International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 5 May 2021, pp: 1458-1465 www.ijaem.net ISSN: 2395-5252

Effects of Horsepower Variations of Grinding Models on Depositional Level of Nickel during Wet Milling in Bauchi Metropolitan Area

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Submitted: 15-05-2021 Revised: 26-05-2021 Accepted: 28-05-2021

ABSTRACT: Wear elements with adverse health effects in human metabolism are suspected to be present during wet milling and required to be detected and compared with WHO standards.They are described as undesirable substances that may be found in food (Kim et al., 1996). Wear elements which are part of mineral contaminants are inorganic elements that are present in food usually in amount well below 50 mg/l and which have some toxicological or nutritional significance on the body of the consumers.Nickel is not exceptional amongst the wear element studiedwhere high uptake can be a danger to human and animal health. Nickel depositional level was studied in Bauchi town by conducting the parametric studies, experimentally and computationally. Studies were performed with three different foods (Cowpea, Millet and Tomatoes) as C_1, C_2 and C_3, three different wet grinding models with different horse power variations as GX 160, GX 200 and GX 390) as H_1, H_2 and H_3 and four different grinding plates (Adex, Nas, Lotus-Zamfara and Lotus-India) as P_1, P_2, P_3 and P_4 to understand the effect of wet grinding plates, horsepower variations (rotational) and wearability of different wet grinding plates on the depositional level of nickel on the ground crops during wet milling. The depositional level of the resulting progeny of particles were analysed through AAS techniques prior to and after milling. The results showed that about (98%) of the nickel elementvariance is explained by the wet grinding plates and wet grinding mill (92 %). The type of wet grinding mills was a major predictor of depositional level, and hence the change in the horsepower of wet grinding mill predicts the depositional level of the nickel element during the wet milling of food products. Moreover, the predicted model can further be used to predict different wet grinding plates. Higher depositional level of Nickel was observed at higher horsepower of wet grinding model (GX 390) and wet grinding plate (Lotus (Zamfara)). Based on the results of the research it is recommended that a grinding plate with less nickelrate should be designed and fabricated in order to minimize the consumption of such harmful nickel element.

Keywords: Grinding plate, grinding models, crops, wet milling, Atomic Absorption Spectroscopy, Nickel

I. INTRODUCTION

Nickel is the 28th element in the periodic table where high uptake can be a danger to human and animal health but small doses is essential for proper functioning of the organs (ATSDR, 2011). Its fumes can cause pneumonitis and exposure to its compounds may result in the development of a "nickel itch" or dermatitis in sensitized individuals (geology.com). Ingestion of this metal in large doses and prolonged contact can result in serious health risks because nickel is known for its genotoxicity and carcinogenicity (Adeti, 2014).

Nickel is a silver-white metal found in several oxidation states, ranging from -1 to +4. Nickel existing in the form of +2 oxidation state [Ni(II)] is the most common in biological systems (Denkhaus andSalnikow, 2002). Nickel easily forms nickel-containing alloys, which have found an ever increasing use in modern technologies for over a hundred years now. It is used to make stainless steel and other alloys stronger and better able to withstand extreme temperature and corrosive environments. This explains why equipment and parts made of nickel-bearing alloys are often used in chemical plants, petroleum refineries, jet engines, power generation facilities and offshore installation. Global input of nickel on the human environment is approximately 150,000 and 180,000 metric tonnes per year from natural and anthropogenic sources, respectively. The major anthropogenic sources include emissions from fossil fuel consumption and Industrial use, disposal of nickel compounds and alloys (Kasprzaket al,. 2003).

A burr mill or burr grinder is the device used to grind small and hard food products between rotating abrasive surfaces separated by distance usually set by the user (Fellows, 2003). Burr mill or plate mill consists of two plates, one rotating plate and the other stationary. Size reduction process can be achieved by successive compaction and shear, as in a burr or plate mill (Olajide, 2016). The reduction in size of food grains is brought about by mechanical means without change in chemical properties of the materials (Enrique, 2012). Grinding as a form of food processing involves the mechanical breaking down of food samples into fine powder or paste form before cooking and consumption (Yahayaet al, 2012). Grinding plates are usually about 200–300 mm in diameter, they are normally aligned in a vertical direction, but horizontal alignment is more convenient when the grinding model mill is run by a diesel engine. Grinding model mill can run as fast as possible but normally at about 2,500–3,500 revolutions/minute, as overheating of the grinding plates limits the speed of the grinding model mill (Ababioet al., 2012).

