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# Response of sunflower (*Helianthus annuus* L.) to arsenic stress: Accumulation and partitioning in different plant parts

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## Abstract

*The experiment was performed using two cultivars (FH-331 and FH-385) of sunflower (Helianthus annuus* L.*) to study the arsenic distribution pattern in different plant tissues. Arsenic was applied at 0, 20, 40, 60, 80 and 100 mg $kg^{-1}$ soil in the form of $Na_2HAsO_4.7H_2O$ or $NaAsO_2$. Results revealed that increase in rhizospheric arsenic significantly reduced the root depth, shoot height, fresh and dry mass of root as well as shoot, number of leaves per plant and yield parameters, such as, capitulum diameter and achene mass. Arsenic accumulation in the plant tissues increased with increase in soil arsenic level with varied uptake in different plant tissues. Arsenic concentration in different plant tissues were in order of: roots > leaves > shoot > achenes. The maximum concentration of arsenic (87.66 $\mu g\ g^{-1}$ dry mass) was found in root tissues of plants receiving 100 and 36.6 mg As $kg^{-1}$ soil in the form of $NaAsO_2$ and $Na_2HAsO_4.7H_2O$, respectively. Lower accumulation of arsenic in achenes as compared to all other plant tissues revealed poor translocation of this toxic element to the fruit. We concluded from present study that Arsenic predominantly deposited into the leaves of sunflower rather than the seeds. Our findings may assist the sunflower cultivation program in Arsenic contaminated soil.*

**Keywords:** Arsenic, metal toxicity, phytoremediation, plant tissues, sunflower

## Introduction

Arsenic (As), a carcinogenic trace metalloid (Matschullat, 2000; Ahmad *et al.,* 2009; Pigna *et al*., 2009), occurs naturally in the earth's crust and is the 28$^{th}$ most abundant element (Bhattacharya and Pal, 2012) found in all environmental media (Fitz and Wenzel, 2002). It can enter the environment through weathering of rocks, biological activity, and volcanic activity (Meharg and Hartley-Whitaker, 2002). Anthropogenic inputs from agricultural and industrial practices, wastewater irrigation, precipitation from heavy coal combustion and smelter wastes and residues from metalliferous mining, increase the levels of As contamination in soil and ground as well as surface water (Zhang *et al.,* 2002; Sun *et al.,* 2009; Wu *et al.,* 2013). The higher level of arsenic in the environment may set off a variety of problems, such as loss of vegetation, ground water contamination, and arsenic toxicity in plants, animals, and humans (Mahimairaja *et al.,* 2005; Fu *et al.,* 2008; Paul and Shakya, 2013; Falinski *et al.,* 2014). Inorganic As species which usually predominates the soils (e.g. arsenite) are carcinogenic while organic As species (arsenobetaine) are less toxic to humans (Zhao *et al.,* 2010). Alarming levels of ground water arsenic concentration in different regions of Pakistan has been observed during the course of water quality surveys (PCRWR, 2004). The situation is devastating in Bangladesh that can easily be reflected by the number of affected people where out of 7-11 million hand pumped tube-wells, approximately half have been estimated to supply groundwater with an arsenic concentration more than 50 µg $L^{-1}$, which is the maximum level of arsenic allowed in drinking water.

Plants have evolved a variety of mechanisms, including avoidance or exclusion, which help detoxify toxic elements, thus allowing plants to survive in Arsenic contaminated environment (Goldsbrough, 2000). Scientists are now focusing their studies to explore the phyto-extraction potential of different species and to find out the distribution pattern of metalloids (Arsenic) in commercially important crops (Marmiroli *et al.,* 2007). The distribution of As species can occur both in the xylem and the phloem within plants (Ye *et al.,* 2010) and its root to shoot translocation may vary among plant species. Arsenite predominated in the xylem sap of *Solanum lycopersicum*, *Cucumis sativus* and *Oryza sativa* while arsenate predominated in xylem sap of *Ricinus communis*, *Triticum aestivum*, *Brassica juncea* exposed either to arsenate or arsenite (Ye *et al.,* 2010). However, arsenate predominated in the phloem sap of *Ricinus communis* exposed to either arsenate or arsenite (Ye *et al.,* 2010). Information regarding the soil-to-plant translocation of metals and metalloids and their

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accumulation patterns in edible plant parts is lacking and is required to evaluate the possible health risks in consumers (Meharg and Hartley-Whitaker, 2002).

