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Comparative Study of Three Ornamental Plant Species for Their Phytoextraction Potentials of Cadmium Polluted Soil

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Authors' contributions

This work was carried out in collaboration between both authors. Author NA designed the study, wrote the protocol and the first draft of the manuscript. Author FBGT managed the analyses of the study and the literature searches and performed the statistical analysis. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: A comparative study of three ornamental plants species in the remediation of cadmium polluted soil was investigated.
Duration and Place of Study: A 12 week phytoextraction trial was conducted at the Centre for Ecological Studies, University of Port Harcourt.
Study Design: 20 polythene bags (5 kg loamy soil each) were arranged in 4 batches (designated as A, B C and D) of 5 replicates each. Each bag was artificially polluted with 100 mg of cadmium solution (that is, 20 mg kg^{-1}). Two seedlings of *Moringa oleifera, Polyalthia longifolia* and *Aloe vera* were transplanted from the nursery into batch A, B, C, respectively (phytorextraction treatments) while batch D had no planting (control).
Results: *Moringa oleifera, Polyalthia longifolia*, and *Aloe vera* showed 43.1%, 47.0% and 41.3% reductions of Cd in phytoextracted soil, respectively. The transfer factor was in the order of *Aloe vera* > *Moringa oleifera* > *Polyalthia longifolia* while translocation factors indicate that cadmium were

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largely retained in roots of *Polyalthia longifolia* and *Aloe vera* and in the shoot of *Moringa oleifera*. The suitability of the plants for phytoextraction was in the order of *Moringa oleifera* > *Polyalthia longifolia* > *Aloe vera.*

Conclusion: The three plants are suitable for the remediation of cadmium contaminated soils. Based on the experimental results, *Moringa oleifera* can be classified as Cd accumulator plant while *Polyalthia longifolia* and *Aloe vera* are Cd excluder plants.

Keywords: Heavy metal; contamination; Moringa oleifera; Polyalthia longifolia; Aloe vera; phyto-accumulation.

1. INTRODUCTION

The contamination of the environment with pollutants such as crude oil, heavy metals, pesticides, and poisonous gases, resulting from human activities is a mercurial and multidimensional problem in the world today; many of which have been reported to have grave consequences on the environment. For instance, some heavy metals such as Cd, Zn, Fe, Ni, Hg and Pb have been reported to have not only detrimental effects on the ecosystem functioning but also pose potential health risk to man [1]. Cd toxicity has been reported to cause reduction in root length/ volume, with deleterious effect on net photosynthetic rate and intracellular CO_2 concentration in plants [2]. Although, low concentrations of some of the metals such as Ni, Mn, Cu, Zn, Mg and Fe are essential for plant growth; but are detrimental to crop performance at high concentrations. This is because at high concentrations, these metals interfere with plant physiological and biochemical processes such as photosynthesis, respiration and degeneration of main cell organelles, which can eventually lead to death of plants [3].

One major characteristic of heavy metals that makes them dangerous and toxic is that they are not easily biologically degradable, but are only transformed from one oxidation state to another [4]. Due to the environmental risk associated with heavy metals pollution; it is thus, imperative to apply some remedial measures as to remove or reduce their toxicity levels. Conventional remediation method of heavy metal contaminants is always based on civil engineering method [5,6]. This involves the use of heavy and sophisticated equipment in the operation. This method has been found to be expensive [7] and disruptive to the ecosystem due to the destruction of soil biological activities [8].

Certain ecofreindly, effective, affordable, viable and easy-to-use technologies have been developed for the remediation of contaminated environment. One of such technologies is phytoremediation. In phytoremediation process, plant is used to degrade, contain as well as transfer volatile contaminants from soil to the atmosphere. One advantage of using phytoremediation is the relatively low maintenance requirements [9]. Phytoextraction has been recognized as a viable phytoremediation option for the removal of heavy metal from soil [10]. Phytoextraction of heavy metals involves two major strategies. These are the use of natural hyperaccumulating plants otherwise known as natural phytoextraction and; induced phytoextraction with chemical amendment [11]. Some plants have been reported to be hyperaccumulators while others are metal excluders. Examples of Cd hyperaccumulating plants are *Colocasia antiquorum* [12]; *Helianthus annuus* [13]; *Arabidopsis halleri* [14]; *Atriplex halimus* [15]. Furthermore, *Moringa oleifera* can accumulate Pb from a contaminated soil [16].

