

Assessing Phytoremediation Potential of the Plant: Palma Amaranth

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Abstract- This paper is aimed at assessing the phytoremediation ability of the plant Palma amaranth naturally. To achieve this, fresh samples of soil and the plant were collected from automobile mechanical workshop in Gombe state Metropolis. Collection were made in the morning hours, this was to get the plants fresh. These were separated in root, stem and leaves. Soil from the surface to sub-surface portion beneath the root of plant were collected, dried ground and sieved. This was then digested using aqua regia (HCl:HNO₃ in the ration of 3:1) the plant sample were equally treated but with 6m HCl. Both digested samples were then analyzed using Atomic Absorption Spectroscopy (AAS) model AA240FS for the metals; Cd, Cu, Cr, Ni, Pb and Zn. The results indicate that, the soil has the highest concentration of; 0.290 ± 0.037 , 0.163 ± 0.017 , 0.512 ± 0.006 , 1.816 ± 0.011 , 0.295 ± 0.017 and 0.334 ± 0.022 for the metals; Cd, Cu, Zn, Pb, Cr and Ni respectively. Variation in the levels of the metals was observed in the different parts of the plants. The stem has the highest concentration of Zn (0.691 ± 0.026) followed by the leaves, 0.644 ± 0.009 . High level of Cu (0.144 ± 0.039) was found in the leaves that of Pb, Ni, and Cr (0.174 ± 0.005 , 0.069 ± 0.005 and 0.046 ± 0.035 respectively) were found in the root. All measurements were made in $\mu\text{g/g}$ units. Copper has the translocation factor (TF) of 3.254, Zn has 3.550 whereas their enrichment coefficient (EC) are; 1.178 and 2.607 respectively. The rest of the elements have the TF and EC values less than one. For having TF and EC values greater than one, Palma amaranth may not serve as a good phytoextractor or phytostabilizer for the metals determined but rather a good metal excluder or metal indicator especially for Cu and Zn.

Keywords- Soil, Pollution, Bioremediation, Absorption, Heavy Metals, Environment

I. INTRODUCTION

The quality of life on Earth is linked extensively to the overall quality of the environment. It is very difficult to define soil quality, for soil composition varies from place to place. Soil quality is concerned with more than the soil's constituents and composition, but how it functions in a specific environment. The major functions of a soil are generally recognized to include the ability to protect water and air quality, the ability to sustain plant and animal productivity,

and the ability to promote human health [1,2]. Since the beginning of the industrial revolution, soil pollution by toxic metals has accelerated dramatically. As a result of human activities such as mining and smelting of metalliferous, electroplating, gas exhaust, energy and fuel production, fertilizer and pesticide application, etc., metal pollution has become one of the most serious environmental problems worldwide. Due to their non-degradable nature, metals are a group of pollutants of much concern. Majority of heavy metals are toxic to the living organisms and even those considered as essential can be toxic if present in excess. Toxic heavy metals can impair important biochemical processes, displacing other metal ions, or modifying the active conformation of biological molecules posing a threat to human health, plant growth and animal life [3, 4, 5].

Soil pollution especially by heavy metals has recently been attracting considerable public attention since the magnitude of the problem in our soils calls for immediate action [6]. Currently, the conventional in-situ decontamination methods of heavy metal contaminated soils include electrokinetical treatment, chemical oxidation or reduction, leaching, solidification, vitrification and the off-site treatment (ex-situ) mostly excavation. But the offsite burial is not an appropriate option because it merely shifts the contamination problem from one place to another [7] and also because of the hazards associated with transportation of the contaminated soil [8]. In most cases these techniques (in-situ and ex-situ treatment) are expensive and technically limited to relatively small areas with a possible secondary effect as in excavation. The knowledge of the mechanism of uptake, transport, tolerance and exclusion of heavy metals and other potentially hazardous contaminants in microorganisms and plants have recently promoted the development of a new technology, named bioremediation.