The milling horsepoweris one of the most important variables to be considered in milling operations. It is carefully optimized to obtain maximal collision energy. The energy input exerted on the plates by burr milling depends upon how fast the grinding mill rotates. However, the maximum speed employed is somewhat limited by the design of the grinding mill. It should also be emphasized that the maximal speed of rotation is of big importance on particle size reduction and morphology of the grains being milled. In this regard, the milling speeds lower or higher than the optimal value have some drawbacks; for example, very low rotational horsepower speeds variations lead to very long periods of milling and a large inhomogeneity in the food crops because of inadequate kinetic energy input (Biyika, 2014).

Foods processed by such fabricated mill were sometimes found to be mixing up with contaminants such as metal, paints, corroded products, and lubricants (Haas et al,. 2001). Food contaminants (mineral, plant, animal, chemical and microbial) are described as undesirable substances that may be found in foods (Brenan et al,. 1991). Nickel contaminant which is part of mineral contaminant is inorganic element that may be present in food usually in amount well below 50mg/l and which have some toxicological or nutritional significance on the body of the consumers, it is known to have deleterious effects even when the diet contains less than 10mg/l to 50mg/l (Machiwa, 2010).

Limited studies have been done on the level of nickel on wet milled food crops, arising from different grinding plates under horsepower variations. It is imperative that the concentration of nickel in the grinding plates for wet milled foods was evaluated so that the safety of foods consumed by human beings is guaranteed. It is in an attempt to fill this knowledge gap that this study has been undertaken. The study set to examine the effects of horsepower variations of grinding models on depositional level of nickel during wet milling of some agricultural crops such as cowpea, tomatoes and millet. It is hoped that the findings will guide in policy making so that foods for consumption are safely processed devoid of contamination with injurious heavy metals in the study area.

II. MATERIALS AND METHODS

2.1 Study Area

Bauchi metropolis is located in North-East Nigeria. It lies between latitude 9^0 3’ and 12^0 3’ north and longitudes 8^0 5^{0}’ and 11^0 East. It has a land area of 49,119 km^2 (18,965 sq mi). it is bordered by seven states, Kano and Jigawa to the North, Taraba and Plateau to the South, Gombe and Yobe to the East and Kaduna to the West. It had a population of 4,676,465 people (NPC, 2006). Based on this figure, the current projected population of the state at a 2.8 percent growth rate is 4,876,580 people. The population is made up of civil servants, traders, artisans of which milling is one of it.

The tests were conducted in the Chemistry laboratory of the Tatari Ali polytechnic.

2.2 Reagents Used and chemicals Preparation

All aqueous solutions and dilutions were prepared with ultrapure water (18.2 MΩ cm) obtained from an SG Ultra Clear UV Plus system (Wasseraufbereitung und Regenerierstation GmbH, Germany). HNO_3, H_2O_2, and H_2SO_4 are analytical grade. All glass-ware was cleaned by soaking in 15% (v/v) HNO_3 for 24 h and rinsed with ultrapure water prior to use. High purity argon (99.99%) was used as a plasma sustaining gas.

2.3 Features, characteristics and sample preparation for depositional level of nickel during wet milling

Wet grinding plates made from Nigeria and India were purchased from the Nigerian open market which were used for the research. The mode of selection of the wet grinding plates was at random sampling. The wet grinding plates are in a form of a disc having a diameter of about 30 cm and a hollow core diameter of about 11cm and they are not of uniform thickness. The thickness ranges from about 10 mm at the outer circumference and tapers down to 3 mm at the centre. In addition, the grinding plate surface has grooves/striations for effective grinding/milling operation. Crop samples (Cowpea, Millet and Tomatoes) were purchased from identified farmers not in an open market (Plate 1). This control over the mix up in the crops and the soil where such crops were produced. The grains were soaked and rinsed repeatedly with tap water, and then rinsed three times (each time for 3 min) with ultra-pure water in an ultrasonic cleaner, then placed in constant temperature oven drying at 45 °C to constant weight.

