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CHARACTERIZATION AND MICROBIAL EXTRACTION OF ZINC FROM A ZINC-RICH MUNICIPAL SOLID WASTE USING *Aspergillus niger*: A SUSTAINABLE APPROACH

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Abstract

This study explores the potential of using Aspergillus niger for the sustainable bioleaching of zinc from municipal solid waste (MSW), offering an eco-friendly alternative to conventional extraction methods, which are often capital- and energy-intensive as well as environmentally hazardous. The physiochemical characterization of MSW was performed, with XRD analysis revealing the presence of quartz, graphite, anhydrite, garnet, muscovite, and sphalerite, while XRF analysis confirmed a composition of 20.239% Zn, 0.0785% Cu, 4.235% Fe, 4.203% Al, 0.082% Pb, 0.082% Ti, and 17.470% Si. The study investigated the influence of pH, temperature, agitation, and inoculum percentage on the efficiency of zinc bioleaching. Optimal conditions were determined to be pH 4.5, temperature 30°C, agitation at 150 rpm, and 20% (v/v) inoculum, achieving a maximum zinc bioleaching efficiency of 63.59%. These findings highlight the efficacy of Aspergillus niger in bioleaching zinc from MSW, presenting a sustainable and environmentally friendly alternative to traditional metal extraction methods

Key Words: *Bioleaching, Eco-friendly, Environment, Metal, Optimum*

Introduction

Zinc is an essential metal for humanity, widely utilized in large quantities across various industries due to its versatility and importance. It can also serve as a supplement in diet, for this reason there is, high demand for zinc which has led to the depletion of its original sources and the accumulation of zinc waste (Brierley, 2008). Municipal solid waste (MSW) has been recognized as a significant source of heavy metals, especially zinc, and accumulation of this heavy zinc metal needed urgent extraction. The conventional methods of zinc extraction are capital intensive, energy-intensive and environmentally hazardous (Dunpei *et al*., 2017).

An eco-friendly and cheap approach called bioleaching, has become a promising solution for zinc recovery, because it utilizes microorganisms to extract metals from waste materials. (Rawlings, 2002). Such microorganism is

called, *Aspergillus niger*, is a filamentous fungus known for its ability to produce organic acids and dissolve metals, has been identified as a potential tool for zinc bioleaching (Sukla *et al*., 2015). However, the effectiveness of zinc bioleaching using *Aspergillus niger* is determined by some parameters, such as pH, temperature, inoculum percentage and agitation speed (Kumar *et al*., 2015). Optimizing these parameters is vital to maximize zinc recovery and minimize the environmental impact of Municipal Solid Waste disposal (Wang *et al*., 2017).

This study aims to investigate the effects of influencing parameters such as pH, temperature, inoculum percentage, and agitation speed on zinc bioleaching from Municipal Solid Waste using *Aspergillus niger* and to optimize the conditions for maximum zinc recovery. The findings of this research are expected to contribute to the development of a sustainable and efficient bioleaching process for zinc recovery from Municipal Solid Waste.

Materials and Methods

The source of zinc-rich Solid Waste for this research is a Municipal Solid Waste obtained from Kumbotso Local Government, Area of Kano State-Nigeria (longitude 8° 30′ 10″ E and latitude 11° 53′ 17″ N). Composite samples were obtained from five points (diagonals and centre from the Municipal Solid Waste dump site at weekly interval for a period of six weeks and homogenized to give a representative sample. The zinc rich waste was then calcined at 1000°C for 2 hour in a muffle furnace (Thermo fisher Scientific Muffle Furnace, USA) equipped with temperature control device in order to convert every form of zinc to oxide (Mukhtar *et al*., 2023).

Sample Characterization

The elemental compositions of the municipal solid waste were identified and quantified using X-Ray fluorescence (XRF) analysis while the mineralogical compositions of the municipal solid waste were identified and quantified using X-Ray diffraction (XRD) analysis (X-ray Fluorescence, X-MET800, England).

Microorganisms and Culture Media

Aspergillus niger was isolated from the soil of the Municipal Solid Waste dump site. A solid media (malt extract, 30 g/l; meat peptone, 3 g/l and agar, 15 g/l, at pH 5.6) were employed for the growth and maintenance of the microorganism at 30 °C. A synthetic media containing sucrose (120 g/l), NH_4NO_3 (450 mg/l), KH_2PO_4 (100 mg/l), $MgSO_4{\cdot}7H_2O$ (300 mg/l), $FeSO_4{\cdot}7H2O$ (0.1 mg/l), $ZnSO_4{\cdot}7H_2O$ (0.25 mg/l) was employed as culture media (Hosseini *et al*., 2007).

