

PAPER 37 – ASSESSMENTS OF METAL PARTICLES IN GROUND FOOD

Segun Isaac Talabi^{1,*}, Jamiu Kolawole Odusote¹, Jeleel Adekunle Adebisi¹, Ismaila Idowu Ahmed¹,
Taiwo Yahaya¹, Modupe Rasheedat Mahamood¹, Lawrence Aderemi Olatunji², Mariam Kehinde
Sulaiman³, Suleaiman Abdulkareem⁴

¹Department of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Nigeria.

²Department of Physiology, University of Ilorin, Ilorin, Nigeria.

³Department of Medical Microbiology and Parasitology, University of Ilorin, Ilorin, Nigeria.

⁴Department of Mechanical Engineering, University of Ilorin, Ilorin, Nigeria.

*Email: talabi.si@unilorin.edu.ng

ABSTRACT

Food processing encourages safe preservation and provides opportunities for the production of several types of diets. In Nigeria, some foodstuffs are commonly processed in the dried or wet form to powder or paste using an abrasive cutting process involving cast-iron discs. Despite the popularity of this method, metallic and non-metallic contaminants including heavy metals such as cadmium and lead that are detrimental to human health are introduced. Consequently, this study systematically determined the presence of metallic contaminants in ground maize grains, which were processed under dry and wet conditions. Locally available grinding discs manufactured using different furnaces were used to assess the quantity and composition of these contaminants. Irrespective of the disc type, different quantities of contaminants were found in the ground food grains. The discs manufactured using a pit and rotary furnaces generated the highest quantity under wet and dry grinding conditions, respectively. These metallic contaminants were found to contain heavy metals such as lead (≤ 0.316 mg/kg), cadmium (≤ 0.024 mg/kg), chromium (≤ 0.016 mg/kg), copper (≤ 0.880 mg/kg), manganese (≤ 0.624 mg/kg) and zinc (≤ 0.006 mg/kg).

KEYWORDS: contaminants, heavy metal, grinding, cast iron discs, metal particles, ground food

1. INTRODUCTION

Foods are edible materials that provide nutrients, energy, protein, vitamins, and minerals for human growth and development. They are essential for the replacement and repair of cells and provide the body with the necessary energy to function and fight against diseases. Food processing provides the opportunity to eat a greater variety of diets and encourages safe food preservation and packaging. Many dried or dehydrated food processing methods require milling (machining using rotary cutters) or grinding (abrasive cutting using grinding discs) the raw materials to flour/powder form under wet or dry conditions. Other methods involved crushing (pulverization by compression force), granulation (grains or granules formation from solid raw materials), pulverization (reduction to powder by hammering or grinding), and mixing (mechanical dispersion to attain homogeneity) (Gao et al., 2020, Ortega-Rivas et al., 2006). These methods offer the benefits and economic advantages associated with reduced volume/weight, convenience, packaging, handling and transportation, improved bioaccessibility, and greater nutritional value (Gao et al., 2020; Ortega-Rivas et al., 2006). More importantly, it ensures that the preserved food is maintained in dried form for future utilization. However, bad food processing strategies can be detrimental, leading to various challenges such as elevated cholesterol, obesity, certain cancers and digestive issues like Crohn's disease (Joardder and Masud, 2019).

Grinding is an ancient technique of particle size reduction that mechanically produces powders via impact, compression, shear, and cutting (Aradwad et al. 2021). It is an energy-intensive process in which solid food substances are broken down into fine particles (Jung et al., 2018). The food materials produced using this procedure are chemically and microbiologically stable and convenient for future use. The use of grinding machines equipped with cast iron discs is a popular method of food processing in Nigeria. Many households rely on this method to prepare grains as a paste or dried powder. Despite its commonality, this food processing method may not be safe as the grinding mechanism depends on the energized rubbing of two grinding discs, which often leads to the incorporation of metallic and non-metallic contaminants, and even heavy metals that are detrimental to human health (Cancer, 2012). This possible health risk, demands detailed quantitative and qualitative analyses of contaminants introduced into food prepared using such a procedure.

This present study involved a wholesome approach directed towards quantitative and qualitative assessment of metallic contaminants introduced into ground food under wet and dry grinding conditions. Moreover, the present

investigation considered the use of various grinding discs that are locally available for purchase in Nigeria, including imported ones. These discs are produced based on various manufacturing methods namely: cupola, pit and rotary furnaces. The selected discs were typically produced by semi-skilled artisans, who are not knowledgeable about the science of metallurgy and casting but possessed foundry experience, which has been acquired over a long period. Consequently, quality assurance of these locally produced discs is usually not carried out since the workers have no code of practice. Government regulations that are supposed to guide their production and usage are also not enforced. This may be due to a lack of adequate data, information and awareness on the nature of contaminants generated in food during processing with such grinding machines. In addition, previous investigations do not involve a systematic approach to the grinding procedure and retrieving of the metallic contaminants from the ground food. The information provided in this study is expected to prompt a series of other investigations to address the menace of food processing using grinding machines in line with SDG No. 9.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The grinding discs used in this study were sourced from local markets in the Southern region of Nigeria. Ten pairs of grinding discs produced using cupola, pit and rotary furnaces were purchased from six different manufacturers. The discs were designated as shown in Table 1.