Plate 1: Crop samples (millet, cowpea and tomatoes)

Preparation of samples for Determination of depositional level of nickel prior to milling

All samples of cowpea, millet and tomatoes were washed with deionized water to remove soil particles or dusts adhering to the grain surface. Samples were oven-dried at 45 °C for 24 hours, then the crops were ground in a stainless steel pestle and mortar to a fine powder and stored in plastic bags for nickel analysis prior to milling (Plate 2). The crops' samples were analysed for the heavy metal nickel prior to wet milling. After digesting with a mixture of nitric acid (HNO_3) and Hydrogen peroxide (H_2O_2) (Barman et al,. 2000).

Plate 2: Ground of one of the Crop Prior to Wet Milling

2.4 Milling and Digestion of crops for determination of depositional level of nickel.

The milling process was carried out using three different wet grinding milling machines (GX 160, GX 200 and GX 390) with varying horse power (5.5, 6.5 and 13 Hp) as H_1, H_2 and H_3 respectively. The Adex, Nas, Lotus-Zamfara and Lotus-India made wet grinding plates (P_1, P_2, P_3 and P_4) were each placed in each of the wet milling machine, 2 Kg weight of the crops (Cowpea, Millet and Tomatoes) as C_1, C_2 and C_3 sample were milled in each of the three wet milling machine immediately after the insertion of the wet grinding plates into the machines.The process was repeated for three replications to assess the depositional level of Nickel as shown in Plate 3. The wet grinding milling machines were located at Food Processing laboratory of the Department of Agricultural and Bioresource of Abubakar Tafawa Balewa University, Bauchi, Nigeria.

Plate 3: Wet Milling of Different Crops (Cowpea, Millet and Tomatoes)

The wet samples (cowpea, millet and tomatoes pastes) were homogenized using an agate homogenizer and stored in polyethylene bags until analysis as shown in Plate 4. Care was taken at each stage of preparation to avoid contamination. Samples collected were thoroughly mixed to make sure that representative samples were obtained. The ground crops from the wet grinding milling were labelled based on replications consecutively. A total of one hundred and eight (108) samples were then obtained.

Plate 4: Sample of wet milled crop

2.4.1 Dry Ashing

2.0 gm of dried samples (Cowpea, Millet and Tomatoes) was accurately weighed into a porcelain crucible, the porcelain crucible was then heated in muffle furnace at 200 °C for 1.5 hrs, and gradually heated to 350 °C for 4 hrs in order to make the sample dry ashing. The ash samples were digested with (5 ml HNO_3, 3 ml HCl and 2 ml H_2O_2) ml of concentrated mixed acid (HCl: HNO_3=3:2:1), then the digestion solution was heated up on electric hot plate at 150 °C until evaporated to near dryness. The residue was filtered and transferred into a volumetric flask and made up to 25 ml with 3% HNO_3. The blank digestion experiments were also carried out in the same way.

Before the depositional level of nickelelement was determined, the instrument was cleaned thoroughly by spraying clean water into the flame and then the instrument was set to zero. 10 g of each sample of Cowpea, Millet and Tomatoes were weighed and put into crucibles respectively. The crucibles were arranged accordingly on the gas burner and ignited gently over a low flame until it charred and then moved into already switched on muffled furnace with temperature controlling regulator. The samples were heated gradually to about 600^0C with an instrument called muffle furnace, see Plate 5. Appropriate temperature for ashing the selected samples is at 6 hours to obtained the ash and to avoid volatilization or interaction between constituents. The ash samples were allowed to cool in desiccators to avoid moisture and contaminants from coming in contact with them, see Plate 6.

Plate 5: Muffle furnace

Plate 6: Desiccators

The ash sample obtained from muffle furnace after getting cooled from desiccators was moistened with water inside a conical flask and 10 ml-diluted hydrochloric acid (1:1) was added. Each diluted sample was evaporated to dryness on a regulated electrical hot plate and allowed to cool. Then later 20 ml water and 10 ml diluted hydrochloric acid were added, boiled and filtered into 250 ml volumetric flask (Plate 7). The remaining contents in the filter were thoroughly washed with hot water; the solution is then allowed to cool and diluted to the mark with water. Atomic absorption spectrophotometer instrument was used to determine the nickel element in the aliquots of the digested samples (Sinayobye and Saalia, 2011).