Bioleaching Procedure

Fungal spores were suspended from a 7-day agar slant in a sterile solution (0.1% Tween80, and 0.9% NaCl) and were enumerated by a microscope. Bioleaching experiments were carried out in 250 cm^3 Erlenmeyer flasks containing 100 cm^3 of culture media inoculated with 10%($\frac{v}{v}$) at a concentration of 10^6spores/cm^3. Then 5g of the ash sample were added and incubated at 30°C, and 150 rpm in an incubator shaker. Sample aliquots of 10 ml were withdrawn from the flask daily during the leaching period of 8 days for determination of zinc concentration using Atomic Absorption spectroscopy (AAS) (Hosseini *et al*., 2007).

Optimization experiments were conducted with different operational conditions to study the effect of

temperature (25°C, 30°C, 35°C, and 40°C), agitation speed (100 rpm, 150rpm, 200 rpm and 250 rpm), pH (3.5, 4.0, 4.5, and 5.0), inoculum percentage (10 %, 15 %, 20 %, 25 %).

The zinc bioleaching efficiency was calculated using the following equation:

$$\alpha = \frac{C.V}{\beta.m} \times 100\%$$

Where α is the zinc leaching efficiency (%), V is the leachate volume (mL), C is the zinc concentration in leachate (g/mL), m is the mass of sample (g), and β is the zinc content in sample (Dunpei *et al.*, 2018).

Results and Discussion

Characterization and microbial extraction of zinc from a zinc-rich municipal solid waste using *aspergillus niger* was conducted and the results presented in the tables below summarizes the key findings of the research.

Table 1: Physicochemical analysis of the sample

Parameters	**Value**
Moisture content/%	2.6 ± 0.005
Loss of mass on ignition/%	2.5 ± 0.005
pH	7.5

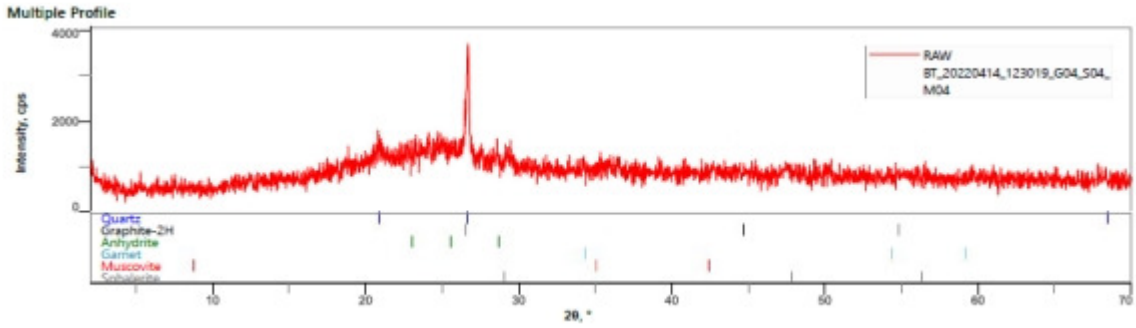

Fig. 1: Mineralogical phase analysis results of the sample

Table 2: Elemental Analysis by X-ray Fluorescence (XRF) of the sample

Element	Zn	**CU**	**Fe**	**Al**	**Pb**	**Ti**	**Si**
Compositions (wt.%)	**20.239**	0.078	4.235	4.203	0.082	0.426	17.470

Results of Bioleaching Studies

From Figure 2, the highest zinc bioleach was observed at temperature of 25-30ºC. This agrees with the optimum temperature range of between 25-35°C for *Aspergillus niger* growth and metabolism, as reported by Rawlings (Rawlings, 2002). However, at temperature of 40ºC, the rate of zinc dissolution decreased significantly due to decrease in microbial activities, which may be due to inability of the microbes to withstand the temperature (Sukla *et al.,* 2015).