Sunflower (*Helianthus annuus* L.), the world's fourth largest oil seed crop (Rodriguez *et al.*, 2002; Burke and Rieseberg, 2003;) has considerable contribution towards the production of edible oil due to high yield potential as well as oil quality. The particular agro-climatic conditions of Pakistan make it possible to cultivate sunflower during spring and autumn seasons. Furthermore, its less water and fertilizer requirements, high profitability due to its versatile role as a high proteinacious meal, oil contents, medicinal use and preparation of textile dyes, etc. attracts the framers to cultivate it over large areas in Pakistan. In view of the increasing arsenic contamination in agricultural soils and cultivation of sunflower over large area in Pakistan, it would be of great interest to investigate the effect of arsenic on this potential oilseed crop. The present study was conducted to evaluate phyto-extraction potential of sunflower and to find out the extent of arsenic accumulation in different plant parts, particularly the achenes.

The current study was aimed (1) to investigate if various As concentrations in soil influenced the As accumulation and partitioning in sunflower and (2) to evaluate the potential of sunflower for decontamination of As polluted soils. We hypothesized a high As translocation from roots to shoots in sunflower making it an appropriate candidate for phyto-extration of As.

## Materials and Methods

A pot experiment was conducted in the wire house of Department of Botany, University of the Punjab, Lahore, Pakistan to explore the toxicity and arsenic uptake or accumulation potential of sunflower (*Helianthus annuus* L.) grown on arsenic contaminated soil. Achenes (seeds) of two sunflower cultivars viz. FH-331 and FH-385 were obtained from the Oil Seeds Department of Ayub Agricultural Research Institute (AARI), Faisalabad, Pakistan. Earthen pots lined with polythene sheets, having capacity of 100 kg soil collected from river Ravi basin were used for this experiment. Soil (clay loam) free from any contamination was air-dried ground and passed through 1 mm sieve. The physico-chemical characteristics of soil were recorded following Jackson (1962) prior to sowing of seeds (Table 1).

There were eleven treatments comprising of five different concentrations of arsenic for both arsenic compounds, and one without any arsenic contamination was control. Sodium arsenate ($Na_2HAsO_4.7H_2O$) as source of $As^V$, and sodium arsenite ($NaAsO_2$) as source of $As^{III}$ (Pigna *et al.*, 2009) of Sigma Aldrich, Japan, were thoroughly mixed in soil at final concentrations of 20, 40, 60, 80 and 100 mg As $kg^{-1}$ dry soil of each of above mentioned salts as described by Liu *et al.* (2012). Plants were watered with half strength Hoagland's (Hoagland and Arnon, 1950) nutrient solution throughout the course of study.

**Table 1: Physico-chemical properties of soil used for the study**

| Soil Property | Value |
|---|---|
| **Soil Texture** | Clay loam |
| **Clay (%)** | 57 |
| **Sand (%)** | 29 |
| **Silt (%)** | 14 |
| **Organic matter (%)** | 0.74 |
| **Saturation percentage** | 29 |
| **Moisture percentage** | 18 |
| **Soil pH** | 7.8 |
| **Electrical conductivity (dS $m^{-1}$)** | 2.3 |
| **Nitrogen (%)** | 4.7 |
| **Available phosphorus (mg $kg^{-1}$ dry soil)** | 5.3 |
| **Potassium (mg $kg^{-1}$ dry soil)** | 188.1 |
| **Calcium (mg $kg^{-1}$ dry soil)** | 105 |
| **Total Arsenic (µg $g^{-1}$ dry soil)** | 0.3 |

The data were collected twice during the course of this study as shoot length (cm), root length, number of leaves, fresh weight of shoot, dry weight of shoot as well as fresh and dry weight of root were recorded at vegetative stage (at commencement of anthesis or flowering, 45 days after sowing). Shoot height, root length, number of leaves, capitulum diameter, achenes mass and arsenic contents in root, shoot, leaves and achenes were recorded at the time of final harvest or maturity. Plants were uprooted carefully and separated into roots, shoots and leaves. Dry mass of different plant parts were recorded after drying completely in an oven for 60 hours at 80°C (Zhang *et al.*, 2009).

