Yield reduction and arsenic accumulation in potatoes (*Solanum tuberosum* L.) in an arsenic contaminated soil

Reducción en el rendimiento y acumulación de arsénico en papa (*Solanum tuberosum* L.) cultivada en suelos contaminados con arsénico

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ABSTRACT

The different levels of arsenic (As) had a significant effect on the yield, yield reduction and As accumulation of different potato varieties. The yield was negatively affected by the As contamination and decreased with the increasing As levels in the soil, but remained statistically similar up to 25 mg kg^{-1} soil of As and thereafter drastically decreased with the increasing As levels. The yield reduction (%) and accumulation of As in the tuber peels and flesh increased with the increasing As levels. Among the fourteen potato varieties, 'Felsina' had the maximum yield and showed the lowest percentage of yield reduction; 'Jam alu' and 'Cardinal' accumulated the least amount of As in their peels and flesh, respectively. Among the treatment combinations, 'Felsina' cultivated in an As-free soil had the highest yield/plant (454.8 g fresh weight). 'Laura' grown in 25 mg kg^{-1} soil of As showed the lowest yield reduction (%). Although 'Jam alu' and 'Cardinal' produced a slightly lower yield compared to some other varieties, these two varieties accumulated the least amount of As, both in the peels and flesh, when grown in 25 mg kg^{-1} soil of As.

Key words: heavy metals, semimetals, soil pollution, tubers, yield losses, cultivar selection, Bangladesh.

RESUMEN

Los diferentes niveles de arsénico (As) tuvieron efecto significativo sobre el rendimiento al disminuir la producción y acumularse el As en las diferentes variedades de papa. El rendimiento fue negativamente afectado por la contaminación de suelo con As observándose una reducción de la producción con el incremento de As en el suelo. No se encontraron diferencias significativas en el rendimiento hasta 25 mg kg^{-1} As en el suelo pero en mayores cantidades el rendimiento se redujo drásticamente. El rendimiento fue reducido, se acumuló el As en la cáscara y en la pulpa del tubérculo en la medida que aumentaba el nivel As en el suelo. Entre las 14 variedades evaluadas, 'Felsina' presentó el máximo rendimiento y, 'Jamalu' y 'Cardinal' la menor acumulación de As tanto en cáscara como en pulpa del tubérculo. Entre los diferentes tratamientos, 'Felsina' se obtuvo el máximo rendimiento en un suelo sin As con 454,8 g peso fresco/planta, mientras 'Laura' presentó la menor reducción del rendimiento cuando en el suelo tenía 25 mg kg^{-1} de As. Aunque 'Jamalu' y 'Cardinal' presentaron el mejor rendimiento frente a las otras variedades, fueron las que mayor acumulación de As presentaron tanto en cáscara como en pulpa del tubérculo cuando fueron cultivadas en suelo con 25 mg kg^{-1} de As.

Palabras clave: metales pesados, semimetales, contaminación del suelo, tubérculos, pérdidas de rendimiento, selección de cultivares, Bangladés.

Introduction

Arsenic is a highly toxic and carcinogenic environmental pollutant and, thus, its presence in groundwater and agricultural field soil is of great concern all around the world (Rahman *et al.,* 2007a). Out of 20 countries in different parts of the world where groundwater arsenic contamination and human suffering have been reported, the highest magnitude is found in Bangladesh, followed by West Bengal, India (Sanyal, 2005).

Recent studies suggest that a number of crops and vegetable plant species accumulate significant amount of As (Norra *et al.,* 2005; Huang *et al.,* 2006; Dahal *et al.,* 2008; Brammer, 2009; Meharg *et al.,* 2009; Bhattacharya *et al.,* 2010a, b; Roberts *et al.,* 2011). Uptake of arsenic by plants and its translocation to different plant parts vary within the plant, even among the cultivars of the same crop (Pillai *et al.,* 2010). 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.,* 1993). Therefore, tuber crops are expected to have higher As contents than other crops when grown in As contaminated soils as the root system is the main part that accumulates As in plants. In the case of vegetables,

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the higher As accumulation was observed in potato, arum, amaranth, radish, lady's finger, cauliflower, and brinjal, whereas the lower level of As accumulation was observed in beans, green chili, tomato, bitter guard, and turmeric, etc. due to the As-contaminated irrigation water (Santra *et al.,* 2013). Mandal and Suzuki (2002), in their study on arsenic around the world, reported that the arsenic concentration in plants varied from less than 0.01 to about 5.0 mg kg^{-1}. From their study in Bangladesh, Das *et al.* (2004) reported that the concentrations of arsenic in vegetables, such as *Colocasia antiquorum*, *Solanum tuberosum*, and *Ipomea reptans* exceeded the food safety limits of 1.0 mg kg^{-1} (Abedin *et al.,* 2002).

