level of significance.

Results showed that variety had significant effect on growth, yield and quality parameters except specific gravity. ‘Diamant’ produced the lowest plant height from 45 to 90 DAP and the maximum number of leaves $plant^{-1}$ at 45 DAP. ‘Cardinal’ accumulated the minimum concentration of As in tuber flesh.

‘Asterix’ produced the maximum number of leaves plant^{-1} at 30 DAP and the highest number of 45-55 mm sized tubers. ‘Granola’ produced the lowest above ground stem dry matter content, tuber flesh dry matter content and tuber peel dry matter content. The highest above ground stem dry matter content, tuber flesh dry matter content, tuber peel dry matter content and the lowest non-marketable yield plant^{-1}, number of under sized tubers (>28 mm) was obtained from ‘Lady Rosetta’. ‘Courage’ produced the lowest number of leaves plant^{-1} from 60 to 90 DAP and the lowest number of tubers hill^{-1}. ‘BARI TPS-1’ produced the highest plant height from 45 to 90 DAP and the lowest number of 45-55 sized tubers. ‘Meridian’ produced the lowest total soluble solids. ‘Felsina’ produced the highest number of stems hill^{-1}, maximum leaf area plant^{-1}, highest chlorophyll content of leaves, maximum stem diameter in all the growth stages, highest yield of tuber plant^{-1}, highest average weight of tuber, highest marketable yield plant^{-1}, highest percentage of marketable tuber number and tuber weight, lowest percentage of non-marketable tuber number and tuber weight. ‘Laura’ produced the tallest plant height at 30 DAP and the maximum number of large sized tubers (>55 mm). The minimum days required for emergence, the lowest chlorophyll content of leaves at all growth stages, highest number of 28-45 mm sized tubers and the lowest number of large sized (>55 mm) tubers was observed from ‘Quincy’. ‘Rumana’ produced the highest non-marketable yield plant^{-1}, accumulated maximum concentration of As in tuber peel and flesh, lowest marketable yield plant^{-1}, lowest percentage of marketable tuber number and the highest percentage of marketable tuber weight. The maximum days required for emergence, the lowest number of leaves plant^{-1} from 30 to 45 DAP but highest number of leaves plant^{-1} from 60 to 90 DAP, highest number of tubers hill^{-1}, highest percentage of non-marketable yield (% by number and weight), highest number of under sized (<28 mm) tuber, lowest number of 28-45 mm sized tubers, highest total soluble solids, lowest number of stems hill^{-1}, lowest stem diameter, lowest leaf area plant^{-1} in all growth stages, lowest yield of tuber plant^{-1}, lowest average weight of tuber and accumulated minimum concentration of As in tuber peel was obtained from ‘Jam Alu’.

Arsenic (As) levels also significantly influenced the growth, yield and quality attributes except total soluble solids. Plant height, number of leaves plant^{-1}, number of stems hill^{-1}, stem diameter, leaf area plant^{-1}, chlorophyll content of leaves at all the growth stages, above ground stem dry matter content, tuber flesh dry matter content, tuber peel dry matter content, yield of tuber plant^{-1}, average weight of tuber, large sized tuber (>55 mm), 45-55 mm sized tuber, 28-45 mm sized tuber, marketable yield plant^{-1}, marketable yield (% by number), marketable yield (% by weight) was maximum at control (As_0) treatment which was statistically similar to the 25 mg As kg^{-1} soil and the minimum was found from the 50 mg As kg^{-1} soil irrespective of above mentioned parameters. Under sized tuber (<28 mm), non-marketable yield plant^{-1}, non-marketable yield (% by number), non-marketable yield (% by weight), specific gravity, As content in tuber peel, As content in tuber flesh, days to emergence showed maximum result at 50 mg As kg^{-1} soil and the minimum was found from control (As_0) treatment.