Bioremediation is based on the potentials of living organisms, mainly microorganisms and plants, to detoxify the environment [9]. A variety of technologies that employ biological resources to clean up metal polluted sites have gained considerable momentum in the last decade or so, both in developed as well as in developing nations, and are currently (according to reports) in the process of commercialization [10]. Plant based bioremediation technologies have been collectively termed as

phytoremediation. It is a feasible and practical 'natural' remediation technique for contaminated soils. It is defined as the engineered use of green plants to remove, contain or render harmless environmental contaminants like heavy metals, trace elements, organic compounds and radioactive compounds in soil or water' [11]. The idea of using metal-accumulating plants to remove heavy metals and other compounds was first introduced in 1983, but the concept has actually been implemented for the past hundreds of years on wastewater discharges [12].

Phytoremediation harnesses natural processes to assist in the clean-up of pollutants in the environment. It takes the advantage of the unique and selective uptake mechanisms by which plants promote the removal of pollutants varied, it include uptake and concentration, transformation of pollutants, stabilization, and rhizosphere degradation, in which plants promote the growth of bacteria underground in the root zone that in turn break down pollutants [11]. Plants have been found to show several and different response patterns to the presence of heavy metal ions in the soil. Most plants are sensitive to metal ions even at low concentrations. Accordingly, the response of plants to bioavailable heavy metals in the soil has been classified as follows:

Metal excluders; are those plants that prevent metal uptake into their roots and/or avoid translocation and accumulation into shoots over a wide range of metal concentrations in the soil [13, 14]. They have a very low potential for metal extraction, but they can be used to stabilize the soil, and avoid further contamination spread due to erosion.

Metal accumulators; this group of plants can accumulate metals in their above ground tissues in concentrations far exceeding than those present in the soil, and such plant species are termed as hyperaccumulators [15].

Metal indicators; these categories of plants show poor control over metal uptake and transport processes, and accumulate metals in their above ground tissues. The extent of metal accumulation in the tissues of these plants reflects metal concentration in the rhizosphere. Indicator species have been used for mine prospecting to find new ore bodies [16].

Some phytoremediation projects have utilized native species [17, 18]. The reasons for doing so include avoiding the introduction of exotic non friendly species into sensitive ecosystems [19, 20]. Many species of plants have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic, and various radionuclides from soils. One of phytoremediation categories, phytoextraction, can be used to remove heavy metals from soil using its ability to uptake metals which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo, and Ni). Some metals with unknown biological function (Cd, Cr, Pb, Co, Ag, Se, Hg) can also be accumulated [21]. This research investigated the possibility of decontaminating heavy metal contaminated soil naturally without amendment; using the native grass, Palmer amaranth (*Amaranthaceae*).

II. MATERIALS AND METHODS

A. Sampling sites

Although the plant was found everywhere in grass land area of the northeastern part of Nigeria, samples for this study were collected in Gombe Metropolis, Gombe State, Nigeria. Gombe is located between latitude $9^{\circ} 30'$ and $12^{\circ} 30' N$ and longitudes $8^{\circ} 45'$ and $11^{\circ} 45' E$ of the Greenwich meridian. It lies within the grass land region of the Northeastern part of Nigeria. The grass samples were collected from Alhaji Mohammed mechanical workshop situated in Je ka da fari ward within Gombe Metropolis. At this site, a lot of activities are taking place; ranging from panel beating, paintings or vehicle body spray, welding, engine repairs and accumulation of non-useful metallic materials for recycling, vulcanization which result into the release of pollutants through oil spillage, combustion and rusting processes.

B. Sample Collection

Sample of Palmer amaranth (figure 1a and b) were chose and collected from this site because it was observed to dominate the site despite the anticipated deposition of pollutants from the activities taking place. Collection was made by uprooting the plants carefully form the soil to avoid damage to the roots. The soil from the surface to sub-surface portion of the soil, beneath the root of the grass was also collected. This was done at a depth of few centimeters (about 5cm) beyond the reach of the roots [18]. Four different samples of plant and soil were collected in the morning hours to get the plant samples fresh.

