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Short Communication

Effects of thorium and bromine on plant development and concentration of essential nutrients in wheat

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By now a lot of experimental materials have been collected on environmental chemistry of different trace elements. However, up to the present time, priority has often been given to only few chemical elements known as "heavy metals". The biogeochemistry of a large group of many other trace elements which are present in the environmental samples at low concentrations so far remains poorly investigated.

For example, between two trace elements, uranium (U) and thorium (Th), much information is available on U, although both these radioactive elements are highly toxic, and the concentration of Th in soils and plants is even higher than the concentration of U (Ebyan, 2019). Similar situation is observed in the pair chlorine (Cl) and bromine (Br). Meanwhile, both Th (Wickleder *et al.*, 2008; Joardan *et al.*, 2015; René, 2017) and Br (Winid, 2015; Nishio *et al.*, 2019; Zuiderveen *et al.*, 2020) are widely used in various fields. As a consequence, these trace elements get to the environment and can be accumulated in soils and edible plants.

The aim of the research was to study the ability of wheat to accumulate Th and Br and estimate possible effects of the bioaccumulation of these potentially toxic elements on the plant development and uptake of essential nutrients.

In the research, two pot experiments were carried out in a naturally illuminated greenhouse. The soil used for the experiments had loamy sand texture (sand 73.7%, silt 24.5%, clay 1.8%). The concentrations of total carbon and nitrogen were 4.1% and 2.2%, respectively. The pH (1:2.5 H_2O) of the soil was 7.9. Seeds of wheat (*Triticum aestivum* L.) were obtained from Microbiological Department of St. Petersburg Technical University. The seeds were germinated on a moist filter paper for six days. Uniformed germinated seedlings were transferred to ceramic pots (volume of 7 kg) filled with soil. Before planting, the soil was carefully mixed and exposed to either clean tap water (control), or 60 mg L^{-1} of Th $(NO_3)_4$ (experiment N1), or 100 mg L^{-1} of NaBr or KBr per kg of soil (experiment N2). The soil was then left for three days. The plants were harvested within eight days and washed carefully just after sampling. Leaves were separated from roots and then the plant samples were air-dried at room temperature to a constant weight. All experiments were performed in at least triplicate.

For first experiment, the concentrations of elements in the samples were determined by instrumental neutron activation analysis. The plant samples were irradiated in a nuclear reactor for 17 hr in a thermal neutron flux of 1 $\times$ 10^{14} n cm^{-2} s^{-1}. The k0-method was used to calculate concentrations of elements (Sathler *et al.*, 2019).

For second experiment, the concentrations of elements in the plants were determined by ICP-MS/ICP-OES after leaching the plant samples with tetramethyl ammonium hydroxide (TMAH) using the method described by Tagami *et al.* (2006). The plant samples were weighted in the Teflon Vessels. Two mL of the TMAH solution were added; the vessels were closed and heated in a sand bath at 60 °C during 16 hr. Then the samples were diluted to 25 mL with ultrapure water. For ICP-MS, the samples were diluted to 1:2 with UP-H_2O. For ICP-OES, the samples were diluted to 1:2 with 5% (v/v) HNO_3.

Each plant sample represented a mean of three replicate pots and consisted of at least six plants.

For multivariate statistical analysis, Statistica for Windows 8.0 Software packages (StatSoft, Tulsa, OK, USA) were applied. The mean concentrations of elements were calculated and analysis of variances was carried out to estimate differences between groups of samples. The level of significance was set to $P<0.05$.

Effects of contamination of soil by nitrate of thorium

Wheat seedlings grown in the Th-contaminated soil were able to accumulate large amounts of Th. The concentrations of Th in roots increased ~50 times and in leaves ~6 times as compared to the concentrations of the element in roots and leaves of the plants grown in non-contaminated soil (Fig. 1). As a result of the bioaccumulation of Th, the leaf and root biomasses decreased (Fig. 2).

