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Effect of modified clay minerals and redmud on the bioavailability of arsenic

SIYARAM MEENA, KAPIL A. CHOBHE*, S.P. DATTA, K.M. MANJAIAH AND V.K. SHARMA

Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi -110012, India

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ABSTRACT

A pot experiment was conducted during the winter (rabi) season of 2020-21 to assess the effect of modified clay mineral and redmud (Fe-bentonite, DMSO-bentonite and Fe-redmud) on Arsenic (As) uptake and yield attributes of Indian mustard (Brassica juncea L). Significant reduction in As concentration in the grain and stem due to application of modified clay mineral and redmud was observed. However, Fe-bentonite, DMSO-bentonite and Fe-redmud reduce plant grain and stem As content at all the applied doses except control pot, but application at 5.00 g kg^{-1} soil was found most significant as compare to control and 1.25 g kg^{-1} pot. Soil treated with iron modified bentonite, DMSO-bentonite and Fe-redmud resulted in significantly higher stem biomass and grain yield of mustard as compared to the control pot. Between the treatments, highest stem weight of mustard plant was recorded at higher dose of Fe-bentonite followed by DMSO-bentonite and Fe-redmud but higher grain yield was found higher in case of higher dose of Fe-Redmud.

***Keywords**: Arsenic, bentonite, clay mineral, mustard, redmud*

INTRODUCTION

Arsenic (As) is classified as a class-I carcinogen and its hazard in drinking water has been reported from more than 20 countries (Sanyal *et al.,* 2015). Arsenic pollution is becoming a major problem in the world these days, owing to its widespread distribution in the environment. In this context, As-polluted groundwater of Bengal delta basin comprising Bangladesh and West Bengal (India), bound by the rivers Ganga and Padma, has a great significance (Sanyal *et al.,* 2015). Arsenic poisoning by crops and leafy vegetables is a major immediate concern for humans and other living things. Inhibition of growth, water potential, nutrient supply, chlorophyll biosynthesis, protein content and decrease in photosynthetic efficiency as well as biomass accumulation are all documented effects of arsenic contamination in plants. Arsenate penetrates mustard roots as a phosphate analogue and is quickly converted to As (III). A little amount of arsenic reaches the mustard tissues above ground (Gusman *et al.,* 2013; Shrivastava *et al.,* 2015). Metal removal and recovery methods have been developed as a result of efforts to mitigate contamination of waste water and soils. There are two types of existing approaches for removing As from the soil and environment: abiotic and biotic. The accumulation of heavy metals by plants or microorganisms is the foundation for biotic methods; abiotic methods include physicochemical processes such as precipitation, co-precipitation, solvent extraction, ion exchange, reverse osmosis and adsorption of the heavy metal by a suitable adsorbent. Among these reverse osmosis and ion exchange process are expensive and complex. Precipitation techniques, produce large amounts of heavy metal-laden sludge, whereas ion-exchange and electrochemical methods are too inefficient for large volumes of water and membrane filtration is costly, due to membrane fouling (Stojanovic and Keppler, 2012).

According to a small number of studies, arsenic load in plants can be decreased by chemical amendments. Out of above-mentioned techniques adsorption has been one of the most successful methods for removing arsenic contaminants from soil and water because it has been found to be very efficient, inexpensive, adaptable and quick, with applicability at very low concentrations, suitability for continuous and batch processes, little sludge generation, recycling and reuse possibilities and low capital costs (Sarkar *et al.,* 2012; Mukhopadhyay *et al.,* 2019; Meena *et al.,* 2022). Clay minerals are well-known for their excellent metal sorption properties. Clay minerals have a high specific

**Corresponding author e-mail: chobhekapil27@gmail.com, Scientist- ICAR-Indian Agricultural Research Institute, New Delhi*

surface area associated with a small particle size (less than 2 µm) lamellar structure, high ion-exchange capacity, are cost efficient, and are abundant in soil systems in most soil and sediment environments. Red mud as environmental restoration materials have the characteristics of low cost, simple process and controlling waste by waste. Raw and modified red mud both has good adsorption efficacy of heavy metal ions in soil and west water system (Ma and Feng, 2011; Meena *et al.,* 2022). As a result, the use of modified clay mineral and redmud in the immobilization of arsenic in soil offer a potential research area.