Table 1. Different grinding discs and samples designation

Samples	Designation
RIL	Grinding discs produced using a rotary furnace and sourced from Ilorin
ROS	Grinding discs produced using a rotary furnace and sourced from Osogbo
RIW	Grinding discs produced using a rotary furnace and sourced from Iwo
PIL	Grinding discs produced using a pit furnace and sourced from Ilorin
CIW	Grinding discs produced using a cupola furnace and sourced from Iwo
ID	Imported grinding discs produced from India and sourced from Ilorin

2.2 Processing of maize grains under wet and dry conditions

The food grains were ground under wet and dry conditions. Regarding wet grinding, 10 kg of dried maize was soaked with deionized water for three days in a 30 litres capacity bucket. After three days, the water was decanted and the soaked weight of each food sample batch was determined as appropriately 10.3 kg. To ensure the reproducibility and uniformity of the grinding procedure, certain parameters including the discs' gap tightening sequence (using marked screw threads) and grinding time (18 minutes, 15 seconds) were kept constant. The grinding was done with 5 litres of water. A similar procedure and grinding conditions were employed to process the maize under a dry environment without soaking the maize in water or introducing water during grinding. Before installation and usage, the grinding discs' surfaces were grooved with the aid of a grinding disc, cleaned with a wire brush and later fixed on the locally fabricated grinding machine.

2.3 Quantification of magnetic contaminants

Scavenging devices were fabricated to trap magnetic contaminants from the ground food using the ferromagnetic principle as shown in Figure 1. The neodymium permanent magnets used were enclosed within the acrylic sheets to ensure they do not have any contact with the ground maize. Under the wet condition, the magnetic bed was kept below the flow of the food paste, while it was placed above the dry food powder. Each batch of ground food was run through the scavenger inclined at 23° for three cycles.

Regarding the scavenging process, the magnetic bed trapped the contaminants after which the device was disassembled with the magnetic bed initially in place to retain the scavenged particles at the upper layer of the curved acrylic sheet before it is removed. Thereafter, the contaminants were recovered using a neodymium permanent magnet wrapped with polyethylene film. The magnet was again separated from the film and the recovered contaminants were weighed after each cycle, kept in a sample bottle and later summed up to give the total amount of recovered magnetic contaminants per each grinding.

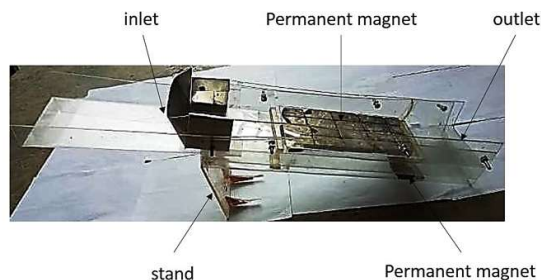


Figure 1. The scavenging device used for separating the magnetic contaminants from ground food.

Characterization of metallic contaminants

A BUCK Scientific ACCUSYS 211 Atomic Absorption Spectrophotometer was used to detect the presence of some heavy metals in the contaminants recovered from ground maize processed under dry grinding conditions. Regarding the analysis, a 10 ml mixture of concentrated HNO₃ and HCl in 3:1 was used to digest 0.05 g of contaminants scavenged from different batches of ground food. After digestion, the solution was diluted with the addition of 90 ml of distilled water and filtered with Whatman 1 filter paper. The filtered liquid solution was analyzed to detect the presence and relative quantity of Pb, Cd, Cr, Cu, Mn, and Zn. The analysis was conducted twice and the reported results represent an average value.

3. RESULTS AND DISCUSSION

3.1 Magnetic contaminants

Firstly, the efficiency of the scavenging devices used in the recovery of magnetic contaminants from the ground food was determined as approximately 85%. The determination was done by introducing a known quantity of metallic contaminants, which were previously generated from the discs during grinding into a known quantity of ground maize. Thereafter, the number of recovered contaminants after running the ground food through the scavenger three times was divided by the initial amount that was introduced into the food and multiplied by 100. Figure 2a shows the quantities of magnetic contaminants generated during the wet grinding of soaked maize grains with various cast iron discs that were produced using rotary, pit and cupola furnaces. Irrespective of the discs' type, significant amounts of contaminants were recovered after sequentially grinding the grains for 18.25 minutes.