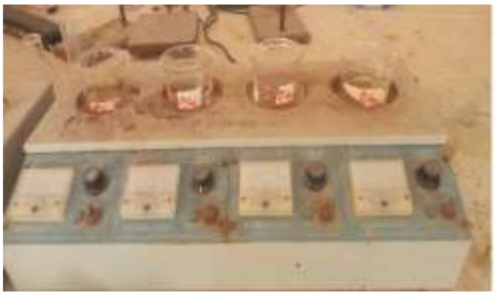

Plate 7: Dry ashing of Sample Crops (Cowpea, Millet and Tomatoes)

2.4.2 Wet Ashingof Sample crops (Cowpea, Millet and Tomatoes)

Recent studies have shown that mixtures of HNO_3/H_2O_2 are better than HNO_3, HCl, or

H_2SO_4 in terms of complete dissolution in a short time period for wet digestion. That was why the mixtures of HNO_3/H_2O_2 were used in the wet digestion procedures. 5.0 gm of dried samples (Cowpea, Millet and Tomatoes) was accurately weighed into 50 mL beaker, added 10 mL of concentrated HNO_3 and 2 ml of 30% H_2O_2, and 3 ml of concentrated HCl were mixed and then heated in a digestion block at 100 °C. After the disappearance of brown fumes, the digestion solution evaporated to near dryness. The residue was filtered and transferred into a volumetric flask and made up to 100 ml as shown in Plate 8 below. The blank digestion experiments were also carried out in the same way.

Plate 8: Wet ashing of Sample Crops (Cowpea, Millet and Tomatoes)

2.5 Determination of Nickel Element in the Samples

The filtered samples were analized for the presence of depositional level of wear elements on a WINCOM AAS 320N Atomic Absorption Spectrophotometer with an air–acetylene burner or nitrous oxide–acetylene burner for flame and a graphite furnace for electro-thermal determinations, with appropriate background (non-atomic) correction with the recommended instrument parameters including detection limits for each metal determined. The determination of structural elucidation of various substances was done by atomic absorption spectroscopy. The samples in solution state were sprayed over a burner. This leads to evaporation of solvent and leave fine dry residue behind which is nothing but neutral atoms in ground state. To these atoms, a light of specific wave length was passed and the un-absorbed light is recorded over a detector. The cathode lamp made of different elements were used and so for nickel all the other metal elementanalyzed. Blanks and standard reference reagents were also run concurrently with the Nickel metal analyses to ascertain reproducibly and quality assurance.

2.6 Statistical Analysis

Statistical analysis and independent t-test were performed using SAS 16.0. Non-normal data were normalised through square root transformation to improve normal distribution and to reduce the influence of high analytical data. Correlation (r) and analysis of variance (ANOVA) were performed on log-transformed Nickel element analytical data. Correlation analysis based on the correlation matrix, were conducted for the nickel element data set. The aim of using t-test was to compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different and ascertain any patterns in the crop samples in relation to these chemical characteristics, and then make a preliminary conclusion to the possible relationship between heavy metal concentrations and corn-grinding plate properties. The data from the HPLC analysis on nickel elements depositional levels were subjected to an analysis of variance (ANOVA) and one sample t-test at a 95 % confidence level.

After the initial profiles and core samples were obtained, the milling operations were performed according to the experimental design layout. Three factors of influence were chosen for this study namely three wet grinding milling machines (GX 160, GX 200 and GX 390) as H_1, H_2 and H_3 respectively, three different crops (Cowpea, Millet and Tomatoes) as C_1, C_2 and C_3 respectively and four different grinding plates (Adex, Nas, Lotus-Zamfara and Lotus-India) as P_1, P_2, P_3 and P_4 respectively. This gives a total of $4 \times 3 \times 3 = 36$ treatments. This was fitted into a completely randomized design (CRD). Consequently, the experiment was replicated through randomized complete design and as such the variations are minimized and the error due to the variations are removed. The treatments were randomly assigned to experimental units such that each treatment occurs equally**.** Each test was conducted in three replications, which gave a total of $36 \times 3 = 108$ experimental tests.

2.7 Results and Discussion

Normality of the data and equality of variances across comparison groups were maintained. Both analyses are performed on log-transformed data and compare the means of the groups.