MATERIALS AND METHOD

Soil sample was collected (0-15 cm depth, order: Inceptisols) from the arsenic affected area of Mitrapur village (Nadia district), West Bengal (22.9981 N, 88.6121 E; 8.8 m above mean sea level). Soil sample was prepared as usual and the physico-chemical characteristics were determined following standard procedures. Total and extractable As, soil was digested with aqua-regia (Quevauviller, 1998) and extracted with 0.5 M $NaHCO_3$, pH 8.5 (Olsen *et al.,* 1954), respectively. The pH of soil was determined in 1:2 (soil: water) suspension using combined electrode (glass and calomel electrodes) by digital pH meter (Datta *et al.,* 1997). Organic carbon content in soil was determined by wet oxidation method using $K_2Cr_2O_7$ as outlined (Walkley and Black, 1934). Soil texture was determined by Bouyoucos, (1962) method. The soil's cation exchange capacity (CEC) was determined using Jackson's (1973) ammonium acetate method. Arsenic concentration in mustard samples was determined by using microwave digester with concentrated (65%) suprapure nitric acid (Guven, and Akinci, 2010). ICP-MS (Inductively Coupled Plasma Mass Spectrometry) was used to determine the total amount of As in the digest. Initial soil organic carbon, pH and EC were 15.6 g kg^{-1}, 6.8 and 0.30 dS m^{-1} respectively. Soil was sandy clay in texture with cation exchange capacity 27.5 cmol (p^+) kg^{-1}. Olsen extractable As and total As were found to be 3.1 mg kg^{-1} and 16.2 mg kg^{-1} respectively.

Pot experiment

To assess the effect of modified clay mineral and redmud (Fe-bentonite, DMSO-bentonite and Iron-redmud) on arsenic uptake to plant, a pot culture experiment was conducted in rabi season using mustard (Variety- Rohinga bullet) as a test crop in 2020-21 at IARI, New Delhi. Experiment was laid out in a factorial completely randomized design with three replications. Different product @ 0, 1.25, 2.50, and 5.00 g kg^{-1} soil were added in plastic pots filled with 4 kg soil. Five plants per pot were used to maintain plant population. To maintain the field capacity moisture, soil was irrigated with tap water. The mustard crop supplied a uniform application of recommended N, P, and K fertilizer doses of 80-40-40 kg ha^{-1}. Fifty percent nitrogen applied as a basal dose and the remaining doses applied 30 days after sowing and other recommended agronomical practices were followed.

RESULTS AND DISCUSSION

The biomass (dry weight) of shoots generally reflects the tolerance ability of plants to unfriendly environments (Sun *et al.,* 2015). Soil treated with iron modified bentonites, DMSO modified bentonite and Fe-redmud resulted in significantly higher stem biomass and grain yield of mustard (Table 1, 2) as compared to the control pot. Results exposed that application of higher dose of product increased the stem biomass of mustard (Table 1).

Table 1**:** Effect of modified clay mineral and redmud on stem weight (g pot^{-1}) of mustard

Dose (g kg^{-1})	Fe-Bentonite	DMSO-Bentonite	Fe-Redmud	Mean B
0	3.56	3.67	3.54	3.59
1.25	3.67	4.07	4.18	3.97
2.50	4.42	3.98	4.27	4.22
5.00	4.91	4.75	4.71	4.79
Mean A	4.14	4.11	4.17	
SE(m)	D- 0.21	C- 0.18	D×C- 0.36	
C.D.	D- 0.61	C- N/A	D×C-N/A	

C= Products; D= Dose

Fe-bentonite treated pots increase stem weight (g pot^{-1}) of mustard from 3.56 to 3.67, 4.42 and 4.91 in treated pot at the rate of 1.25, 2.50 and 5.00 g kg^{-1} respectively. Treated pots increase grain yield (g pot^{-1}) of mustard from 1.55 to 1.55, 1.64 and 2.22 @ 1.25, 2.50 and 5.00 g kg^{-1} dose respectively. Between the treatments, highest stem weight (g pot^{-1}) of mustard was recorded at higher dose of Fe-bentonite followed by DMSO-bentonite and Fe-redmud but higher grain yield (g pot^{-1}) was recorded in case of higher dose of Fe-Redmud (Table 2). Sun *et al*. (2015) also found similar results and stated that using less than 10 g kg^{-1} sepiolite increased spinach productivity by 58.5 to 65.5 percent which support our study. The addition of clay mineral and redmud boosted microbial activity, whereas organic matter mineralization limited the availability of metals and metalloids to microorganisms. Improved soil fertility could potentially be one of the causes for increased plant biomass in bentonite and redmud amended treatments. Although research on the use of modified clay mineral in the soil and arsenic bioavailability in primary food crops and vegetables is limited, they do have an indirect effect on arsenic availability.