Irrigation water with high levels of As may result in land degradation in terms of crop production (loss of yield) and food safety (food chain contamination) (Duxbury and Zavala, 2005). Hence, plants sensitive to As show patterns of toxicity, such as decreases in growth and yield (Meharg and Hartley-Whitaker, 2002). Khan *et al.* (2010) found that the addition of As, in either irrigation water or soil, resulted in yield reductions of from 21 to 74% in Boro rice (dry season) and had a strong residual effect on subsequent crops.

The potato (*S. tuberosum* L.) is grown in nearly 150 countries and is the world's single most important tuber crop with a vital role in the global food system and food security (Singh, 2010). Bangladesh was the world's 7th largest producer of potatoes with a total production of about 8.8 million t in 2012 to 2013 (FAOSTAT, 2013). Potato consumption as processed and fresh food is also increasing considerable in Bangladesh (Brown, 2005). People living in As affected areas are consuming contaminated potatoes that creates serious health problems. With this in mind, our research aimed to study the effect of As on the yield reduction of fourteen popular potato varieties and the As accumulation pattern in tuber peels and flesh.

Materials and methods

Location and plant material

This study was carried out at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, located at 23°77'N and 90°37'E at an altitude of 8.6 m a.s.l., from November 10, 2012 to February 18, 2013. The average air temperature and precipitation during the growth of the potato crop were 15.57 to 26.27°C and 30.25 mm, respectively. The soil of the experimental site was silt loam in texture, with a pH of 6.4, 0.68% organic carbon, 800 mg kg^{-1} of total nitrogen, 10.99 mg kg^{-1} of available phosphorus, 19.5 mg kg^{-1} of available potassium and 10.5 mg kg^{-1} of available sulfur. Fourteen potato varieties: Diamant, Cardinal, Asterix, Granola, Lady Rosetta, Courage, BARI TPS-1, Meridian, Felsina, Laura, Quincy, Sagitta,Rumana, and Jam Alu and three arsenic levels of 0, 25 and 50 mg kg^{-1} soil of As were selected for this experiment.

Soil arsenic treatment

Alam and Sattar (2000) reported that the soils collected from different locations in Bangladesh had elevated As concentrations, up to 57 mg kg^{-1}. However, Kabata-Pendias and Pendias (1992) recommended 20 mg kg^{-1} as the safe level for As in agricultural soils. Sodium meta-arsenate ($Na_2HAsO_4{\cdot}7H_2O$) was used as the source of As in the soil, according to the treatment.

Yield reduction (%)

Yield reduction was calculated with the following Eq. 1:

$$\text{Yield reduction (\%)} = \frac{YC - YT}{YC} \times 100 \qquad (1)$$

where, *YC* = Yield/plant in As free soil and *YT* = Yield/plant in As contaminated soil

Chemical analysis

After harvesting, samples were collected and dried. Tubers were washed and peeled with a mechanical peeler to obtain uniformity in thickness (2 mm) of the peel. The dried samples were smashed with a mortar and pastel machine. Then, a chemical analysis was done to find out the uptake amount. This analysis was done in the Bangladesh Council of Scientific Research Institute (BCSRI). The chemical analysis to determine the total As concentration in the plant samples was done with an atomic absorption spectrophotometer where argon was used as the carrier gas and As was melted at 925°C.

Statistical analysis

The experiment was arranged in a randomized complete block design with three replicates. The analysis of variance (ANOVA) and Duncan's multiple range test for the variables at a 5% level of probability were conducted using the MSTAT-C program (Gomez and Gomez, 1984).