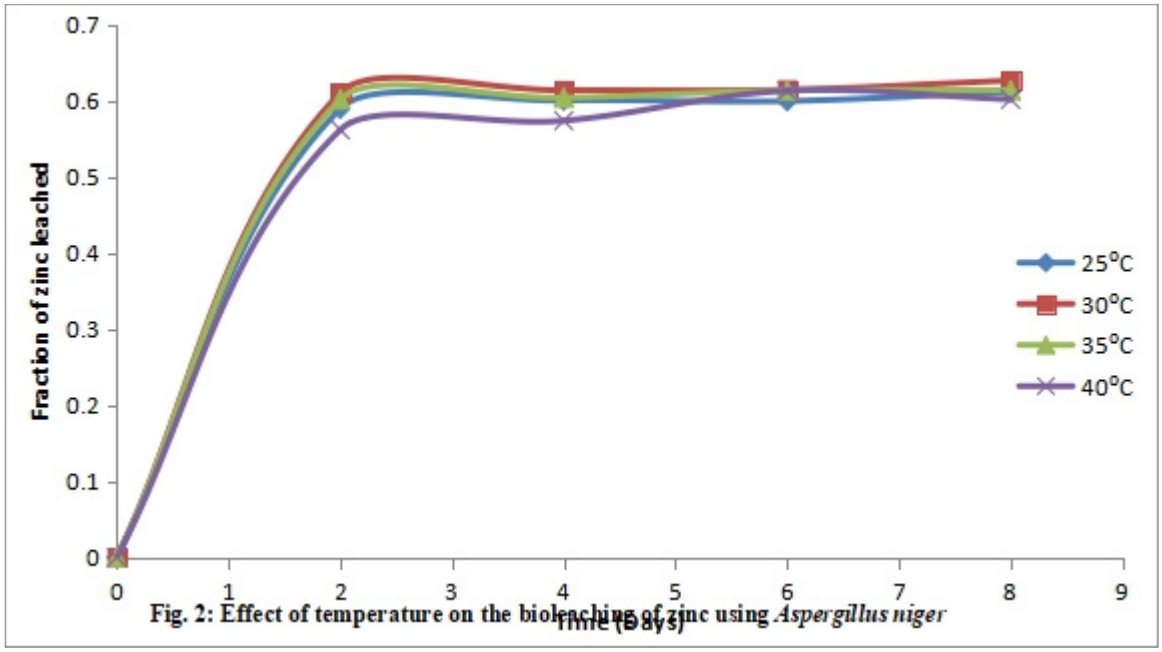

Fig. 2: Effect of temperature on the bioleaching of zinc using *Aspergillus niger*

From the result in figure 3, between 10-15% (v/v) inoculum, the zinc bioleaching was low, with the least value of 57.2% after eight days while the highest bioleaching was observed at 20% inoculum percent. At 25% inoculum, the rate of zinc dissolution slightly decreased, this may be as a result of increased competition for nutrients; oxygen limitation can consequently lead to excessive acid production and hence bring about pH imbalance leading to reduction in bioleaching efficiency (Kumar *et al.,* 2015).

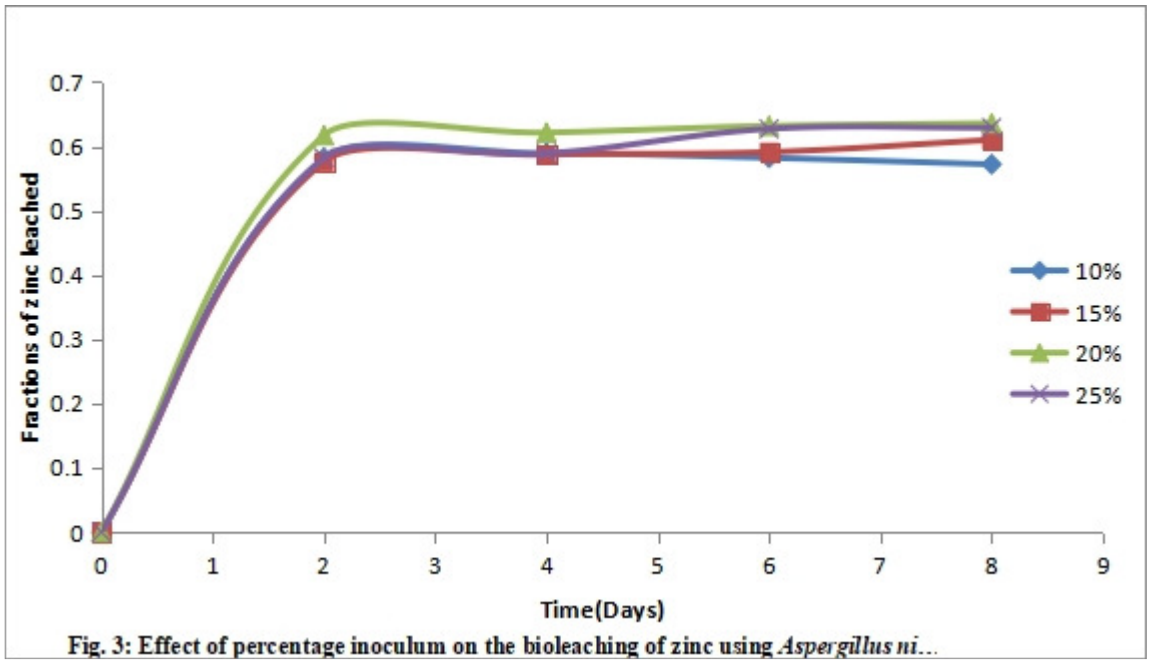

Fig. 3: Effect of percentage inoculum on the bioleaching of zinc using *Aspergillus ni…*