Interaction effect of varieties and As levels also significantly affected growth, yield and quality contributing characters. The maximum number of leaves plant^{-1} at 45 DAP was found from ‘Diamant’ with control treatment. Variety ‘Cardinal’ with 25 mg As kg^{-1} soil accumulated minimum concentration of As in tuber flesh. The maximum number of leaves plant^{-1} at 30 DAP was obtained from ‘Asterix’ with control treatment. ‘Granola’ with control treatment produced highest marketable yield (% by number) and lowest non-marketable yield (% by number). ‘Granola’ with 50 mg As kg^{-1} soil produced lowest number of leaves plant^{-1} at 75 DAP, lowest number of large sized (>55 mm) tuber, lowest above ground stem dry matter content, the minimum tuber flesh dry matter content, the minimum tuber peel dry matter content and the minimum specific gravity. ‘Lady Rosetta’ with control treatment produced highest above ground stem dry matter content, tuber flesh dry matter content, tuber peel dry matter content, 45-55 mm sized tuber, marketable yield (% by weight), lowest non-marketable yield plant^{-1}, lowest non-marketable yield (% by weight) and lowest number of under sized (<28 mm) tuber. 'Lady Rosetta' with control treatment, 'Lady Rosetta' with 25 mg As kg^{-1} soil produced maximum specific gravity. 'Lady Rosetta' with 50 mg As kg^{-1} soil produced shortest plant height at 45 to 90 DAP. The highest average weight of tuber and lowest number of tubers hill^{-1} was counted from 'Courage' with control treatment. 'Courage' with 50 mg As kg^{-1} soil produced lowest number of leaves plant^{-1} at 60 and 90 DAP. The tallest plant height at 45 to 90 DAP was recorded from 'BARI TPS-1' with control treatment. 'BARI TPS-1' with 50 mg As kg^{-1} soil produced lowest marketable yield (% by weight) and lowest number of 45-55 mm sized tuber. 'Meridian' with 50 mg As kg^{-1} soil produced minimum amount of total soluble solids. 'Felsina' with control treatment produced tallest plant height at 30 DAP, maximum number of stems hill^{-1}, stem diameter, leaf area plant^{-1}, maximum chlorophyll content of leaves in all the growth stages, yield of tuber plant^{-1} and marketable yield plant^{-1}. The maximum number of large (>55 mm) sized tuber was counted from 'Laura' with control treatment. 'Quincy' with control treatment required minimum days to emergence and produced highest 28-45 mm sized tuber. 'Quincy' with 50 mg As kg^{-1} soil produced lowest number of stems hill^{-1} and lowest chlorophyll content of leaves at different growth stages. The highest non-marketable yield plant^{-1} was recorded from 'Rumana' with 25 mg As kg^{-1} soil. 'Rumana' with 50 mg As kg^{-1} soil produced lowest marketable yield plant^{-1} and accumulated maximum concentration of As in tuber peel and flesh. 'Jam Alu' with control treatment produced maximum number of leaves plant^{-1} at 60 to 90 DAP, highest number of tubers hill^{-1} and TSS. 'Jam Alu' with 25 mg As kg^{-1} soil produced the highest number of under (<28 mm) sized tuber, lowest number of 28-45 mm sized tuber and accumulated highest concentration of As in tuber peel. 'Jam Alu' with 50 mg As kg^{-1} soil treatment required maximum days to emergence, lowest plant height at 30 DAP, lowest number of leaves plant^{-1} from 30 to 45 DAP, lowest number of stems hill^{-1} at 30 DAP, lowest stem diameter and leaf area plant^{-1} at different growth stages, lowest yield of tuber plant^{-1} and lowest average weight of tuber. 'Jam Alu' with control treatment, 'Jam Alu' with 25 mg As kg^{-1} soil and 'Jam Alu' with 50 mg As kg^{-1} soil produced highest non-marketable yield (% by number and weight, respectively).

Considering the results of the present experiment, it may concluded that growth, yield and quality parameters of potato slowly decreased up to 25 mg As kg^{-1} soil and thereafter drastically decreased by increased As level. Among the potato varieties, though the variety 'Felsina' produced maximum yield at 50 mg As kg^{-1} soil but As accumulation was also maximum (0.247 mg kg^{-1} in flesh). So, on the basis of above mentioned discussion, the variety 'Cardinal' and 'Diamant' showed better yield performance and less As accumulation compared to those of other varieties.