This study aims at investigating the phytoextraction potentials of three ornamental plants (*Moringa oleifera, Polyalthia longifolia* and *Aloe vera*) in cadmium polluted soil. The choice of these three plants is because of their availability, abundance, easy to cultivate and their uses for ornamental purpose especially in the urban areas where heavy metal pollution is prevalent due to high industrial activities. Hence, results obtained from this study will provide a clue on other uses of these plants apart from their use as ornaments. It will also add to the existing knowledge on plants that can be used in the remediation of cadmium polluted soil.

2. MATERIALS AND METHODS

This study was carried out at the Centre for Ecological Studies, University of Port Harcourt. It is situated in the Niger Delta area of Nigeria on geographical coordinates: latitude 4° 65 N and longitude 7° 5' E.

Twenty (20) polythene bags of 5 kg of loamy soil each were arranged in 4 sets: A, B, C and D of 5 replicates each. 100 mg of cadmium solution was artificially added as the contaminant to each bag of all the batches (equivalent to 20 mg kg^{-1}). The soil was thoroughly mixed in the bag to enhance the homogeneity of the metal solution with the soil and allowed for 14 days. Five seedlings each of *Moringa oleifera, Polyalthia longifolia* and *Aloe vera* that were raised in nursery were transplanted from the nursery into set A, B, C respectively while set D received no planting (control). The planted seedlings were of the same size and vigour. After one week of planting, the seedlings were thinned to 2 seedlings per bag. 50 cl of tap-water was used three times a week for the watering of each bag. Weeds control was also done by hand-picking method when the need arose. The phytoextraction trial lasted for 12 weeks after planting.

Soil analysis was done twice (after contamination and at the termination of the experiment). The first soil analysis was done to ascertain the level of cadmium present in the soil before phytoextraction. The second one was done to determine the extent of phytoextraction by the test plants from the soil. The second soil analysis was done 12 weeks after planting (phytoextraction trial). At the end of the 12 weeks period, the plants were also harvested from each bag with the shoots cut-off from roots with a sharp knife.

All collected samples of soil and plant parts with proper labeling according to their treatments were taken to the laboratory for Cd content determination. All clumps and clods in the soil sample were removed. The soil was then air-dried and sieved using 2 mm sieve to remove coarse particles before analysis. The soil was then analyzed by Atomic Absorption Spectrophotometer (BUCK scientific 200A model) after digestion on a hot plate for 15 minutes with 3 ml of perchloric acid and 5 ml of nitric acid. The soil pH and nitrate were determined electronically using a glass electrode pH metre (HANNA HI Series) and Brucine method [17] respectively.

Plant samples were first rinsed with distilled water to remove all soil particles; then oven-dried at 100℃ for 48 hours. This was later ground to fine powder before digestion and analyzed for cadmium using Atomic Absorption Spectrophotometer (AAS).

Transfer factor was obtained by using metal concentration in the extracts of soils and plants [18] as follows:

$$\text{Transfer Factor} = C_{plant}/C_{soil}$$

Where C_{plant} is the concentration of Cd in plant extract; and C_{soil} represents the Cd concentration in soil.

Translocation factor (TF) was calculated according to Barman et al. [19] using the formula below.

$$TF = \frac{concentration\ in\ shoot}{concentration\ in\ root}$$

Means and standard error mean (SEM) were calculated from the data obtained. Least Significant Difference (LSD) was used to separate means using SPSS data analysis package (2007 version 9.1).

3. RESULTS

Fig. 1 showed the concentration of cadmium in the different soil treatments. There were reductions in soil Cd in all the artificially polluted soils phytoextracted with the plant species as compared with the control soil. There was a significant difference (p=0.05) between the treatment options, with the control showing a higher Cd concentration than the soil grown with phytoextracted plants. Between the phytoextracted soils; soil phytoextracted with *Polyalthia longifolia* showed a significant reduction in Cd concentration than the other phytoextracted soil. The percentage reduction of cadmium in the phytoextracted soil was in the order of *Polyalthia longifolia* (47.0%) > *Moringa oleifera* (43.1%) > *Aloe vera* (41.3%).