Results and discussion

Tuber yield per plant

The biomass production and yield of crop varieties are reduced significantly at elevated As concentrations (Carbonell-Barrachina *et al.,* 1997). An application of only 50 mg kg^{-1} soil of As significantly decreased the yields of

barley and rye grass (Jiang and Singh, 1994). An application of 25 mg kg^{-1} soil of As did not have negative effects on potato yield when compared to a control (Tab. 1). At higher concentrations, As interfered with plant metabolic processes, resulting in a loss of yield and fruit production and morphological changes when plants were grown in As treated soils (Srivastava *et al.,* 2009). The highest tuber yield/plant (426.2 g fresh weight-FW) was obtained from the 'Felsina' variety, which was statistically similar to 'Diamant' and 'Asterix', while the lowest one (77.15 g FW) was found with 'Jam Alu'. The yields of the different cultivars of potato were significantly different from each other, as reported by Kundu *et al.* (2012a). A similar trend of yield performance was also reported by Hossain (2011), Dhar *et al.* (2009) and Das (2006). The probable reason for the yield variation was due to the heredity of the variety.

On the other hand, the highest tuber yield/plant (334.6 g FW) was recorded with the control, which was statistically similar to 25 mg kg^{-1} soil of As and the lowest (247.3 g FW) was recorded with 50 mg kg^{-1} soil of As. Carbonell-Barrachina *et al.* (1998) and Gulz (1999) observed that yield increases with small additions of As for corn, potatoes, rye and wheat. The tuber yield/plant was significantly influenced by the effect from the varieties and As levels interaction. Among the treatments, the highest tuber/plant yield was observed in 'Felsina' with the control (454.80 g), which was statistically similar to 'Felsina' and 25 mg kg^{-1} soil of As, 'Diamant' and the control, 'Diamant' and 25 mg kg^{-1} soil of As, 'Asterix' and the control and 'Asterix' and 25 mg kg^{-1} soil of As; whereas, the lowest (34.50 g FW) was seen with 'Jam Alu' and 50 mg kg^{-1} soil of As (Tab. 2).

Percentage yield reduction

The high rates of As application were closely related to the reduction of crop yield (Woolson *et al.,* 1971) and the increase in As concentration in the plants (Thoresby and Thornton, 1979). 'Jam alu' showed the highest yield reduction (23.69%) and the lowest one was observed with 'Felsina' (6.29%), which was statistically similar to that

TABLE 1. Effect of variety and As level on the yield, yield reduction and As content in the peels and flesh of the potato varieties.

Variety	Tuber yield/plant (g FW)	Percentage of yield reduction	As content in tuber peels (mg kg^{-1} DW)	As content in tuber flesh (mg kg^{-1} DW)
Diamant	408.1 ab	7.69 ef	2.590 ef	0.104 d
Cardinal	370.0 c	8.89 de	2.583 ef	0.100 d
Asterix	394.6 b	7.38 ef	2.657 c-e	0.127 cd
Granola	258.4 g	11.10 cd	2.657 c-e	0.124 cd
Lady Rosetta	336.4 de	7.91 ef	2.598 d-f	0.116 cd
Courage	309.8 f	9.00 de	2.748 b	0.174 ab
BARI TPS-1	262.8 g	10.94 cd	2.553 f	0.129 cd
Meridian	359.7 cd	8.38 ef	2.654 c-e	0.124 cd
Felsina	426.2 a	6.29 f	2.678 b-d	0.147 bc
Laura	363.4 c	8.14 ef	2.701 bc	0.173 ab
Quincy	138.2 i	17.39 b	2.654 c-e	0.126 cd
Sagitta	330.8 ef	8.64 ef	2.922 a	0.187 a
Rumana	216.0 h	11.84 c	2.946 a	0.189 a
Jam Alu	77.15 j	23.69 a	2.309 g	0.108 d
SE value	8.481	0.739	0.026	0.0105
Level of significance	**	**	**	**
As levels in the soil (mg kg^{-1})				
0	334.6 a	0.00 c	0.00 c	0.000 c
25	329.1 a	1.98 b	1.985 b	0.178 b
50	247.3 b	29.58 a	5.997 a	0.236 a
SE value	3.926	0.342	0.012	0.0049
Level of significance	**	**	**	**

** significant at $P \leq 0.01$.

Means with different letters in each column indicate significant differences according to the Duncan's multiple range test ($P \leq 0.05$).