Figure 4 shows the effect of pH, from figure 4, it is glaring that pH has a significant effect on the bioleaching of zinc from Municipal Solid Waste using *Aspergillus niger*. The optimum pH value was found to be 4.5, with a maximum zinc bioleaching efficiency of 62.9%. Below pH of 4.5, the zinc bioleaching efficiency decreased, with a minimum of 58.2% at pH 3.5. This corresponds to an earlier finding that low pH values can inhibit the growth and metabolic activity of *Aspergillus niger* (Kumar *et al*., 2015). Above pH of 4.5, the zinc bioleaching efficiency also decreased slightly, with a minimum efficiency of 60.12% at pH 5.0. This is as a result of the fact that high pH values can lower the dissolution of zinc as well as impede bioleaching process (Sukla *et al*., 2015).

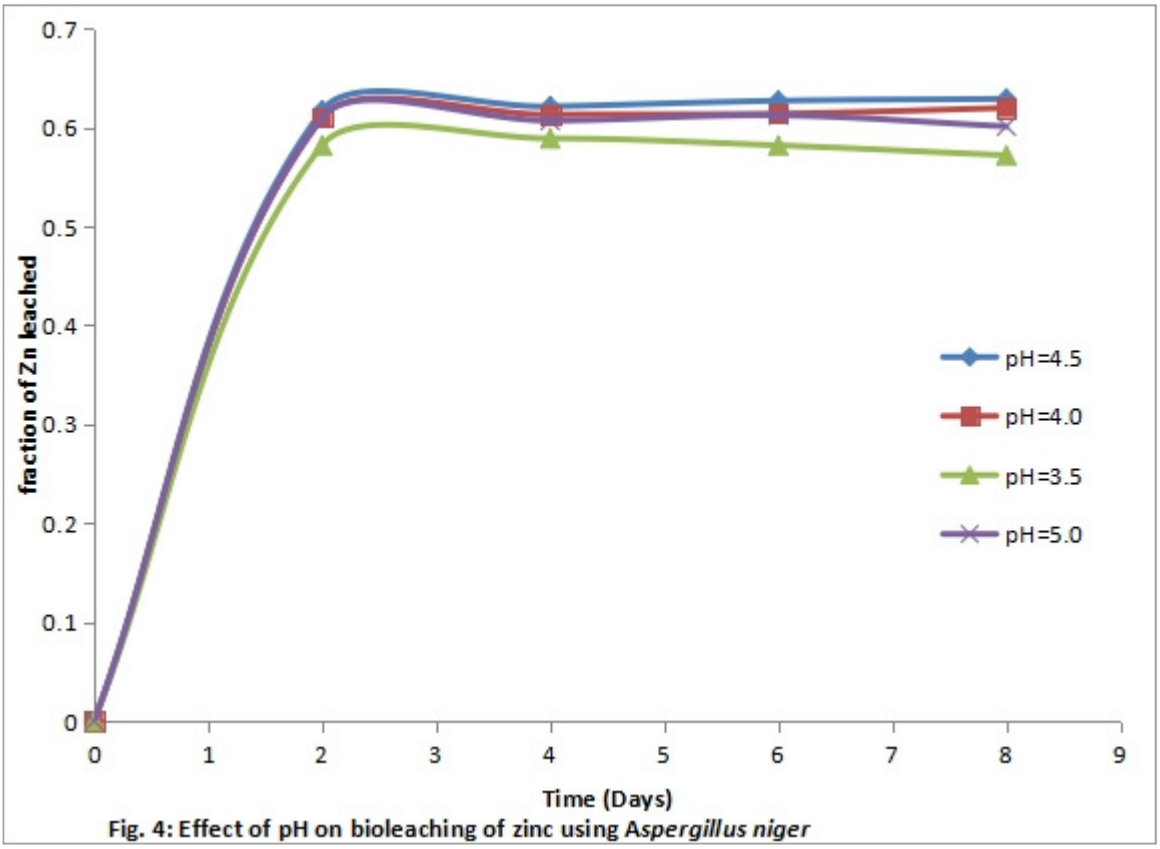

Fig. 4: Effect of pH on bioleaching of zinc using A*spergillus niger*

Figure 5 shows the effect of agitation speed on the bioleaching. Figure 5 clearly demonstrates that agitation has a significant impact on the bioleaching of zinc from Municipal Solid Waste using *Aspergillus niger*. In this study, the effect of flask shake speed at different variants like 100 rpm, 150 rpm and 200 rpm and 250 rpm were investigated. The optimum agitation speed for zinc bioleaching was found to be 150 rpm, with maximum zinc dissolution of 63.59%. However, at higher agitation speeds (200-250 rpm), it was observed that the amount of zinc being leached decreased drastically, with a value of 53.41% at 250 rpm on the eighth day. Sukla *et al.* (2015) claimed that the drastic decrease may be due to turbulence that occurs at this speed leading to cell detachment to the sample and rupture. The