In all the three plant species, the concentration and accumulation of Cd in plants root was significantly highest in *Aloe vera* followed by *Polyalthia longifolia* plant and then *Moringa oleifera* as shown in Fig. 2. The reverse was the case for accumulation in the shoot of the plants in which *Moringa oleifera* accumulated and concentrated more Cd in the shoot than the other two plants (Fig. 3). That is, there was high Cd concentration in *Moringa oleifera* shoot and lowest in *Aloe vera* shoot.

The result revealed that *Polyalthia longifolia* and *Aloe vera* retained more of the Cd metal in their roots while *Moringa oleifera* retained more in their shoot as indicated by the translocation factor (Fig. 4). The transfer values from soil to plant are as shown in Fig. 5. The result indicated that transfer factor from soil to plant was highest for *Aloe vera*. The transfer factors of Cd in plant species were in the order of *Aloe vera* >*Moringa oleifera* > *Polyalthia longifolia*. Reduction in Transfer factor was more in *Polyalthia longifolia*.

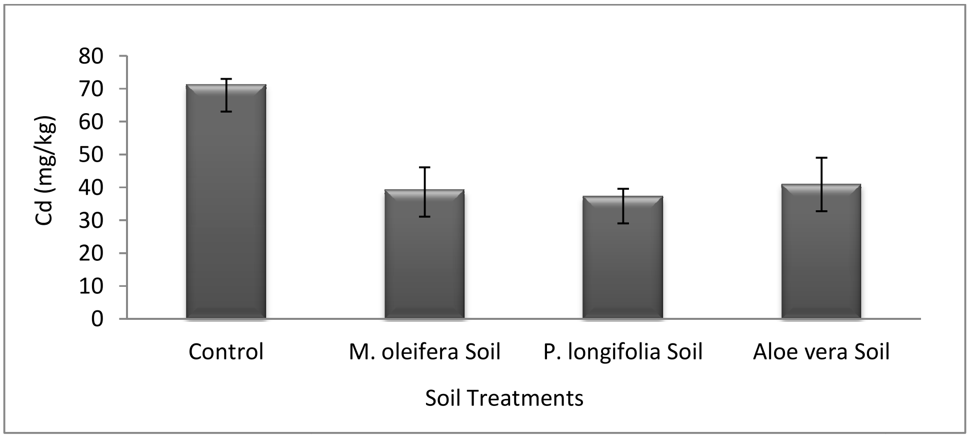

Fig. 1. Cadmium concentration in soil