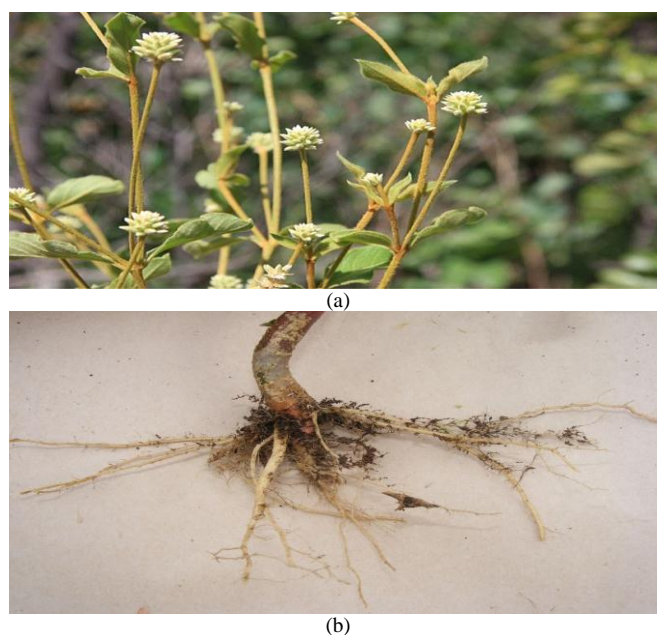


Figure 1. (a) Shoot portion of Palmer amaranth. (b) Root portion of Palmer amaranth

C. Samples Preparation and Analysis

The butch of the grass sample collected was washed thoroughly in the laboratory with distilled water, carefully separated into; roots and shoot which comprises the stems and leaves [17]. These were then dried at 60°C to a constant weight, ground into fine powder and sieved through a 2mm nylon sieve according to Lombi et al [22] and Garba et al, [18].

For the soil sample, it was homogenized, dried at 60°C to a constant weight, grounded into fine powder, and equally sieved through a 2mm mesh ready for analysis. The dried and sieved soil sample was characterized for some of its physicochemical properties [18, 22] that supported the growth of plant. The dried and sieved soil sample was digested using aqua regia (HCl:HNO₃ in the ration of 3:1)

The sieved and dried plant samples were then digested by treating, 0.5g of the dried and sieved sample with 6M HCl in a furnace at 500°C. The mixture was then allowed to cool and filtered through a Whatman No. 541 filter paper into a 50ml

volumetric flask. This was made up to the mark with distilled water [23]. A blank was equally prepared following the same procedure but without the sample. Analysis of the digested samples was done using Atomic Absorption Spectroscopy (AAS) model AA 240FS, company Varian.

D. Statistical data handling

All statistical data handling were performed using SPSS 17 package. Differences in mean concentration of samples were detected using One-way ANOVA, followed by multiple comparisons using LSD tests at (P ≤ 0.05).

III. RESULTS

The physicochemical property of the soil from the sampling site is as shown in figure one below. The taxonomy of the soil indicates that, the soil is sandy. Its pH ranges between 5 - 6%, EC of 62% and the cation exchange capacity (CEC) of 32%. It has the organic carbon content of 0% and 0 % for nitrogen as shown in figure one below.

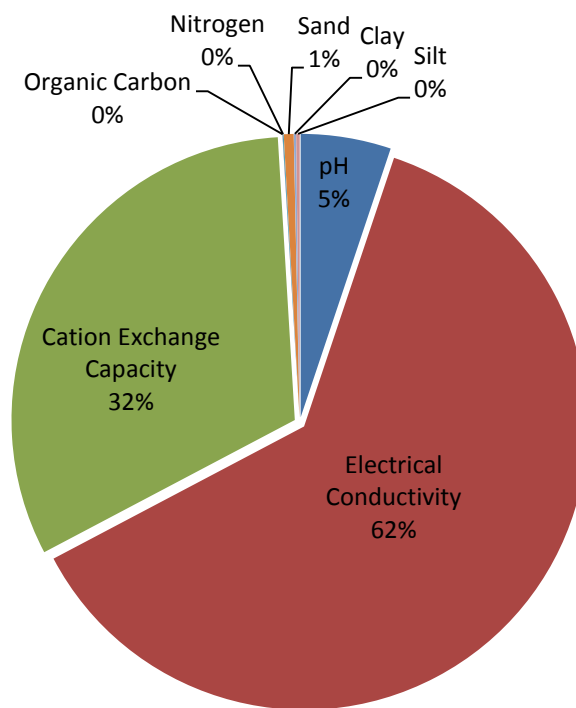


Figure 2. Physicochemical Property of the Soil from the Sampling Sites

The level of the elements determined in this study is as shown in table 1 below. The result shows that lead (Pb) was found at high level (1.816 µg/g ±0.011) in the soil followed by zinc (Zn), nickel (Ni), chromium(Cr), cadmium (Cd) and copper (Cu) with the levels; 0.512 ±0.006, 0.334 ±0.022,