Table 2: Effect of modified clay mineral and redmud on grain yield (g pot^{-1}) of mustard

Dose (g kg^{-1})	Fe-Bentonite	DMSO-Bentonite	Fe-Redmud	Mean B
0	1.55	1.47	1.53	1.52
1.25	1.55	1.50	1.54	1.53
2.50	1.64	1.53	1.55	1.58
5.00	2.22	2.16	2.43	2.27
Mean A	1.74	1.67	1.76	
SE(m)	C- 0.07	D- 0.08	C × D- 0.14	
C.D.	C- N/A	D- 0.24	C × D- N/A	

C= Products; D= Dose

Arsenic uptake

Significant reduction in arsenic concentration in the mustard grain and stem at harvesting stage was observed due to application of modified clay mineral and redmud. Fe-bentonite reduce the arsenic concentration in the grain from 1.18 mg kg^{-1} in the control to 0.99, 0.55 and 0.41 mg kg^{-1} in the treated pot at the rate of 1.25, 2.50 and 5.00 g kg^{-1} clay dose respectively. DMSO-bentonite also reduce arsenic uptake from 1.14 mg kg^{-1} to 0.99, 0.62 and 0.46 mg kg^{-1} in treated pot at the rate of 1.25, 2.25 and 5.00 g kg^{-1} clay dose respectively. Fe-redmud reduce the arsenic concentration from 1.11 to 0.44 mg kg^{-1} in the treated pot at the rate of 5.00 g kg^{-1} clay dose respectively. However, all treatment reduce grain As concentration @ all the applied doses (Table 3), but application @ 2.50 and 5.00 g kg^{-1} were found most significant compare to the control and 1.25 g kg^{-1}dose. Sarkar *et al*. (2012) also showed the similar results in their study. Usman *et al*. (2006) also found similar results as they used 2% Na-bentonite and Ca-bentonite, which reduced heavy metal concentrations in wheat.

Table 3: Effect of clay mineral and redmud on As concentration (mg kg^{-1}) in the plant grain

Dose (g kg^{-1})	Fe-Bentonite	DMSO- Bentonite	Fe-Redmud	Mean B
0	1.18	1.14	1.11	1.14
1.25	0.99	0.99	0.98	0.99
2.50	0.55	0.62	0.54	0.57
5.00	0.41	0.46	0.44	0.43
Mean A	0.78	0.80	0.76	
SE(m)	C= 0.013	D= 0.02	C×D= 0.03	
C.D.	C= N/A	D= 0.04	C×D= N/A	

C= Products; D= Dose

Pots which are treated by the Fe-bentonite reduce As concentration in plant stem from 1.85 mg kg^{-1} to 1.22, 0.77 and 0.52 mg kg^{-1} in treated pot at the rate of 1.25, 2.50 and 5.00 g kg^{-1} respectively (Table 4). DMSO-bentonite and Fe-redmud also reduce the As concentration in stem from 1.81 and 1.85 mg kg^{-1} to 0.57 and 0.53 mg kg^{-1} respectively in treated pot at the rate of 5.00 g kg^{-1} clay dose. So, Fe-bentonite was observed a good arsenic absorbent into the soil (Table 4). According to Sun *et al*. (2015), ferrihydrite decreased arsenic content in *B. campestris* from 1.84 to 0.97 mg kg^{-1}. This means that modified types of bentonites and redmud boost mustard productivity by reducing arsenic concentration.

Table 4**:** Effect of clay mineral and redmud on as concentration (mg kg^{-1}) in the plant stem

Dose (g kg^{-1})	Fe-bentonite	DMSO-bentonite	Fe-redmud	Mean B
0	1.85	1.81	1.85	1.83
1.25	1.22	1.42	1.43	1.36
2.50	0.77	0.86	0.79	0.80
5.00	0.52	0.57	0.53	0.54
Mean A	1.09	1.17	1.15	
SE(m)	D- 0.01	C- 0.02	D×C- 0.02	
C.D.	D- 0.04	C-0.04	D×C- 0.07	

C= Products; D= Dose

Based on findings of the current investigation the modified clay mineral and redmud including Fe-bentonite, DMSO-bentonite and redmud were found effective for reduction of arsenic uptake by different plant parts. The stem weight and grain yield of the mustard was increased by application of modified products @ 2.50 and 5.00 g kg^{-1}. This means that modified types of clay minerals (bentonite) and redmud boost mustard productivity by reducing arsenic concentration.

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