Wet ashing of plant samples was performed according to Mir *et al.* (2007) and digested with the help of conc. $HNO_3$, 72% $HClO_4$ and diluted (1:1) HCl. The diluted digest was passed through a Whatman No. 42 filter paper. Arsenic concentration in the extracted solution was determined with the help of Inductively Coupled Plasma, Optical Emission Spectrometer (ICP-OES, Perkin Elmer, Germany).

The experiment was laid out in completely randomized design (CRD) with three replicates. The data regarding all morpho-chemical parameters was subjected to two-way analysis of variance (ANOVA) with the help of SPSS computer software, version 16 (SPSS, software, 2008,

Monterey, California) and to compare significance of interaction means.

The present research work was conducted in accordance with national and institutional guidelines for the protection of human health subjects and animal welfare.

## Results and Discussion

In current study, the concentration-dependent uptake of As by *H. annuus* was investigated. All the morpho-chemical attributes of sunflower cultivars were affected by different levels of applied arsenic. The higher concentrations (80 and 100 mg As $kg^{-1}$ soil) exerted significant toxic effects on all parameters and for both sunflower cultivars. Two way analysis of variance (ANOVA) showed highly significant differences (Table 2,4,5) for shoot height, root depth, number of leaves, fresh and dry mass of root as well as shoot examined either at the vegetative or the reproductive stages. The arsenic concentrations in root, shoot, leaves and seeds (achenes) of plants treated with different levels of inorganic arsenicals also varied significantly. Number of leaves and capitulum diameter recorded at the maturity stage also differed significantly. In contrast, root length, number of leaves, shoot dry matter of arsenic treated and untreated plants recorded at the vegetative stage did not differ statistically. Similarly, shoot height, root depth and 100 achene weight of arsenic treated and untreated plants recorded at the reproductive stage differed non-significantly. Cultivar x treatment interaction (C×T) showed significant differences for shoot dry weight calculated at the vegetative stage and capitulum diameter at the maturity stage. Whereas, non-significant differences in cultivar x treatment interaction (C×T) were observed for all other parameters appraised at the vegetative or the reproductive stage, except for arsenic concentration in root, shoot, leaves and seeds.

The reduced root or shoot growth in response to arsenic exposure has been reported by a number of investigators in certain other plants (Sneller *et al.*, 2000; Hartley-Whitaker *et al.*, 2001; Abedin *et al.*, 2002). The results of the present study clearly indicated that the growth reduction due to arsenic stress was much more pronounced in the root than the shoot (Table 3, 6 and7), which further constrained the growth of the whole plant, decreasing the plant biomass and ultimately the yield. One possible reason might be the fact that roots were the first point of contact to higher level of arsenic in the growth media.

**Table 2: Two way analysis of variance (ANOVA) showing the effects of arsenic treatments on morphological aspects and yield of sunflower at the vegetative stage (Mean ± SE)**