Hypotheses:

H_o = there is no significant difference between the depositional level of the nickel elements in the studied factor

H_1 = there is significant difference between the depositional level of nickel elements in the studied factor

$$t(\text{degrees of freedom}) = \text{the t statistic}, p = \text{p value} \quad \ldots (1)$$

2.8 Analysis of variance (ANOVA) on effects of grinding plates, grinding speeds and crops on nickel

The data collected from the laboratory digestion (Table 1) were analyzed using analysis of variance (ANOVA). In the analysis, the significant effects of grinding plates, grinding speeds, and different types of crops and their interactions were determined for depositional level of Nickel in the course of milling of crops. The results of the ANOVA showed that there were significant differences of the grinding plates (F= 0.44, P= 0.0054 (P-value) <0.05) on depositional level of Nickel. This means the change in the material content on grinding plate had a significant effect on depositional level of nickel due to milling of crops. Explicitly, mean of nickel depositional level were not same amongst grinding plates. The speed levels of grinding models also indicated significant difference on depositional level of Nickel (F= 0.85, P= 0.0038 (P-value) <0.05). This shows that the higher the grinding speeds the higher the depositional level of nickel. Conclusively, at least one of the mean values of the grinding models was significantly different. The crops showed a significant difference on depositional level of nickel (F= 2.40, P= 0.0054 (P-value) <0.05). Meaning crops had significant effect on depositional level of nickel.

The combinations between grinding plates and grinding speeds, grinding speeds and crops showed significant effects on depositional level of nickel (F= 0.60, P= 0.0035 (P-value) <0.05) and (F= 0.69, P= 0.0041 (P-value) <0.05). Likewise, interactions between grinding plates and crops show a highly significant effect on depositional level of nickel (F= 0.36, P= 0.0001 (P-value) <0.05). Expressively, all the two factors interactions were having significant effects on the average depositional level of nickel. However, interaction effects show that relationship between grinding plates, grinding speeds and crops with depositional level of nickel relied on the different grinding speeds, grinding plates and crops. The treatments three factors interaction of grinding plates, grinding speeds and crops also indicated a significant effect on depositional level of nickel (F= 0.77, P= 0.0062 (P-value) <0.05). It revealed that at least one of the average depositional level of nickel values was significantly different. However, comparison mean was further analyzed to determine where the level of significance lies.

Table 1: ANOVA on effects of grinding plates, grinding speeds and crops on depositional level ofNickel

Source	DF	Mean Square	F Value
Model	35	0.00002405	0.73*
Grinding Plates	3	0.00001440	0.44*
Grinding Models	2	0.00002811	0.85*
Crops	2	0.00007894	2.40*
Grinding Plates*Grinding Speed	6	0.00001965	0.60*
Grinding Speeds*Crops	4	0.00002283	0.69*
Grinding Plates*Crops	6	0.00001190	0.36**
Grinding Plates*Grinding Speeds*Crops	12	0.00002532	0.77*
Error	72	0.00003295	
Corrected Total	107		

2.8.1 Effects of grinding plates, grinding speeds and crops on depositional level ofNickel

Analysis of variance (ANOVA) was performed to determine the statistical significance of the independent factors of study which were grinding speeds, grinding plates and different crops on depositional level of Nickel. Also, Tukey's means comparison test was performed to find out which of the levels of the significant treatments was most significant. The test showed that means having similar letters are not significantly different as illustrated in Table 2. The entire tests were conducted at P< 0.05 of significance level. The combination of grinding speed (S_1) and crop (C_1), grinding plates P_1, P_2 and P_4were not significantly different with mean of depositional level of Nickel 0.189, 0.180 and 0.188 mg/L correspondingly. There was significant difference between grinding plate P_3 with mean value of 0.191 mg/L with other grinding plates. Grinding speed (S_1) interacting with crop (C_2), grinding plates P_1 and P_3were not significantly different with mean values of 0.173 and 0.178 mg/L accordingly on depositional level of nickel. However, there were no noticeable differences between the grinding plates P_1, P_2 and $P_4$for grinding speed (S_1) and crop (C_3) with mean values of 0.185, 0.187 and 0.187mg/L on depositional level of nickel. Likewise, the differences between the grinding speed (S_1) and crop (C_3) were found to produce significantly different on depositional level of nickel by the grinding plate P_3 with mean value of 0.191 mg/L.