0.295 ±0.017, 0.290 ±0.037, and 0.163 ±0.017µg/g respectively. The concentration of these metals in the root of the grass plant was found to decrease to various levels. For instance, Pb decreases to 0.174µg/g. Nickel, Cu, Cr and Cd were found to decrease to the levels; 0.069, 0.059, 0.046, and

0.019 $\mu\text{g/g}$ respectively. Similarly trend of decrease in concentration was observed in the stem (Table 1) except for Zn in which the level increases to 0.691 $\mu\text{g/g}$ in the stem and 0.644 $\mu\text{g/g}$ in the leaves. Copper was equally found to increase to the level (0.144 $\mu\text{g/g}$) in the leaf, greater than what was

observed in the root (0.059 $\mu\text{g/g}$) and the stem (0.048 $\mu\text{g/g}$) as shown in table one. The levels of the metals, Ni, Cr, Pb and Cd were found to drastically decrease to the levels; 0.016, 0.011, 0.005 and 0.003 $\mu\text{g/g}$ respectively as shown in table one.

TABLE I. LEVEL OF HEAVY METAL ($\mu\text{G/G}$) IN SOIL, ROOT, STEM AND LEAF OF PALMA AMARANTH (*AMARANTHACEAE*)

Elements	Soil	Root	Stem	Leaf
Cd	0.290 \pm 0.037a	0.019 \pm 0.007	0.015 \pm 0.008ab	0.003 \pm 0.006a
Cu	0.163 \pm 0.017	0.059 \pm 0.010bc	0.048 \pm 0.009c	0.144 \pm 0.039
Zn	0.512 \pm 0.006	0.376 \pm 0.009	0.691 \pm 0.026	0.644 \pm 0.009
Pb	1.816 \pm 0.011	0.174 \pm 0.005	0.147 \pm 0.004	0.005 \pm 0.002a
Cr	0.295 \pm 0.017a	0.046 \pm 0.035c	0.012 \pm 0.010a	0.011 \pm 0.008a
Ni	0.334 \pm 0.022	0.069 \pm 0.005b	0.034 \pm 0.006b	0.016 \pm 0.007a

Means with same letters within a column are not significantly different at ($p = 0.05$) according to Least Significant Difference (LSD) Test with $n = 4$

IV. DISCUSSION

A. Physicochemical Property of the soil Sample

Soil pH affects the soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level. Soils with high acidity tend to have toxic amounts of aluminum and manganese and to be hostile to most legume crops. Plants need calcium and moderate alkalinity, but most minerals are more soluble in acid soils. Soil organisms are hindered by high acidity, and most agricultural crops do best with mineral soils of pH 6.5 or with organic soils of pH 5.5 [24]. Reeves, [25] showed that soil organic carbon is the most often reported attribute from long-term agricultural studies and is chosen as the most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological indicators of soil quality. Soil electrical conductivity (EC) measures the ability of soil water to carry electrical current. Electrical conductivity is an electrolytic process that takes place principally through water-filled pores. Cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and NH_4^+) and anions (SO_4^{2-} , Cl^- , NO_3^- , and HCO_3^-) from salts dissolved in soil water carry electrical charges and conduct the electrical current. Consequently, the concentration of ions determines the EC of soils. In agriculture, EC has been used principally as a measure of soil salinity; however, in non-saline soils, EC can be an estimate of other soil properties, such as soil moisture, salt concentration, organic matter, cation exchange capacity, soil texture, soil thickness, water holding capacity and drainage conditions. Hence the level of EC determined in the soil of this study as shown in figure one. It is expressed in deciSiemens per meter (dS/m). Soil EC does not directly affect plant growth but has been used as an indirect indicator of the amount of nutrients available for plant uptake and salinity levels [26, 27].