| SOV | Cultivar (C) | Arsenic Treatments (T) | Interaction (C×T) | Error |
|---|---|---|---|---|
| **DF** | 1 | 10 | 10 | 1 |
| **Shoot height** | 582.54 *** | 241.47 *** | 7.3 $^{NS}$ | 13.22 |
| **Root depth** | 20.06 * | 62.62 *** | 3.12 $^{NS}$ | 4.2 |
| **Leaves plant$^{-1}$** | 0.01 $^{NS}$ | 9.77 *** | 0.76 $^{NS}$ | 1.47 |
| **Fresh Weight Stem** | 53.22 *** | 35.53 *** | 1.62 $^{NS}$ | 1.45 |
| **Dry Weight stem** | 0.1 $^{NS}$ | 2.04 *** | 0.09 $^{NS}$ | 0.06 |
| **Fresh Weight root** | 0.51 * | 5.37 *** | 0.08 $^{NS}$ | 0.11 |
| **Dry Weight root** | 0.02 *** | 0.03 *** | 0 $^{NS}$ | 0 |
| **Capitulum diameter** | 14.13 *** | 30.83 *** | 2.31 ** | 0.65 |
| **100 achene mass** | 0.01 $^{NS}$ | 1.95 *** | 0.26 $^{NS}$ | 0.16 |

SOV = source of variation; DF = degree of freedom

**Table 3: Two way analysis of variance (ANOVA) showing the effects of arsenic treatments on arsenic accumulation in different plant parts at the maturity stage (Mean± SE)**

| SOV | DF | As Root | As Shoot | As Leaf | As Seed |
|---|---|---|---|---|---|
| Cultivar (C) | 1 | 207.06 * | 15.49$^{NS}$ | 857.26 *** | 2.84** |
| Arsenic Treatments (T) | 10 | 4287.44 *** | 1311.39 *** | 2327.66 *** | 5.74*** |
| Interaction (C×T) | 10 | 654.42 *** | 72.97 *** | 2084.35 *** | 1.65*** |
| **Error** | 48 | 32.09 | 4.77 | 0.39 | 0.33 |

SOV = source of variation; DF = degree of freedom

Overall growth of sunflower plants grown in higher arsenic (80 and 100 mg As $kg^{-1}$ soil) containing soils was suppressed as compared to untreated plants indicating that sunflower plant, (although retarded), can grow in arsenic contaminated soils and can also accumulate to some extent.

**Table 4: Influence of different arsenic treatments on morphological attributes of sunflower at the vegetative stage in sunflower cultivar FH-331(Mean± SE)**