TABLE 2. Variety and As level interaction effect on the yield, yield reduction and As content in the peels and flesh of the potato varieties.

Variety× As level in soil (mg kg^{-1})		Tuber yield/plant(gFW)	Percentage of yield reduction	As content in tuber peels (mg kg^{-1} DW)	As content in tuber flesh (mg kg^{-1} DW)
'Diamant'	0	442.1 a-c	0.00 h	0.00 m	0.000 m
	25	436.1a-d	1.36 gh	1.883 jk	0.130 kl
	50	346.0 i-l	21.71 de	5.887 d-f	0.183 e-k
'Cardinal'	0	405.9 b-g	0.00 h	0.00 m	0.000 m
	25	399.0 c-h	1.75 gh	1.873 jk	0.120 l
	50	305.0 l-o	24.92 de	5.877 ef	0.180 e-l
'Asterix'	0	426.0 a-e	0.00 h	0.00 m	0.000 m
	25	421.4 a-f	1.08 gh	1.980 ij	0.160 g-l
	50	336.4 k-n	21.06 ef	5.990 c-e	0.220 c-g
'Granola'	0	292.2 n-q	0.00 h	0.00 m	0.000 m
	25	286.2 o-q	2.30 gh	1.977 jk	0.157 h-l
	50	196.8 tu	31.00 c	5.993 c-e	0.217 c-h
'Lady Rosetta'	0	365.3 g-k	0.00 h	0.00 m	0.000 m
	25	359.4 g-k	1.63 gh	1.890 jk	0.143 i-l
	50	284.6 o-r	22.11 de	5.903 d-f	0.203 c-i
'Courage'	0	340.3 j-m	0.00 h	0.00 m	0.000 m
	25	334.8 k-n	1.64 gh	2.110 i	0.233 b-e
	50	254.3 p-r	25.35 d	6.133 b	0.290 ab
'BARI TPS-1'	0	295.0 m-p	0.00 h	0.00 m	0.000 m
	25	290.8 n-q	1.44 gh	1.823 k	0.163 f-l
	50	202.5 s-u	31.38 c	5.837 f	0.223 c-f
'Meridian'	0	392.2 d-i	0.00 h	0.00 m	0.000 m
	25	386.3 e-j	1.57 gh	1.977 ij	0.157 h-l
	50	300.5 l-p	23.57 de	5.987 c-e	0.217 c-h
'Felsina'	0	454.8 a	0.00 h	0.00 m	0.000 m
	25	448.8 ab	1.32 gh	2.010 ij	0.193 c-j
	50	374.9 f-k	17.56 f	6.023 b-d	0.247 b-d
'Laura'	0	395.7 c-h	0.00 h	0.00 m	0.000 m
	25	392.0 d-i	0.96 gh	2.043 i	0.233 b-e
	50	302.6 l-p	23.47 de	6.060 bc	0.287 ab
'Quincy'	0	167.3 u	0.00 h	0.00 m	0.000 m
	25	161.4 u	3.52 gh	1.977 ij	0.160 g-l
	50	86.01 v	48.65 b	5.987 c-e	0.217 c-h
'Sagitta'	0	362.2 g-k	0.00 h	0.00 m	0.00 m
	25	356.3 h-k	1.66 gh	2.377 h	0.250 b-d
	50	274.1 o-r	24.26 de	6.390 a	0.310 a
'Rumana'	0	245.0 q-s	0.00 h	0.00 m	0.000 m
	25	239.2 r-t	2.39 gh	2.410 h	0.253 bc
	50	163.9 u	33.14 c	6.427 a	0.313 a
'Jam Alu'	0	101.0 v	0.00 h	0.00 m	0.000 m
	25	95.90 v	5.12 g	1.457 l	0.133 j-l
	50	34.50 w	65.96 a	5.470 g	0.190 d-k
SE value		14.69	1.279	0.045	0.0183
Level of significance		**	**	**	**

** significant at $P \leq 0.01$.

Means with different letters in each column indicate significant differences according to the Duncan's multiple range test ($P \leq 0.05$).