In As contaminated areas (up to 25 mg As kg^{-1} soil) 'Cardinal' and 'Diamant' may cultivate because in this soil above mentioned potato varieties accumulate 0.120 and 0.130 mg As kg^{-1} in potato flesh, respectively which is lower than that of food hygiene concentration limit (1.0 mg kg^{-1}) and is not harmful for human being after deep peeling (2 mm) since maximum As accumulation was in peel.

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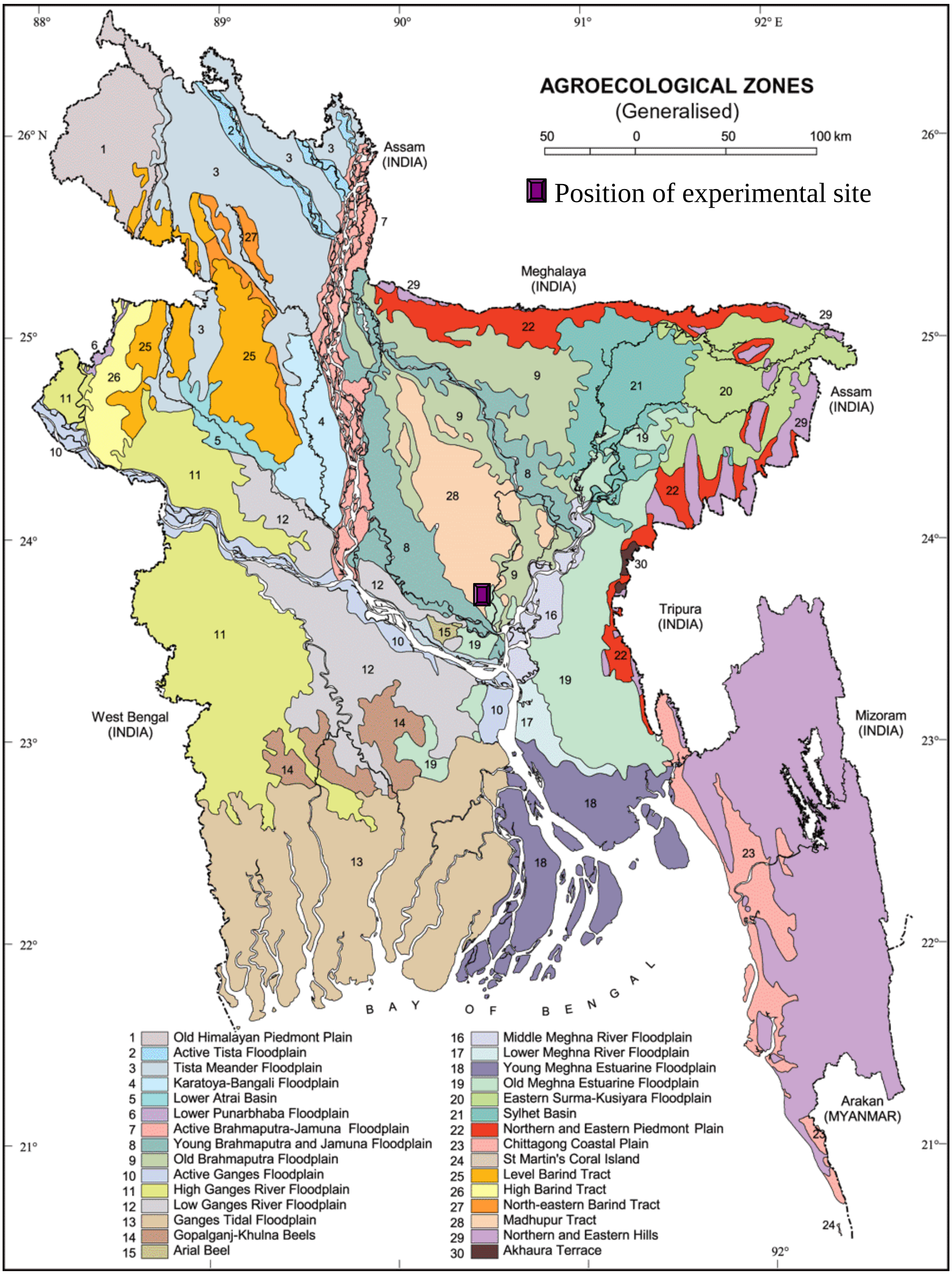
Appendices

APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Weather data, 2012-2013, Dhaka

Month	Average Relative Humidity (%)	Average Temperature ($^{\circ}C$)		Total Rainfall (mm)
		Minimum	Maximum	
November	68.21	19.14	28.73	68
December	78.58	14.54	23.93	5
January	65.39	12.09	24.55	14
February	47.16	16.5	27.86	34
March	43.8	23.3	31.6	43.4

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207.

Appendix III. Mean square values for days to emergence and plant height of potato

Sources of variation	Degrees of freedom	Mean Square					
		Days to emergence	Plant height (cm) at				
			30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	8.008	3.461	1.798	13.141	14.101	8.251
Variety (A)	13	36.479**	257.353**	466.671**	710.920**	832.495**	910.197**
As level (B)	2	243.246**	388.099**	1314.487**	2134.135**	1919.507**	1988.582**
Interaction (A×B)	26	0.297**	4.470**	4.233*	5.728*	2.215**	1.049**
Error	82	1.317	1.808	1.925	3.271	3.896	2.040

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

Appendix IV. Mean square values for number of leaves plant^{-1} of potato

Sources of variation	Degrees of freedom	Mean Square				
		Number of leaves plant^{-1} at				
		30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	100.024	28.881	16.960	35.056	16.960
Variety (A)	13	1983.348**	3339.942**	11485.480**	14457.034**	11485.480**
As level (B)	2	101.024**	2911.167**	4614.294**	5191.960**	4614.294**
Interaction (A×B)	26	0.101**	30.953**	36.935**	77.935**	36.935**
Error	82	7.130	9.222	11.684	12.129	11.684

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

Appendix V. Mean square values for number of stems plant^{-1} of potato

Sources of variation	Degrees of freedom	Mean Square				
		Number of stems plant^{-1} at				
		30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	1.167	0.095	0.246	0.246	0.246
Variety (A)	13	16.803**	20.196**	21.255**	21.255**	21.255**
As level (B)	2	20.786**	38.952**	47.008**	47.008**	47.008**
Interaction (A×B)	26	0.025**	0.286**	0.316**	0.316**	0.316**
Error	82	0.305	0.551	0.905	0.905	0.905

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

Appendix VI. Mean square values for leaf area plant^{-1} (cm^2) of potato

Sources of variation	Degrees of freedom	Mean Square				
		Leaf area plant^{-1} (cm^2) at				
		30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	2.849	0.880	6.541	4.524	5.193
Variety (A)	13	715.817**	1129.715**	1348.098**	1321.990**	1309.941**
As level (B)	2	1242.026**	1425.961**	1278.426**	1207.016**	1358.684**
Interaction (A×B)	26	3.282**	3.181**	2.064**	1.707**	1.415**
Error	82	2.662	2.561	2.099	2.421	3.008

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

Appendix VII. Mean square values for chlorophyll content of leaves (SPAD value) of potato

Sources of variation	Degrees of freedom	Mean Square				
		Chlorophyll content of leaves (SPAD value) at				
		30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	64.415	36.523	19.897	22.614	51.188
Variety (A)	13	248.175**	252.641**	250.130**	251.187**	193.365**
As level (B)	2	1501.850**	1659.605**	1600.906**	1663.074**	1702.939**
Interaction (A×B)	26	0.064**	0.325**	0.201**	0.064**	0.046**
Error	82	7.333	7.243	6.309	6.322	6.430