| Treatment | Sht. L 1(cm) | Rt. L 1(cm) | No. Lvs.1 | Shoot. F.wt. (g) | Shoot. D.wt. (g) | Root. F.wt. (g) |
|---|---|---|---|---|---|---|
| **0mg As** | 35.67 ±3.21 | 17.33 ±2.52 | 12.33 ±0.58 | 14.15 ±8.2 | 2.35 ±1.37 | 2.95 ±1.71 |
| **20mg $As^{5+}$** | 32.33 ±3.06 | 16.33 ±1.53 | 10.33 ±0.58 | 12.67 ±1.02 | 1.7 ±0.26 | 2.53 ±0.42 |
| **40mg $As^{5+}$** | 32 ±7.21 | 15.67 ±3.06 | 10.67 ±1.15 | 11.27 ±1.17 | 1.19 ±0.28 | 1.93 ±0.51 |
| **60mg $As^{5+}$** | 25.77 ±3.91 | 13.67 ±1.53 | 10 ±1 | 11.07 ±1.01 | 0.71 ±0.04 | 0.92 ±0.33 |
| **80mg $As^{5+}$** | 22.17 ±2.25 | 11 ±1.73 | 9.33 ±1.15 | 10.3 ±1.73 | 0.47 ±0.11 | 0.76 ±0.23 |
| **100mg $As^{5+}$** | 17.33 ±1.53 | 8.33 ±1.53 | 7.67 ±1.53 | 7.03 ±0.95 | 0.36 ±0.04 | 0.42 ±0.07 |
| **20mg $As^{3+}$** | 30.33 ±1.53 | 16.33 ±1.53 | 10.33 ±0.58 | 11.13 ±1.21 | 1.02 ±0.17 | 1.57 ±0.45 |
| **40mg $As^{3+}$** | 28.33 ±1.53 | 15.67 ±1.53 | 10 ±1 | 11.07 ±1.1 | 0.84 ±0.09 | 1.1 ±0.26 |
| **60mg ($As^{3+}$)** | 26.33 ±1.53 | 13.33 ±1.15 | 9.67 ±1.53 | 10.57 ±1.63 | 0.75 ±0.11 | 0.8 ±0.18 |
| **80mg ($As^{3+}$)** | 23 ±3 | 11.67 ±1.15 | 10.33 ±2.08 | 9.57 ±1.29 | 0.62 ±0.08 | 0.62 ±0.04 |
| **100mg ($As^{3+}$)** | 20.33 ±1.53 | 9.67 ±1.53 | 9.67 ±1.53 | 9.33 ±2.08 | 0.53 ±0.24 | 0.48 ±0.11 |
| | **Root. D.wt. (g)** | **Sht. L 2(cm)** | **Rt. L 2(cm)** | **No. Lvs.1** | **Cap. Dia. (cm)** | **100 wt. (g)** |
| **0mg As** | 0.24 ±0.14 | 194 ±112.29 | 29 ±16.77 | 29.67 ±1.53 | 15.75 ±9.12 | 4.34 ±2.5 |
| **20mg $As^{5+}$** | 0.17 ±0.04 | 191 ±8.54 | 25.67 ±3.06 | 26.33 ±0.58 | 15.17 ±0.15 | 3.82 ±0.31 |
| **40mg $As^{5+}$** | 0.15 ±0.03 | 182.67 ±9.07 | 26 ±4 | 26 ±2 | 14.63 ±0.45 | 2.8 ±0.44 |
| **60mg $As^{5+}$** | 0.1 ±0.01 | 161.67 ±14.36 | 21.33 ±1.53 | 22.33 ±3.21 | 13.17 ±0.85 | 2.57 ±0.1 |
| **80mg $As^{5+}$** | 0.06 ±0.02 | 146.67 ±5.51 | 20.67 ±2.08 | 18.67 ±1.53 | 11.77 ±1.08 | 2.57 ±0.43 |
| **100mg $As^{5+}$** | 0.04 ±0.02 | 123.67 ±10.41 | 20 ±2.65 | 16.33 ±2.08 | 8.83 ±1.53 | 2.22 ±0.34 |
| **20mg $As^{3+}$** | 0.18 ±0.03 | 182 ±21.63 | 25.67 ±2.52 | 22.67 ±2.52 | 14.07 ±0.31 | 3.62 ±0.43 |
| **40mg $As^{3+}$** | 0.1 ±0.02 | 161.67 ±9.07 | 23 ±2.65 | 22 ±2 | 13.73 ±0.64 | 3.01 ±0.29 |
| **60mg ($As^{3+}$)** | 0.07 ±0.02 | 160.33 ±21.2 | 24 ±3 | 20.33 ±1.53 | 13.03 ±0.45 | 3.12 ±0.07 |
| **80mg ($As^{3+}$)** | 0.06 ±0.03 | 144.33 ±12.74 | 24 ±3.61 | 19.67 ±1.53 | 12.03 ±0.15 | 2.63 ±0.46 |
| **100mg ($As^{3+}$)** | 0.05 ±0.03 | 140.67 ±17.04 | 20.67 ±2.08 | 19.33 ±1.15 | 10.47 ±0.5 | 2.66 ±0.48 |

**Table 5: Influence of different arsenic treatments on morphological attributes of sunflower at the vegetative stage in sunflower cultivar FH-385 (Mean± SE)**