Cation exchange capacity or CEC is the number of exchangeable cations per dry weight that a soil is capable of holding, at a given pH value, and available for exchange with the soil water solution [28]. It is used as a measure of soil fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. It is expressed as milliequivalent of hydrogen per 100 g of dry soil ($\text{meq}^+/\text{100g}$), or the SI unit centi-mol per kg (cmol^+/kg). For many soils, the CEC is dependent upon the pH of the soil. As soil acidity increases (i.e., as pH decreases), more H^+ ions become attached to the colloids. Inversely, when soils become more basic (pH increases), the available cations in solution decrease because there are fewer H^+ ions to replace the cations from the colloids thus the CEC increases [29]. The cation exchange capacity of the soil of this study was characterized by having low CEC (the combined levels of the ions; Mg^{2+} , Ca^{2+} , Na^+ and K^+ of Figure one).

B. Heavy Metals in the Soil

The level of the heavy metals; Cd, Cu, Cr, Zn, Pb and Ni determined in the root and aerial parts of Palma amarant of this study is shown in table one above. Sources of heavy metals in soils in urban environment has been identified to include; its natural occurrence in the soil derived from parent materials and human activities which are associated with activities such as atmospheric deposition, industrial discharges, waste disposal, waste incineration, urban effluent, long-term application of sewage sludge, fertilizer application in soil, and vehicle exhausts [30]. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil [31]. Garba et al. [30] has reported high concentration of the metals; Pb, Cd, Zn, and Cu in an automobile workshop. Thus, the level of these metals (Pb, Cd, Zn, and Cu) could be attributed to vehicular activities such as abrasion, emission and oil leakage. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg [32].

C. Heavy Metal uptake and accumulation by Plant

Metal concentrations in plants vary with plant species [33, 34]. Plant uptake of heavy metals from soil occurs either passively with the mass flow of water into the roots, or through active transports, and crosses the plasma membrane of root epidermal cells. Generally uptake of metal ions occurs through secondary transporters such as channel proteins and/or H⁺-coupled carrier proteins. Uptake of cations through secondary transporters is facilitated by potential of the plasma membrane [35]. Reports has it that, under normal growing conditions, plants can potentially accumulate some metal ions in order of magnitude greater than the surrounding medium [36, 37].

In this study almost all the metals determined were found at high concentration in the roots. Except for Zn (0.691) in the stem and (0.644) in the leaves, these levels were greater than the level in the roots (table 1). Transpiration pull as well as water, evaporating from plant leaves, serves as a pump to absorb nutrients and other soil substances into plant roots. This process, termed evapotranspiration, is responsible for moving contamination into the plant shoots as well. Metals and non-metals must cross the soil solution across root cell plasma into the roots where they are being loaded into the xylem for translocation to the shoots via the transpiration stream. In the shoots, the metals and non-metals must also cross the leaf cell plasma membrane and enter the leaf cell where they are being detoxified [38]. Zn transport in plants takes place through both the xylem and the phloem. Following absorption by the root, Zn is rapidly transported via the xylem to the shoot [39]. Since contamination is translocated from roots to the shoots, which are harvested, contamination is removed while leaving the original soil undisturbed. Reports has it that in plants [40], adequate Zn supply leads to a high proportion of Zn located in the shoots (especially stems) as it is in this study and as shown in table 1. It has also been reported that essential metals such as Zn and Cu are easily translocated to the aerial parts of plants [41]