rate of zinc dissolution was also lower at 100 rpm with a minimum leaching efficiency of 57.20%. This is in agreement with the findings that" lower flask shake speeds can lead to decrease in oxygen transfer and microbial growth" (Kumar *et al*., 2015).

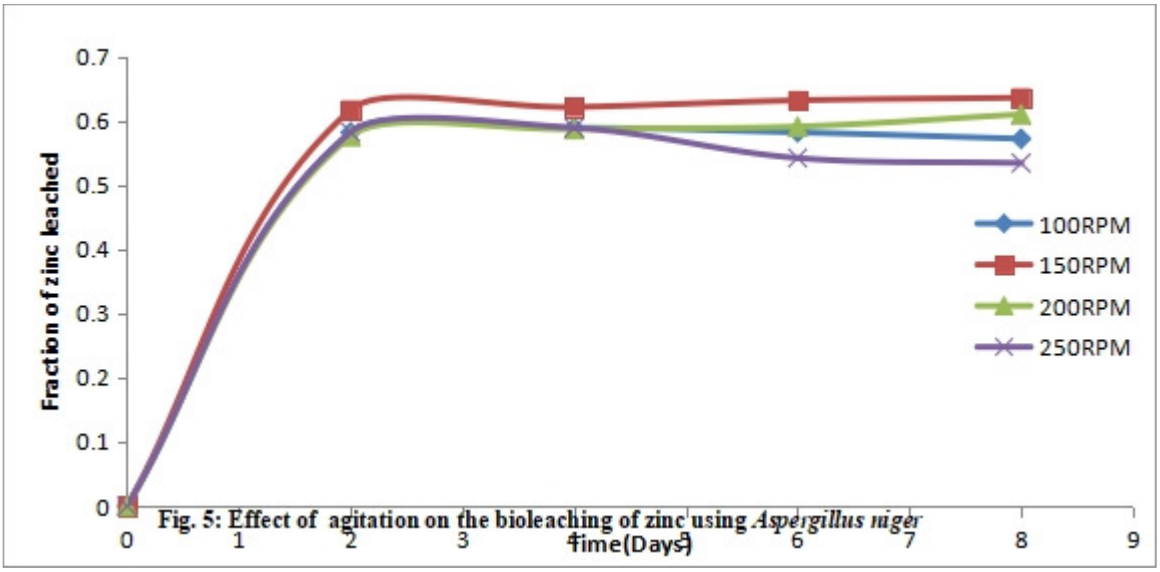

Fig. 5: Effect of agitation on the bioleaching of zinc using *Aspergillus niger*

Conclusion

The physicochemical study of the Municipal Solid Waste sample reveals pH 7.5, loss of mass on ignition 2.5±0.005, moisture content 2.6±0.005. Also, the mineralogical characterization using XRD (X-Ray diffraction) shows that the MWS sample contain quartz, graphite, anhydrite, garnet, muscovite and sphalerite; while the elemental analysis using X-ray Fluorescence (XRF) confirmed that the sample contains 20.239% Zn, 0.0785% Cu, 4.235% Fe, 4.203% Al, 0.082% Pb, 0.082% Ti, and 17.470% Si. Furthermore, the optimum bioleaching conditions for zinc were pH 4.5, temperature 30°C, 20% inoculum and flask shake speed 150 rpm with a maximum bioleaching efficiency of 63 .59%. Therefore, the results revealed that *Aspergillus niger* can tolerate high concentrations of heavy metals and effectively leach zinc under the optimized conditions.

The research shows the feasibility of using *Aspergillus niger* for the bioleaching of zinc from Municipal Solid Waste, providing a sustainable, economical and eco-friendly approach to metals extraction and is thereby recommended for scaling up by industries.

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