| Treatment | Sht. L 1(cm) | Rt. L 1(cm) | No. Lvs.1 | Shoot. F.wt. (g) | Shoot. D.wt. (g) | Root. F.wt. (g) |
|---|---|---|---|---|---|---|
| **0mg As** | 40.33 ±1.53 | 19.67 ±1.53 | 12.33 ±1.53 | 14.4 ±0.79 | 2 ±0.7 | 2.97 ±0.45 |
| **20mg $As^{5+}$** | 40.67 ±1.53 | 19.33 ±2.52 | 11 ±1 | 11.43 ±0.51 | 0.96 ±0.12 | 1.77 ±0.38 |
| **40mg $As^{5+}$** | 37.83 ±1.26 | 17.67 ±1.53 | 10.33 ±0.58 | 9.9 ±0.36 | 1.18 ±0.23 | 1.47 ±0.47 |
| **60mg $As^{5+}$** | 33 ±6.56 | 14.67 ±2.08 | 10.67 ±0.58 | 8.73 ±1.25 | 0.85 ±0.11 | 0.96 ±0.23 |
| **80mg $As^{5+}$** | 26.53 ±5.85 | 13 ±3 | 10 ±1 | 8 ±1.11 | 0.62 ±0.09 | 0.64 ±0.06 |
| **100mg $As^{5+}$** | 18.33 ±1.53 | 9.33 ±1.53 | 7.67 ±1.53 | 6.17 ±1.06 | 0.48 ±0.05 | 0.44 ±0.08 |
| **20mg $As^{3+}$** | 37.17 ±2.57 | 15.67 ±3.21 | 10.33 ±0.58 | 9.53 ±0.5 | 0.93 ±0.08 | 1.5 ±0.62 |
| **40mg $As^{3+}$** | 33 ±2.65 | 13.67 ±2.52 | 10.33 ±1.53 | 9.07 ±1.68 | 0.86 ±0.06 | 1 ±0.08 |
| **60mg ($As^{3+}$)** | 32 ±2 | 13.67 ±1.53 | 10.33 ±0.58 | 7.73 ±2.05 | 0.75 ±0.1 | 0.67 ±0.3 |
| **80mg ($As^{3+}$)** | 32.67 ±6.66 | 11.67 ±2.08 | 9 ±1 | 7.1 ±0.95 | 0.64 ±0.07 | 0.54 ±0.3 |
| **100mg ($As^{3+}$)** | 25.67 ±6.66 | 11 ±2.65 | 8.33 ±2.08 | 5.9 ±0.85 | 0.57 ±0.09 | 0.45 ±0.17 |
| | **Root. D.wt. (g)** | **Sht. L 2(cm)** | **Rt. L 2(cm)** | **No. Lvs.1** | **Cap. Dia. (cm)** | **100 wt. (g)** |
| **0mg As** | 0.27 ±0.04 | 202.67 ±7.64 | 29.67 ±2.52 | 28 ±2 | 18.8 ±1.41 | 4.22 ±0.34 |
| **20mg $As^{5+}$** | 0.21 ±0.03 | 192.67 ±7.51 | 26.33 ±2.52 | 24.33 ±2.52 | 15.3 ±0.62 | 2.99 ±0.2 |
| **40mg $As^{5+}$** | 0.17 ±0.04 | 165.67 ±16.26 | 25.67 ±4.04 | 22 ±2 | 14.43 ±0.51 | 3.45 ±0.32 |
| **60mg $As^{5+}$** | 0.13 ±0.04 | 155.67 ±12.66 | 23 ±3 | 20.67 ±1.15 | 13.57 ±0.6 | 2.77 ±0.61 |
| **80mg $As^{5+}$** | 0.1 ±0.04 | 144.33 ±8.39 | 23.67 ±6.43 | 19 ±1 | 12.33 ±0.95 | 2.92 ±0.46 |
| **100mg $As^{5+}$** | 0.06 ±0.02 | 135 ±6.08 | 23 ±4.36 | 18 ±2.65 | 10.9 ±1.23 | 2.48 ±0.56 |
| **20mg $As^{3+}$** | 0.18 ±0.04 | 172.67 ±9.07 | 27.67 ±1.53 | 22 ±2 | 14.27 ±0.75 | 3.21 ±0.61 |
| **40mg $As^{3+}$** | 0.16 ±0.02 | 165.67 ±24.58 | 24.67 ±3.06 | 20 ±2 | 14.23 ±0.25 | 2.82 ±0.21 |
| **60mg ($As^{3+}$)** | 0.15 ±0.04 | 162.67 ±17.95 | 26 ±4 | 20 ±1 | 12.77 ±0.68 | 2.86 ±0.25 |
| **80mg ($As^{3+}$)** | 0.1 ±0.04 | 142 ±13.08 | 24.67 ±4.16 | 19 ±1 | 11.87 ±0.42 | 2.9 ±0.24 |
| **100mg ($As^{3+}$)** | 0.06 ±0.02 | 136.33 ±6.51 | 23.67 ±5.13 | 17.33 ±1.15 | 11.53 ±0.55 | 2.37 ±0.23 |