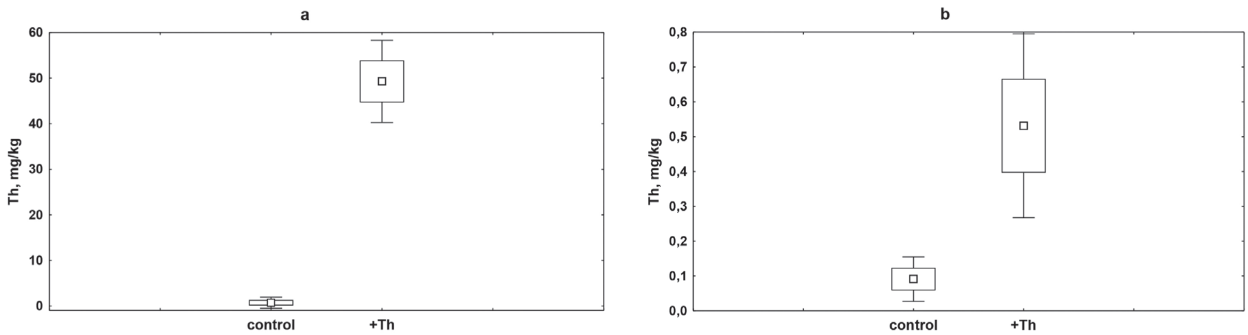

Fig 1 Mean concentrations of Th in roots (a) and leaves (b) of wheat seedlings grown in non-contaminated soil (control) and in the soil spiked with $Th(NO_3)_4$

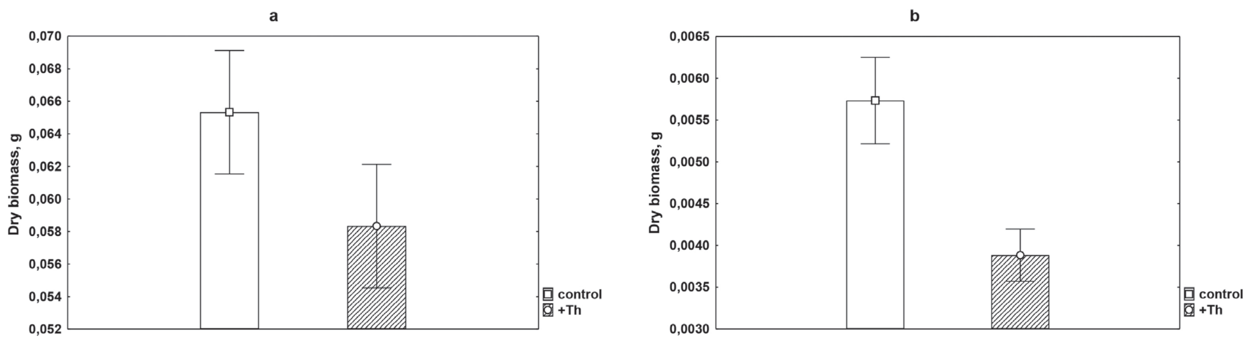

Fig 2 Dry leaf (a) and root (b) biomasses of wheat seedlings grown in non-contaminated soil (control) and in the soil spiked with $Th(NO_3)_4$

One might expect that such a significant accumulation of Th in the wheat seedlings could lead to certain variations in the concentrations of some other elements in the plants. The concentrations of Na and K in both roots and leaves of the wheat seedlings grown in the Th-contaminated soil slightly decreased as compared with concentrations of the macro-elements in the seedlings grown in non-contaminated soil. The concentrations of Ca in leaves of the wheat seedlings grown in contaminated soil slightly increased. However, these changes were not statistically significant.

Effects of contamination of soil by bromides

As a consequence of the growth of wheat seedlings in the soil spiked with bromides, the concentrations of Br increased both in roots and in leaves of the plants (Fig. 3). The level of accumulation of Br depended on the bromide compound applied to the soil. It is interesting that the Br concentration was higher in leaves than in roots. This means roots did not prevent the transfer of Br to upper plant parts.

Wheat accumulated much more Br when it was grown in the soil spiked with KBr. It can be assumed that in this case the higher concentration of K in the growth medium was mainly responsible for the enhanced uptake of both these elements, K and Br, which were present in the bromides. Potassium is an important macro-nutrient. It is the most abundant cation in higher plants. The K^+ is essential for various physiological processes in plants (Mäser *et al.*, 2002). The lower accumulation of Br in the case when it was applied to the soil as NaBr might be due to the presence of Na in the bromide. For most of plants, Na^+ is toxic at high concentrations (Zörb *et al.,* 2019).