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

Appendix VIII. Mean square values for stem diameter (cm) of potato

Sources of variation	Degrees of freedom	Mean Square				
		Stem diameter (cm) at				
		30 DAP	45 DAP	60 DAP	75 DAP	At Harvest
Replication	2	0.004	0.001	0.003	0.003	0.001
Variety (A)	13	0.106**	0.118**	0.109**	0.111**	0.107**
As level (B)	2	0.284**	0.260**	0.251**	0.215**	0.286**
Interaction (A×B)	26	0.001**	0.001**	0.001**	0.001**	0.001**
Error	82	0.001	0.001	0.001	0.001	0.001

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

Appendix IX. Mean square values for above ground stem dry matter content, tuber flesh dry matter content, tuber peel dry matter content, number of tubers hill^{-1}, yield of tuber plant^{-1} and average weight of tuber of potato

Sources of variation	Degrees of freedom		Mean Square				
		Above ground stem dry matter content (%)	Tuber flesh dry matter content (%)	Tuber peel dry matter content (%)	Number of tubers hill^{-1}	Yield of tuber plant^{-1} (g)	Average weight of tuber (g)
Replication	2	0.170	1.104	12.128	4.024	49.291	5.078
Variety (A)	13	33.448**	35.812**	35.368**	1554.166**	94992.913**	1363.686**
As level (B)	2	607.832**	677.972**	154.994**	278.000**	100460.459**	2423.669**
Interaction (A×B)	26	0.295**	0.220**	0.235**	1.624**	78.437**	45.845**
Error	82	0.368	0.301	0.490	1.894	647.317	6.294

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

Appendix X. Mean square values for grading of tuber (% by number)

Sources of variation	Degrees of freedom	Mean Square			
		Grading of tuber (% by number) for			
		>55 mm	45-55 mm	28-45 mm	<28 mm
Replication	2	114.572	107.711	104.342	41.680
Variety (A)	13	1544.661**	1644.246**	1246.991**	4430.323**
As level (B)	2	993.217**	1113.054**	255.599*	6478.003**
Interaction (A×B)	26	71.623*	86.917*	69.107**	217.092**
Error	82	32.739	48.180	69.150	65.301

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

Appendix XI. Mean square values for marketable yield plant^{-1}, non-marketable yield plant^{-1}, marketable yield (% by number), marketable yield (% by weight), non-marketable yield (% by number) and non-marketable yield (% by weight)of potato

Sources of variation	Degrees of freedom		Mean Square				
		Marketable yield plant^{-1}	Marketable yield (% by number)	Marketable yield (% by weight)	Non-marketable yield plant^{-1}	Non-marketable yield (% by number)	Non-marketable yield (% by weight)
Replication	2	197.942	66.485	37.795	438.325	66.456	37.795
Variety (A)	13	120538.259**	4121.534**	7195.327**	23584.415**	4121.641**	7195.327**
As level (B)	2	143745.333**	19489.657**	4018.900**	4294.103**	19489.769**	4018.900**
Interaction (A×B)	26	1458.885*	325.265**	79.529**	993.667**	325.263**	79.529**
Error	82	749.813	30.250	21.082	184.357	30.250	21.082

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

Appendix XII. Mean square values for As content of tuber peel, As content of tuber flesh, specific gravity and total soluble solids of potato

Sources of variation	Degrees of freedom	Mean Square			
		As content of tuber peel	As content of tuber flesh	Specific gravity	Total soluble solids (TSS)
Replication	2	0.004	0.001	0.001	0.260
Variety (A)	13	0.214**	0.009**	0.002^{NS}	4.098**
As level (B)	2	392.063**	0.632**	0.010**	0.115^{NS}
Interaction (A×B)	26	0.054**	0.002**	0.001**	0.001*
Error	82	0.006	0.001	0.001	0.063