In some cases, heavy metals are retained in the roots and only a minor portion reaches the shoot [42]. This retention can be due to insolubilization at the root surface and in the root apoplast [43] or to a compartmentation in cells avoiding the release to the xylem [44]. The abundance of ligands and the formation of heavy metal complexes with organic acids [45], with phytochelatin [46] or with nicotianamine [47] were found to be important for the retention in the roots. In this study, high levels of the metals; Cd (0.019), Pb (0.174), Cr (0.046) and Ni (0.069) were all observed in the roots, greater than the levels observed in other parts of the plants (table 1). Mangabeira et al. [48] studied the structure of different organs of tomato plants (root, stem, leaf) which shows visible symptoms of Cr toxicity and reported that Cr (VI) induces changes in the ultrastructure of these organs. Similar observations were made by Vazquez et al. [49] for Cd in vacuoles and nuclei of bean roots. Since both metal are known to be non-essential to plant nutrition, it is suggested that they are likely confined in roots by a barrier-effect as defense strategy during stress. Good evidence was presented for the involvement of Ni-histidine complexes in the vacuolar compartmentation of Ni and as a consequence in the retention

of this heavy metal in roots [50]. A heavy metal ATPase was suggested to be involved in Cd accumulation in vacuoles of root cells causing Cd retention in roots and decreasing the transport to the shoot [51]. It has been reported that, metal uptake by plants can be affected by several factors including metal concentrations in soils, soil pH, cation exchange capacity, organic matter content, types and varieties of plants, and plant age. It has also generally been accepted that, metal concentration in soil is the dominant factor that affect metal uptake by plants [52, 53].

D. Translocation Factor(TF) and Enrichment Coefficient (EC)

The levels of metals accumulated in the different parts of plants especially the root, stem and the leaves does not simple predict the phytoremediation potentials of such plants. A plant's ability to accumulate metals from soils can be estimated using the EC, which is defined as the ratio of metal concentration in the shoots or the above ground tissues to that in soil [54, 55]. A plant's ability to translocate metals from the roots to the shoots is measured using the TF [37]. According to MacFarlane et al. [56], TF is defined as the ratio of concentration of metals in the shoot or above ground parts of plants to those in the roots. By comparing EC and TF values, one can predict the phytoremediation ability of plants in taking up metals from soils and translocating them to the shoots. Table two below shows the TF and EC values of the metals determined in this study. Translocation factor (TF) of heavy metals from roots to shoots and enrichment coefficient (EC) of heavy metals from soil to roots are calculated as follows:

$$TF = \frac{[\text{Metal}] \text{ in shoot}}{[\text{Metal}] \text{ in root}}$$

$$EC = \frac{[\text{Metal}] \text{ in shoot}}{[\text{Metal}] \text{ in soil}}$$

TABLE II. TRANSLOCATION FACTOR (TF) AND ENRICHMENT COEFFICIENT (EC) OF THE METALS DETERMINED IN THIS STUDY

Elements	Soil	Roots	Shoot	TF	EC
Cd	0.290	0.019	0.018	0.947	0.06
Cu	0.163	0.059	0.192	3.254	1.178
Zn	0.512	0.376	1.335	3.550	2.607
Pb	1.816	0.174	0.152	0.084	0.874
Cr	0.295	0.046	0.023	0.500	0.078
Ni	0.334	0.069	0.05	0.150	0.725

Heavy metal-tolerent species with high EC and low TF can be used for phytostabilization of the metals within the root in the soil [37]. From the table above, the TF values for Cu and Zn are far greater than one. These two metals equally has the EC values greater than one. This indicate that the plant , Palma amaranth can only serve as a metal indicator or excluder. As mentioned earlier, metal excluders; are those plants that prevent metal uptake into their roots and/or avoid translocation and accumulation into shoots over a wide range of metal concentrations in the soil [14]. They have a very low potential for metal extraction, but they can be used to stabilize

the soil, and avoid further contamination spread due to erosion. Metal indicators; these categories of plants show poor control over metal uptake and transport processes, and accumulate metals in their above ground tissues. The extent of metal accumulation in the tissues of these plants reflects metal concentration in the rhizosphere. Indicator species have been used for mine prospecting to find new ore bodies.

V. CONCLUSION

This study about the phytoremediation ability of the grass-plant, Palma amaranth shows that the plant is a poor phytoextractor. Though it has the TF value greater than one indicating its ability for phytoextraction, it equally has the EC value greater than one for the same metals. It may therefore be best described as a metal excluder or metal indicator. These could be attributed to the poor root network especially in terms of length and short fibrous root system. The roots could not therefore penetrate or is highly selective when it comes to metal absorption.

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