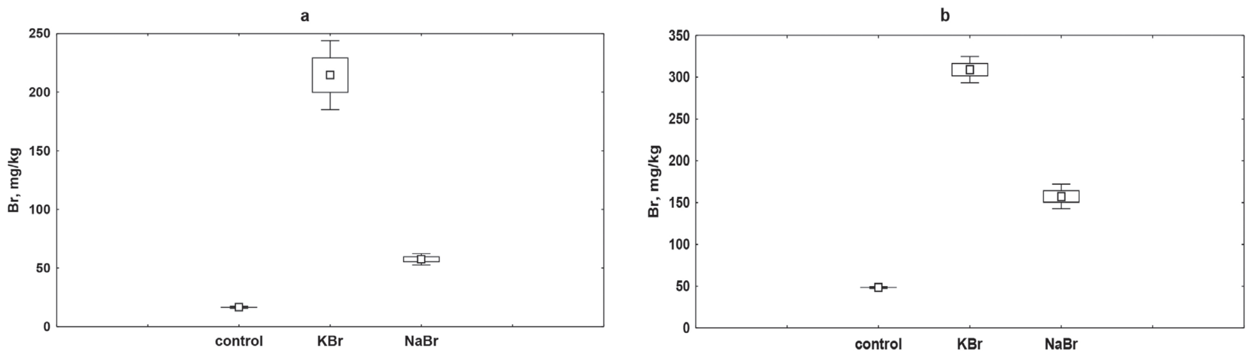

Fig 3 Mean concentrations of Br in roots (a) and leaves (b) of wheat seedlings grown in non-contaminated soil (control) and in the soil spiked with KBr and NaBr

It might be expected that the bioaccumulation of Br can be followed by suppression of the plant development. However, the dry biomass of roots of the wheat seedlings grown in the soil contaminated with NaBr and especially with KBr increased as compared to the root biomass of the seedlings grown in non-contaminated soil (Fig. 4). Similar trend was also observed for leaves. One can suggest that an additional effect on the changes in the plant development were due to both Br and K or Na. The presence of K more positively affected the plant growth than the presence of Na.

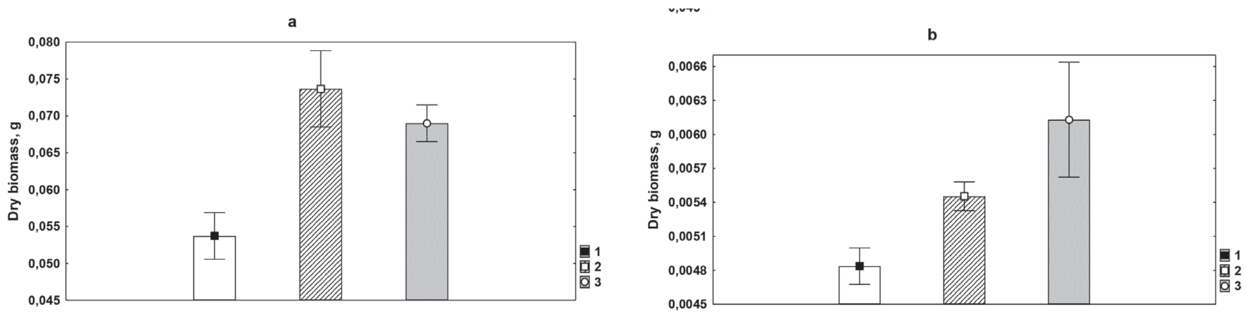

Fig 4 Dry leaf (a) and root (b) biomasses of wheat seedlings grown in non-contaminated soil (1) and in the soil spiked with KBr (2) and NaBr (3)