Sht. L: Shoot length; Rt. L: Root length; No. Lvs.: Number of leaves; Shoot. F.wt.: Shoot fresh weight; Shoot. D.wt.: Shoot dry weight; Root. F.wt.: Root fresh weight; Root. D.wt.: Root dry weight; Cap. Dia.: capitulum diameter; 100 wt.: 10 Achene weight

**Table 6: Arsenic accumulation in different tissues of sunflower cultivar FH-331 grown on arsenic contaminated soil (Mean± SE)**

| Treatment | As Root µg $g^{-1}$ d.wt. | As Shoot µg $g^{-1}$ d.wt. | As Leaf µg$g^{-1}$ d.wt. | As Seed µg $g^{-1}$ d.wt |
|---|---|---|---|---|
| **0mg As** | 0.8 ±0.36 | 0.4 ±0.26 | 0.3 ±0.2 | 0.17 ±0.12 |
| **20mg $As^{5+}$** | 2.27 ±0.8 | 1.53 ±0.45 | 2 ±1 | 2.17 ±0.31 |
| **40mg $As^{5+}$** | 6.6 ±1.71 | 1.2 ±0.36 | 2.8 ±0.4 | 2.5 ±0.6 |
| **60mg $As^{5+}$** | 8 ±1.64 | 2.43 ±0.65 | 6.54 ±0.39 | 2.8 ±0.4 |
| **80mg $As^{5+}$** | 12.17 ±1.9 | 4.8 ±0.46 | 18.87 ±0.55 | 3.1 ±0.9 |
| **100mg $As^{5+}$** | 36.6 ±6.17 | 48.73 ±3.47 | 20.4 ±0.3 | 3.33 ±0.45 |
| **20mg $As^{3+}$** | 4.2 ±1.75 | 2.03 ±0.45 | 4.03 ±0.15 | 1.53 ±0.71 |
| **40mg $As^{3+}$** | 20.3 ±10.65 | 6.23 ±0.31 | 22.33 ±0.35 | 2.37 ±0.7 |
| **60mg ($As^{3+}$)** | 59.83 ±3.94 | 5.47 ±0.65 | 34.37 ±0.57 | 1.33 ±0.7 |
| **80mg ($As^{3+}$)** | 58.07 ±10.3 | 14.1 ±2.81 | 90.24 ±0.32 | 2.07 ±0.45 |
| **100mg ($As^{3+}$)** | 100.77 ±11.61 | 28.8 ±3.4 | 87.33 ±0.59 | 2.7 ±0.4 |

**Table 7: Arsenic accumulation in different tissues of sunflower cultivar FH-385 grown on arsenic contaminated soil (Mean± SE)**