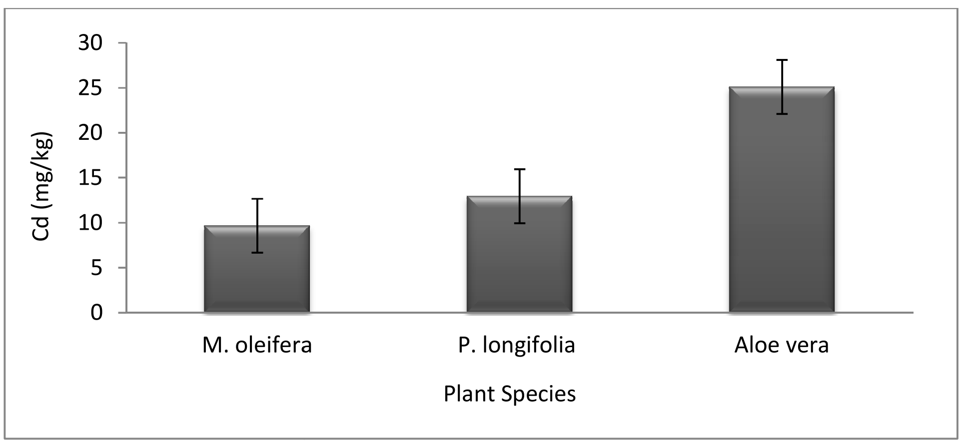

Fig. 2. Cadmium concentration in roots of plant

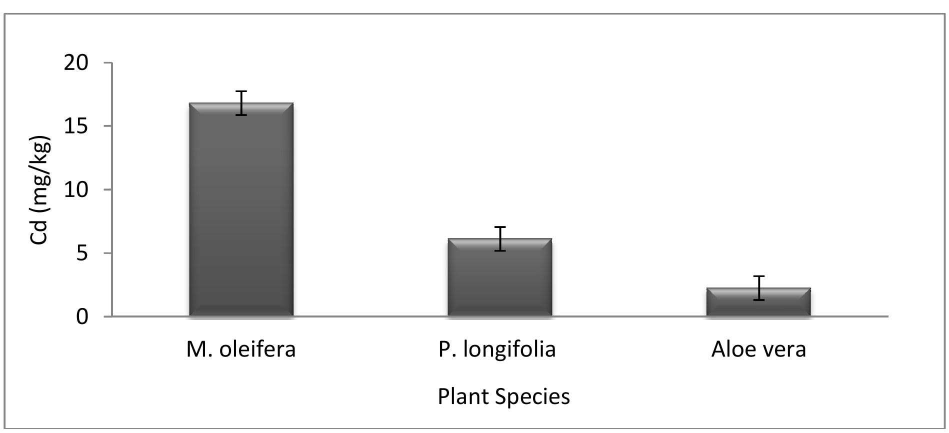

Fig. 3. Cadmium concentration in shoots of plant

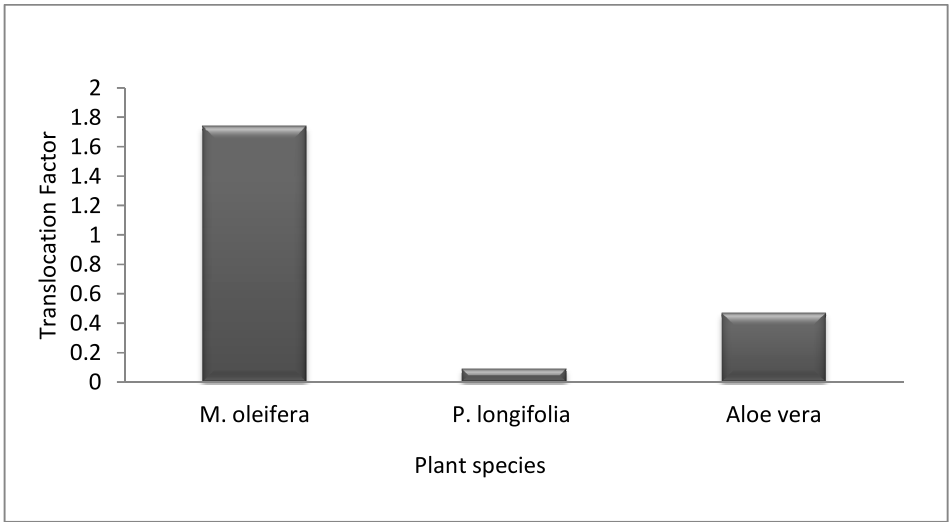

Fig. 4. Translocation factor of cadmium in plant species

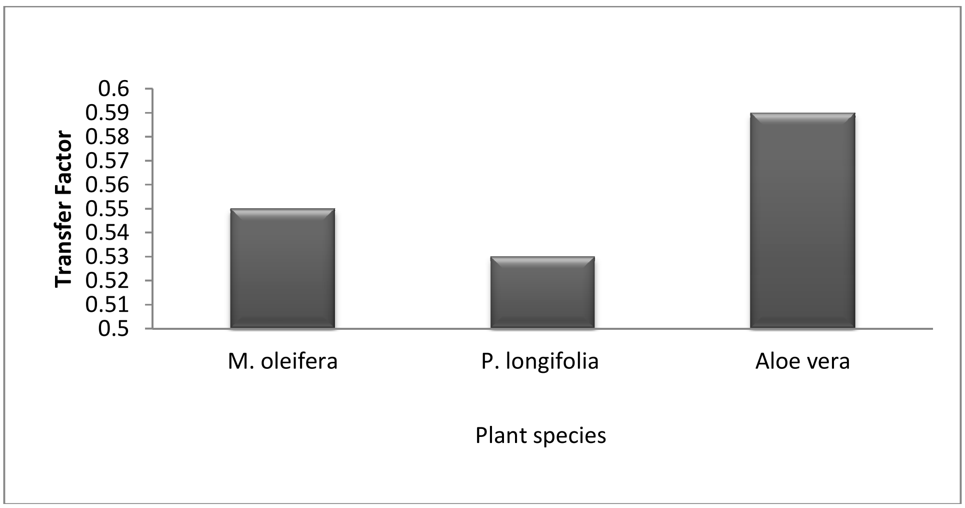

Fig. 5. Tranfer factor of cadmium in plant species

Generally, there was a reduction in soil pH in all polluted soil phytoextracted with plant species as compared with the control soil. The control soil pH and soil phytoextracted with *Moringa oleifera, Polyalthia longifolia* and *Aloe vera* in Cd treated soil were significantly (p=0.05) different, with the control soil showing a significant increase. Although there was a significant difference (p=0.05) when compared to pH in soil phytoextracted with *Aloe vera* and *Polyalthia longifolia*.

There was a general increase in soil nitrate in all the polluted soil phytoextracted with the plant species as compared with the control soil (Fig. 7). Increase in soil nitrate was more in soil phytoextracted with *Polyalthia longifolia*.

4. DISCUSSION