The interaction between grinding speed (S_2) and crop (C_1) reveal that there were significant differences with grinding plates P_2 and P_4 with mean values of 0.202 and 0.179 mg/L respectively. The grinding plates $P_1$and P_3 were not significantly different on depositional level of nickel with average values of 0.191 and 0.198 mg/L. Also, at combination of grinding speed (S_2) and crop (C_2) grinding plates P_1 and P_2 recorded significant difference on depositional level of nickel with averages of 0.69 and 0.183 mg/L accordingly. While grinding plates P_3 and P_4 show a non-significant difference with mean values of 0.170 and 0.175 mg/La respectively. Similarly, grinding plates P_1 and P_4 with interactions of grinding speed (S_2) and crop (C_3) show a significant difference on depositional level of nickel with average values of 0.186 and 0.183 mg/L accordingly. Also, grinding speed (S_3) and crop (C_1) the interaction shows non-significant difference on depositional level of nickel with average values of 0.193, 0.194, 0.193 and 0.199 mg/L for grinding plates P_1, P_2, P_3 and P_4 respectively. The interactions between grinding speed (S_3) and crop (C_2) show that grinding plates P_1, P_2 and P_4 did not indicated significant difference with mean values as 0.181, 0.182 and 0.181 mg/L respectively. While a significant difference was shown by the grinding plate P_3 based on the interactions between grinding speed (G_3) and crop (C_2) with average value of 0.204 mg/L. Finally, interactions between grinding speed (S_3) and crop (C_3) shows a non-significant difference between grinding plates P_1 and P_4 with mean values of 0.187 and 0.189 mg/L accordingly. A significant difference is indicated with grinding plates P_2 and P_3 with average mean of 0.191 and 0.211 mg/L respectively. Generally, based on the three factors interaction effects on depositional level of nickel, grinding plate P_4 and with interactions of grinding speed (S_2) and crop (C_3) gave the highest depositional value of nickel, while grinding plate P_1 recorded the lowest depositional level of nickel with grinding speed (S_2) and crop (C_2) interactions. Furthermore, these results confirm that grinding with model of medium horse power with lower speed reduces the depositional level of nickel and these results confirmed that.

Table 2: Effects of grinding plates, grinding speeds and crops on nickel

	Nickel								
	S_1			**S_2**			**S_3**		
Plate	**C_1**	**C_2**	**C_3**	**C_1**	**C_2**	**C_3**	**C_1**	**C_2**	**C_3**
P_1	0.189^{bc}	0.173^{bc}	0.185^{bc}	0.191^{de}	0.169^{de}	0.198^{bc}	0.193^{ab}	0.181^{bc}	0.187^{bc}
P_2	0.180^{b}	0.202^{a}	0.187^{bc}	0.200^{a}	0.183^{a}	0.186^{de}	0.194^{ab}	0.182^{bc}	0.191^{de}
P_3	0.191^{a}	0.178^{bc}	0.191^{de}	0.198^{de}	0.170^{bc}	0.183^{de}	0.193^{ab}	0.204^{a}	0.211^{a}
P_4	0.188^{bc}	0.186^{d}	0.187^{bc}	0.179^{bc}	0.175^{bc}	0.212^{a}	0.199^{bc}	0.181^{bc}	0.189^{bc}

2.9 Conclusion

Nickel is a ubiquitous metal, which finds increasingly more applications in modern technologies. Contact with nickel compounds (both soluble and insoluble) can cause a variety of adverse effects on human health. Given the fact that the results obtained in this study of the nickel content were significantly higher than the FAO/WHO standards recommended. The most important and frequent are nickel allergy in the form of contact dermatitis, lung fibrosis, cardiovascular and kidney diseases, and lung and nasal cancers.

The Nickel concentration recorded in all the wet milled crops were significantly higher than that obtained in the ones prior to grinding with that of Indian plate recording the highest value of 0.212 Mg/L. This shows that the milling process introduced some amount of the Nickel metal into the tomatoes.

2.10 Acknowledgement

The authors sincerely thank TETFUND Nigeria for funding the research work, all staff of the Departments of Agricultural and Bioresource Engineering of the AbubakarTafawaBalewa Universityand Staff of the Chemistry Laboratory of the AbubakarTatari Ali Polytechnic Bauchi Nigeria, for their support and contributions towards the success of this research work.

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