| Treatment | As Root µg $g^{-1}$ d.wt | As Shoot µg $g^{-1}$ d.wt | As Leaf µg $g^{-1}$ d.wt | As Seed µg $g^{-1}$ d.wt |
|---|---|---|---|---|
| 0mg As | 0.7 ±0.7 | 0.27 ±0.21 | 0.5 ±0.4 | 0.37 ±0.31 |
| 20mg $As^{5+}$ | 24.57 ±5.52 | 4.4 ±0.46 | 7.01 ±0.11 | 0.73 ±0.47 |
| 40mg $As^{5+}$ | 17.7 ±3.75 | 2.67 ±0.35 | 12.36 ±0.48 | 1.2 ±0.36 |
| 60mg $As^{5+}$ | 20.57 ±2.45 | 2.6 ±0.5 | 20.17 ±0.67 | 1.33 ±0.4 |
| 80mg $As^{5+}$ | 41.93 ±3.15 | 6.5 ±0.7 | 31.57 ±0.45 | 1.1 ±0.2 |
| 100mg $As^{5+}$ | 71.3 ±8.15 | 57.73 ±7.76 | 75.3 ±0.89 | 3.63 ±1.43 |
| 20mg $As^{3+}$ | 12.63 ±3.86 | 4.23 ±0.71 | 6.3 ±0.3 | 0.87 ±0.35 |
| 40mg $As^{3+}$ | 9.2 ±3.34 | 5.53 ±0.7 | 3.32 ±0.42 | 1.23 ±0.55 |
| 60mg ($As^{3+}$) | 26.07 ±3.68 | 5.3 ±3.9 | 26 ±2 | 2.17 ±0.7 |
| 80mg ($As^{3+}$) | 51.17 ±7.16 | 6.33 ±1.9 | 20.4 ±0.4 | 2.77 ±0.65 |
| 100mg ($As^{3+}$) | 74.57 ±11.41 | 9.17 ±0.35 | 3.28 ±0.37 | 3.7 ±0.46 |

As reported by Zhong *et al.* (2011) that plants belonging to Brassicaceae such as rape and other Indian mustard varieties have high ability of arsenic tolerance compared to sunflower. Yield parameter like capitulum diameter (cm) was also decreased progressively with an increase in arsenic concentration, the plants growing in soil contaminated with 100 mg $As^{5+}$ $kg^{-1}$ soil showed 52% less value for capitulum diameter than arsenic untreated plants (Table 2, 4 and 5). The two forms of arsenic had almost equal growth suppressing effects in terms of shoot as well as root length, number of leaves, fresh and dry weights of root and shoot, particularly when applied at higher level (100 mg $kg^{-1}$ soil).

Arsenic accumulation varied considerably among different plant parts depending upon applied arsenic. Generally highest arsenic concentration was recorded in roots than that in shoot, leaves and seeds. Very little/negligible amount of arsenic was recorded in roots, shoot, leaves and seeds or achenes of arsenic untreated plants. Maximum arsenic concentration was found in roots and leaves out of all four plant organs analyzed. Raab *et al.* (2005) reported that sunflower accumulates much more arsenic in root and leaves than all other plant parts. In our experiment order of arsenic accumulation was found as: roots > leaves > shoot > achenes. The relatively lower accumulation of arsenic in achenes depicted that much of the arsenic was compartmentalized in root and leaves sap translocating very little to the fruiting bodies or seeds. This revealed that roots and to some extent the leaves were powerful sink than achenes.

Moreover, it had been reported that in plants exposed to high concentration of As, the most common mechanism involved in plant tolerance was to reduce the upward transport of this element, resulting higher accumulation in the root (Burlo *et al.,* 1999). In roots, the internal As distribution can be divided between the apoplast and the symplast or can be accumulated into the cellular organelles via phosphate transporters (Meharg and Macnair, 1992). Braven *et al.* (2008) reported that approximately 60% of the total plant As was located in the apoplast of the *O. saiva* roots. Within the root cells, thiol-rich compounds (glutathione and phytochelatins) initiates As speciation

which promotes its storage in the root vacuoles (Moreno-Jiménez *et al.*, 2012) ultimately restricting its translocation to the aerial plant parts.

The similar strategy was developed by sunflower plants to tolerate increasing levels of As in the growth medium by limiting the As transport to shoots and increasing its levels in the root system. However, application of even extremely high As concentrations (100 mg $As^{3+}$) did not cause visual symptoms of toxicity in sunflower plants. This might be attributed to very effective As compartmentalization in sunflower roots which although caused severe effects on root growth but could not induce visual symptoms on above ground plant parts.

The result of present experiment clearly indicated that much more arsenic was accumulated in roots compared to other plant parts. Considering the poor translocation of this toxic element to the fruit, it could be concluded that sunflower FH-385 can be safely cultivated in the As contaminated soils and subsequently the use of these seeds would be harmless for human health. However, sunflower FH-331, owing to its As extraction capability, may be included in decontamination programs for As polluted sediments.

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