**: Significant at 0.01 level of probability *: Significant at 0.05 level of probability NS: Non-significant

LIST OF PLATES

Plate 1: Experimental view

Plate 2: Days to emergence

V_9As_0

$V_{10}As_0$

$V_{14}As_2$

Plate 3: Plant height at 30 DAP

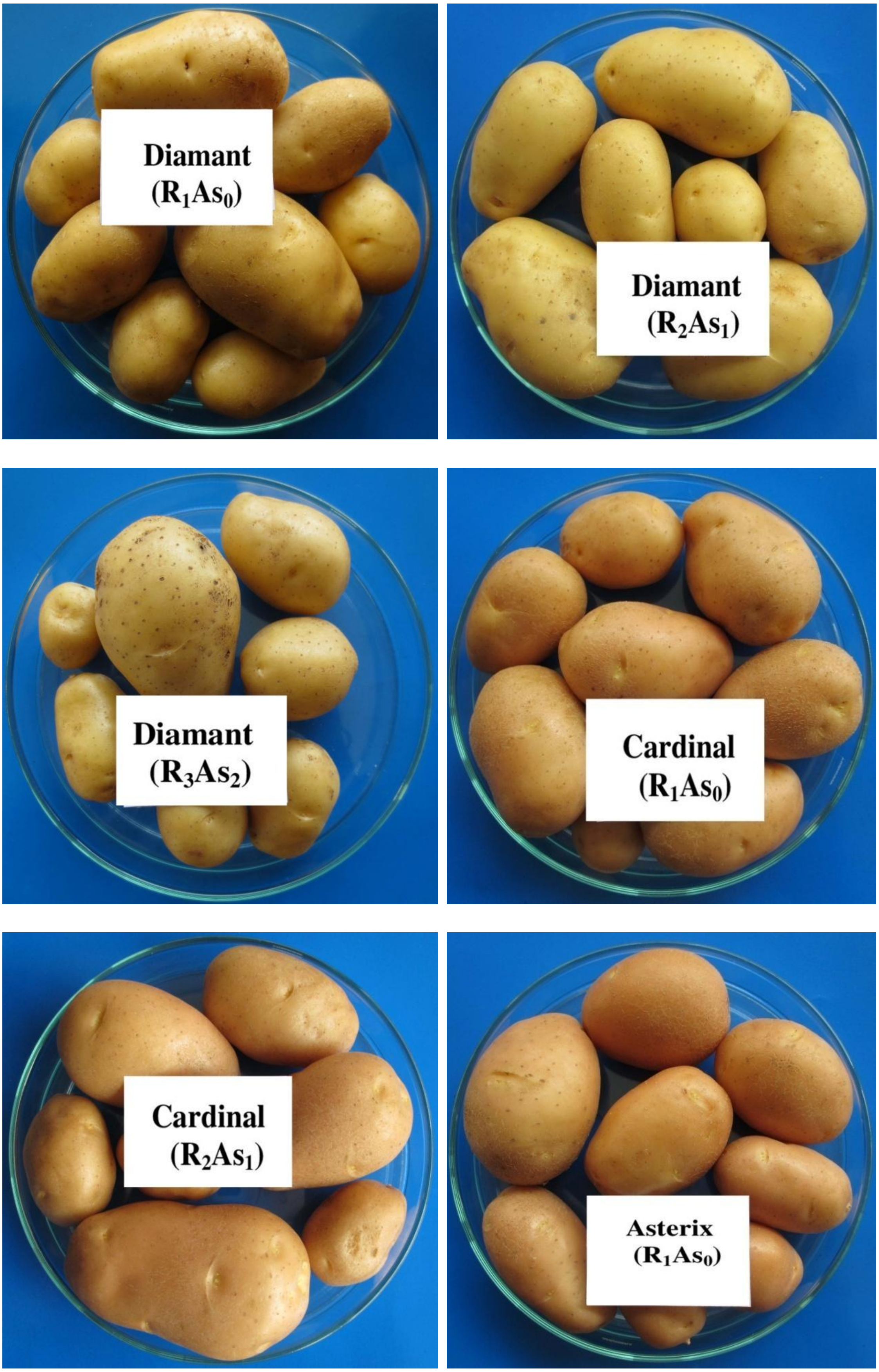


Plate 4: Potatoes produced from different treatment combinations

Plate 4: Continued

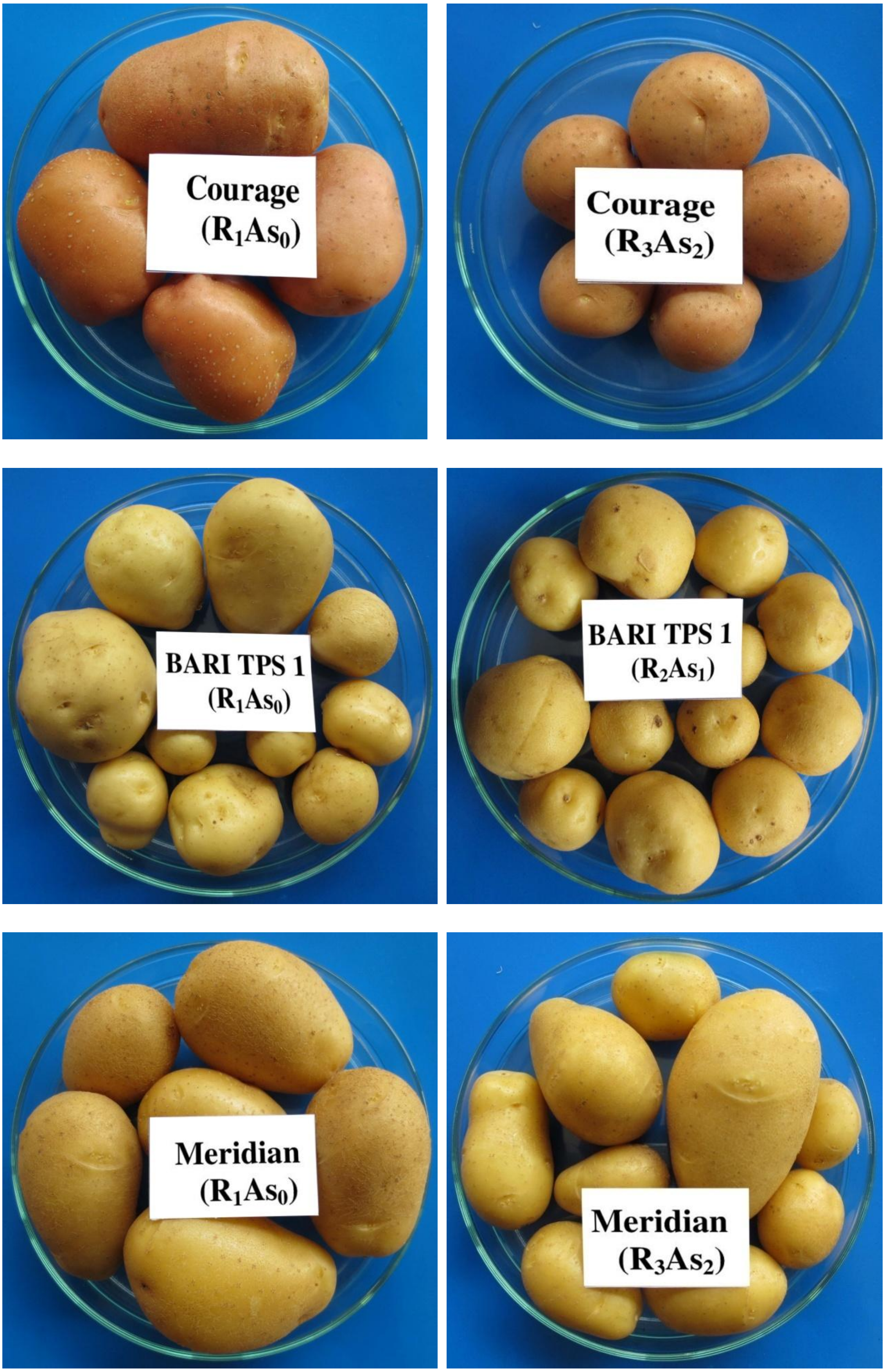


Plate 4: Continued

Plate 4: Continued