This study showed that plants can obtain and accumulate a wide range of metals from soil. Plants grown in metal-enriched substratum take up metal ions in varying degrees. Plants have developed a range of mechanisms to obtained metals from the soil solution and transport these metals within the plant. The mechanism of uptake of metals into plant roots and subsequent translocation to the upper parts is a complex process involving transfer of metals from the soil solution to the root surface and inside the root cells. The solubility of these metals in the rhizophere of plants is sometimes influenced by exudation of substances called chelators [20]. These substances or compounds (chelators) are

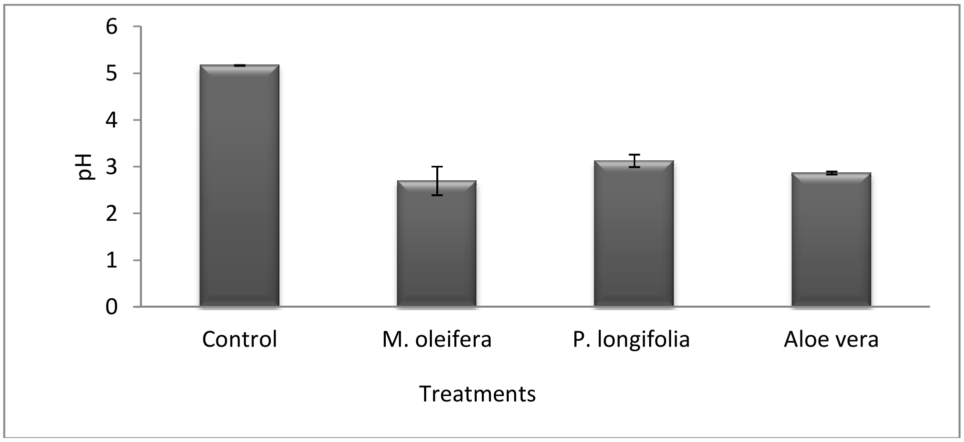

Fig. 6. Soil pH

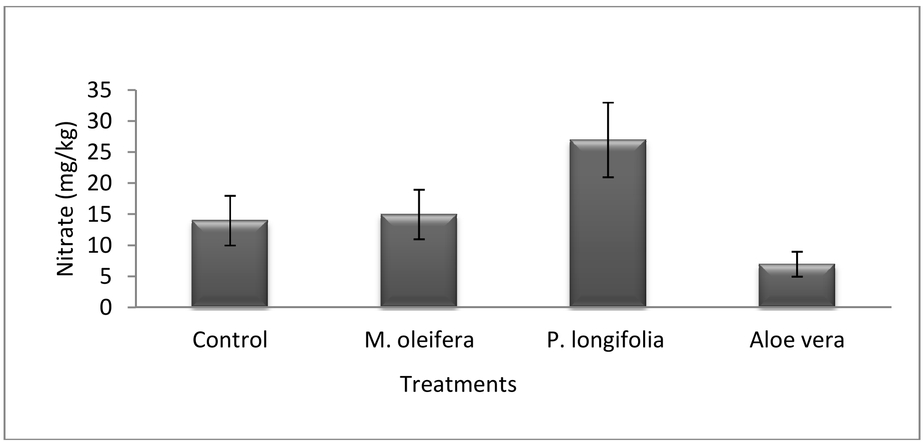

Fig. 7. Soil Nitrate

release to aid the absorption of these metals by the plants especially at low availability [21]. The rate of absorption/uptake is also influenced by the bioavailability of the metals which is in turn determined by both external (soil-associated) and internal (plant-associated) factors. This can be affected by plant species grown on different soils [22].