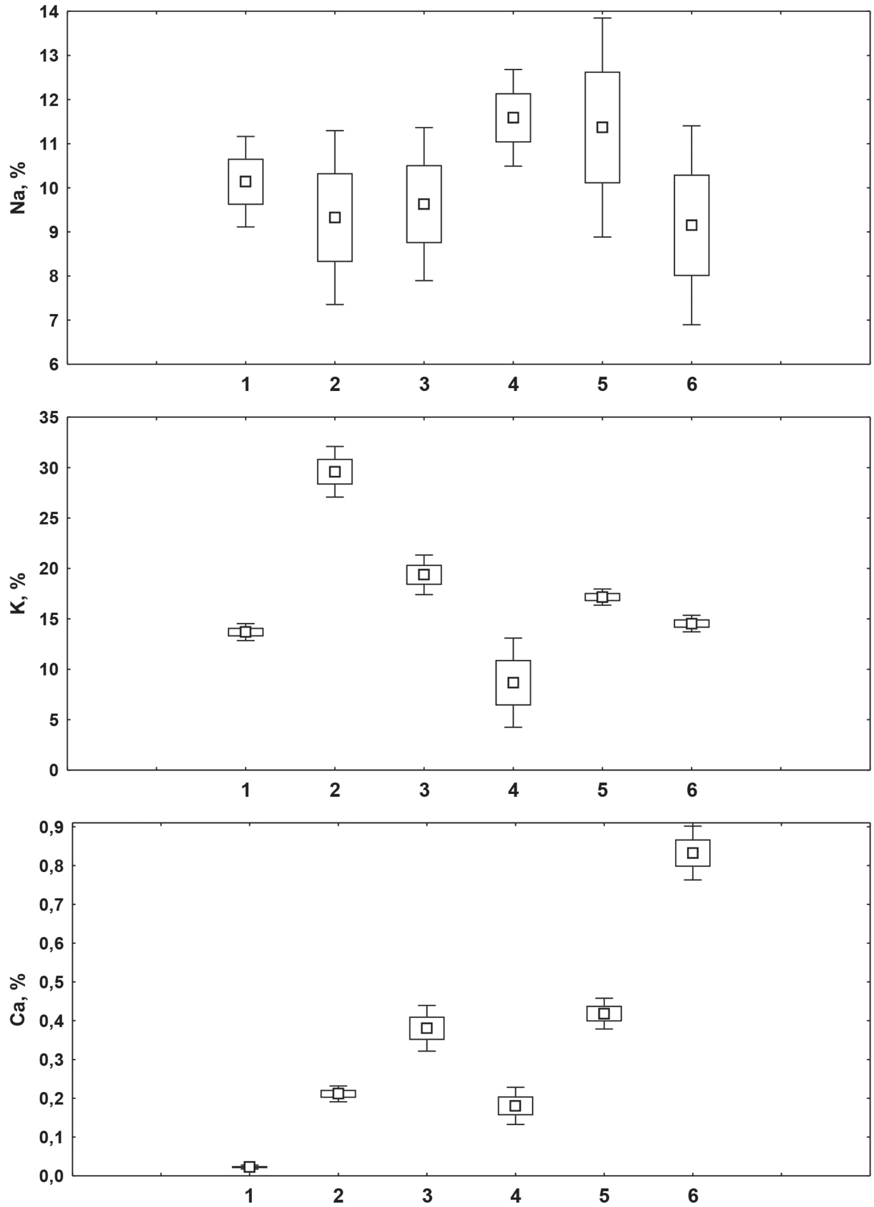

Fig 5 Mean concentrations of Na, K, and Ca in wheat seedlings grown in non-contaminated soil (leaves – 1, roots - 4) and in the soil spiked with KBr (leaves – 2, roots – 5) and NaBr (leaves – 3, roots – 6)

The bioaccumulation of Br also influenced on uptake of Na, K, and Ca by the wheat seedlings (Fig. 5). The plant uptake of Ca was enhanced when the plants were grown in the soil spiked with KBr and NaBr. Moreover, the differences between Ca concentrations in the wheat seedlings grown in clean and bromide-contaminated soils were statistically significant ($P<0.05$). This effect was more marked when wheat seedlings were grown in the soil spiked with NaBr. As was reported by Gattward *et al.* (2012), an increase of the Ca^{2+} accumulation in plants can be a consequence of increasing Na^+ concentration in the growth medium.

As one might expect, growth of wheat seedlings in the soil amended with KBr resulted in enhanced uptake of K. Interestingly, the concentrations of K also increased in roots and leaves of the seedlings grown in the soil spiked with NaBr. Although this increase was not so noticeable as in the case of soil contamination by KBr, the differences between K concentrations in the plants grown in clean and NaBr-contaminated soils were also statistically significant ($P<0.05$). Earlier it was shown that there are certain patterns in the co-transport of Na^+ and K^+ in wheat. In particular, presence of Na^+ in the growth medium can stimulate an uptake of K^+ (Rubio *et al.* 1995).

The uptake of Na by plants was least affected by the amendment of soil with KBr and NaBr. In roots of the seedlings grown in non-contaminated soil and in the soil spiked with KBr, the concentrations of Na were higher than those in leaves of the plants. This is not surprising because plants usually prevent transfer of Na from roots to upper plant parts (Matsushita and Matoh, 1991; Ramoliya *et al*., 2006). However, in the wheat seedlings grown in the soil spiked with NaBr, the root Na concentration was lower than the concentration of Na in roots of control plants and in roots of the plants grown in the soil spiked with KBr (although these differences were statistically insignificant).

There are many different factors that can affect uptake of elements by plants. Among them, an important role is played by the interaction of the main and secondary nutrients that are present in the growth medium (Bassirirad, 2000). One might expect unequal absorption of Br and another cation that is present in the bromide compound (in our case these were Na and K). Steward and Harrison (1939) showed, using rubidium bromide as an example, that there are two different processes: one causes the accumulation of rubidium, and the other affects the absorption of Br.

Declaration

Conflict of interest

No

Compliance with ethical standards

NA

Author contributions

Concept of research and designing of experiments, conduction of experiments, and preparation of manuscript (IS)

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