in 'Asterix', 'Diamant', 'Lady rosetta', 'Laura', 'Meridian', and 'Sagitta', while the yield was further reduced with increasing As levels (Tab. 1). The highest yield reduction (29.58%) was recorded with 50 mg kg^{-1} soil of As and the lowest one (1.98%) was recorded with 25 mg kg^{-1} soil of As. Among the treatment combinations, the highest yield reduction was observed with 'Jam Alu' and 50 mg kg^{-1} soil of As (65.96%) and the lowest one was found with 'Laura' and 25 mg kg^{-1} soil of As, which was statistically similar to the 25 mg kg^{-1} soil of As treatment in all of the varieties (Tab. 2). Carbonell-Barrachina *et al.* (1997) reported that, in beans (*Phaseolus vulgaris*), yield showed a higher reduction of 84% as compared to controls when As was present in the growth solutions.

Arsenic content in tuber peels

The As content in tuber peels varied significantly due to the varieties and/or As levels. The maximum As accumulation of the tuber peels was recorded in the 'Rumana' variety (2.946 mg kg^{-1}), followed by 'Sagitta', whereas, the lowest amount of As was observed in the 'Jam Alu' variety (2.31 mg kg^{-1}) (Tab. 1). Rahman *et al.* (2007b) and Kundu *et al.* (2012a) reported that the As concentration that was considered toxic varied widely with plant genotypes, probably due to varietal differences in As translocation and the phyto-extraction or phyto-morphological potential of the varieties. Table 1 shows that the As accumulation in the tuber peels increased with increasing As levels. The highest As accumulation in the tuber peels (5.997 mg kg^{-1}) was recorded with the 50 mg kg^{-1} soil of As treatment; whereas, the lowest one was accumulated with 25 mg kg^{-1} soil of As (1.985 mg kg^{-1}). No As was detected in the control treatment. Pyles and Woolson (1982) found 3.00 mg kg^{-1}As in potato peels when the soil was treated with 100 mg kg^{-1}As. As appears to accumulate preferentially in potato peels (Roychowdhury *et al.,* 2002; Warren *et al.,* 2003), either because tubers are able to absorb As from the surrounding soil or because soil particles adhered to the tuber surface have not been completely cleaned. The results of the treatment combinations revealed that the maximum As accumulation in the tuber peels (6.427 mg kg^{-1}) was recorded with 'Rumana' grown with 50 mg kg^{-1} soil of As, which was statistically similar to the combination of 'Sagitta' and 50 mg kg^{-1} soil of As; whereas, the lowest accumulation (1.457 mg kg^{-1}) was seen with 'Jam Alu' and 25 mg kg^{-1} soil of As (Tab. 2).

Arsenic content in tuber flesh

The different potato tuber varieties accumulated different amounts of arsenic in the edible parts (Kundu *et al.*, 2012b). However, the potato tubers, despite being an underground part (a modified stem), contained relatively lower amounts of As (Adak and Mandal, 1999). 'Rumana' accumulated the maximum amount of As in the tuber flesh (0.189 mg kg^{-1}), which was statistically similar to 'Sagitta', 'Courage', 'Laura' and 'Felsina'; whereas, the least amount of As accumulation was observed in the Cardinal variety (0.100 mg kg^{-1}), which was statistically identical with 'Diamant' and 'Jam Alu', where the As content of tuber flesh increased with the increasing As levels (Tab. 1). The maximum As concentration (0.236 mg kg^{-1}) was recorded with 50 mg kg^{-1} soil of As and the lowest one (0.178 mg kg^{-1}) was recorded with 25 mg kg^{-1} soil of As. No As was found in the control treatment. A higher content of As in soils also causes higher absorption of this element by the roots (Onken and Hossner, 1995). In the treatment combinations, the maximum As concentration (0.313 mg kg^{-1}) was found with 'Rumana' and 50 mg kg^{-1} soil of As and the lowest one (0.120 mg kg^{-1}) was recorded with 'Cardinal' and 25 mg kg^{-1} soil of As (Tab. 2).

Conclusion

The present experiment showed that the yield of the potatoes slowly decreased up to 25 mg kg^{-1} soil of As and thereafter drastically decreased as the As level increased. The yield of the potatoes was reduced with increasing As levels in the soil. The Felsina, Cardinal and Diamant varieties showed a better yield performance and less As accumulation, as compared to other varieties when cultivated with 25 mg kg^{-1} soil of As.

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