Results revealed that the rate of cadmium absorption/uptake from the soil by *Moringa oleifera, Polyalthia longifolia* and *Aloe vera* plants varies. The results also revealed that biomagnifications of Cd vary among plant parts and treatments. While *Moringa oleifera* plant accumulates metal more in their shoot, *Polyalthia longifolia* and *Aloe vera* accumulate more in the roots than shoots. This suggests that plants have different abilities in bioaccumulating particular heavy metals. Salt et al. [7] and Adriano [23] have long recognized that the uptake and bioaccumulation of metals by plants and plant parts was plant species dependent. This suggests that certain biochemical and physiological factors may have contributed to heavy metal phytoaccumulation in plants and plant parts.

The result indicates that transfer factor was highest in *Aloe vera* and lowest in *Polyalthia longifolia*. The transfer factor of Cd in the plant species were in the order of *Aloe vera* > *Moringa oleifera* > *Polyalthia longifolia*; showing that metal movement from soil to plant is also plant species dependent, which Zurera et al. [24] attributed to the differences in the physico-chemical characteristics of the soil as well as the plant species used. Reichman [25] reported that two plants may take up different amounts of metal from a particular soil pool of metals within a given time frame.

The test plant species (*P. longifolia* and *Aloe vera)* showed translocation factor (TF) of less than 1, indicating that Cd metal accumulations were retained more in root than the shoot. The only exception was *M. oleifera* in which the reverse was the case (TF >1); indicating that Cd metal accumulation was more in the shoot than the root. Any plants with a translocation factor > 1 are classified as accumulator [26]. From the result obtained *Moringa oleifera* can be classified as accumulator for Cd (TF >1.7).

pH is one of the factors which influence the bioavailability and transport of heavy metals in the soil. Sauve et al. [27] observed a connection between soil pH and metal speciation, solubility and adsorption. Metal uptake has been reported to increase due to decreasing pH [28]. As soil pH decreases, metals compete with the extra H^+ for positions on the exchange sites thereby making the metals to be soluble and available as free metal ions in the soil solution [29]. Soil pH was generally low across treatments. Since the pH of the phytoextracted soil was lower than control soil, the lower pH may have influenced the phytoextractability of Cd from the soil by the plants. This observation is true since Cd contaminated soil phytoextracted with *Moringa oleifera* with the lowest recorded pH value showed the highest reduction in soil Cd.

It was also observed that soil nitrate increase across treatments. Highest nitrate content was observed in contaminated soil phytoextracted with *Moringa oleifera*. So the differences in nitrate content in the treatment options can be attributed to the plant species used for the phytoextraction. This is understandable since leaves of *Moringa* sp contain high amount of proteins [30]. It is possible that the decomposition of leaf droppings in the soil might have contributed to the high nitrogen content of the soil. The increased nitrogen in the soil contributed significantly to the growth of the plant which in-turn increase Cd accumulation.

5. CONCLUSION

The three plants have the potential to reduce Cd in contaminated soil and accumulate them in their biomass. The accumulation was more pronounced in roots than shoots except in *Moringa oleifera*. This goes to say that among the phytoextraction plant species studied *(Moringa oleifera, Polyalthia longifolia* and *Aloe vera*); *Moringa oleifera* has the highest potential in the remediation of cadmium contaminated soil. The degree of their phytoextraction potential is in the order of *M. oleifera* > *P. longifolia* > *Aloe vera.* Therefore, *Moringa oleifera* can be classified as accumulator since it has a translocation factor greater than 1 while *Polyalthia longifolia* and *Aloe vera* are Cd excluder plants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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