PIL discs, which were produced using a pit furnace and sourced from Ilorin generated the highest quantity of contaminants. The smallest amount of such inclusions was recovered when ROS discs (sourced from Osogbo and produced using a rotary furnace) were used for grinding the grains. More so, one of the tightening nuts got loosed and was ground into the food while processing the grains with ROS discs. The nut contribution to the overall quantity of recovered contaminants during this batch of experiments was determined by subtracting the weight of the recovered nut from the initial nut weight. This scenario typically occurs during food processing with the locally fabricated grinding machine. The results obtained in this investigation reinforced earlier submissions about metallic inclusion in ground food ([Normanyo et al., 2010](#); [Odusote J. K., 2017](#)) and further assert that their presence is independent of the type of cast iron discs that may be installed on such grinding devices. Nevertheless, the results showed that the chemistry and structure can influence the number of metallic contaminants generated in the ground food. This observation was based on the difference in the number of recovered contaminants for the different discs type despite the similarity in grinding conditions. As expected the discs' structure and composition will affect properties such as wear and hardness ([Kwofie S. and Chandler H. D., 2006](#)), which will determine their performance in service. These contributions advance existing knowledge on the subject matter. Figure 2b is a representation of the contaminants which were recovered using a neodymium permanent magnet wrapped with polyethylene film.

However, under dry grinding conditions, the number of contaminants generated in the ground food increased (Figure 3). It should be noted that the comparison between the number of contaminants based on wet and dry grinding did not consider continuous usage over a long period. Under such circumstances, disc corrosion in synergy with wear may contribute to metal loss in a wet grinding condition. For all the investigated discs, the quantity of recovered magnetic particles/chips increased compared to when wet grinding was used to process the maize grains. Friction is the main mechanism responsible for food pulverization by grinding. In addition, the environment (grinding) plays a significant role in the abrasive wear rate of metallic materials ([Gao et al., 2020](#)). Therefore, the presence of water during grinding serves as a lubricant, which reduced metal loss during the wet grinding operation ([Wirojanupatump and Shipway, 1999](#)). Consequently, the higher number of magnetic contaminants during the dry grinding can be attributed majorly to the lack of lubricating effect by water.

Nevertheless, some other factors such as an increase in temperature due to friction during grinding, and the constituents of the grinding discs could also influence the discs' wear performance. As expected, the quantity of magnetic contaminants generated into the ground food under dry grinding conditions varied for the different cast iron discs. In this instance, the least number of contaminants was introduced by PIL discs while the highest quantity was produced by RIL discs, which were manufactured using pit and rotary furnaces from Ilorin, respectively. It is not very clear why the discs produced using a pit furnace perform better under this condition. Nevertheless, the compositional analysis of contaminants resulting from the usage of these discs showed that the PIL disc has the highest amount of calcium. Calcium has been reported to possess the ability to induce spheroidal graphite generation in cast iron (Oluwole, 2007). The presence of graphite nodules within the microstructure of such cast iron will enhance its wear resistance. This observation may be responsible for the better performance exhibited by the discs (PIL discs).

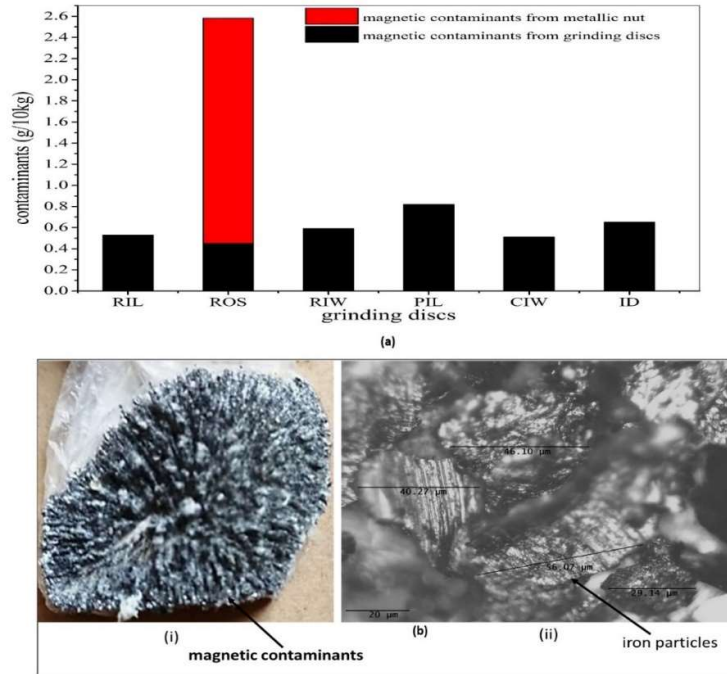


Figure 2. Magnetic contaminants generated from different locally sourced discs during wet grinding for 18.25 minutes (a), and a sample of magnetic contaminants recovered from ground food using a permanent magnet wrapped with a polyethylene sheet (i) and microstructural image (ii) obtained using an Amscope optical microscope (b).

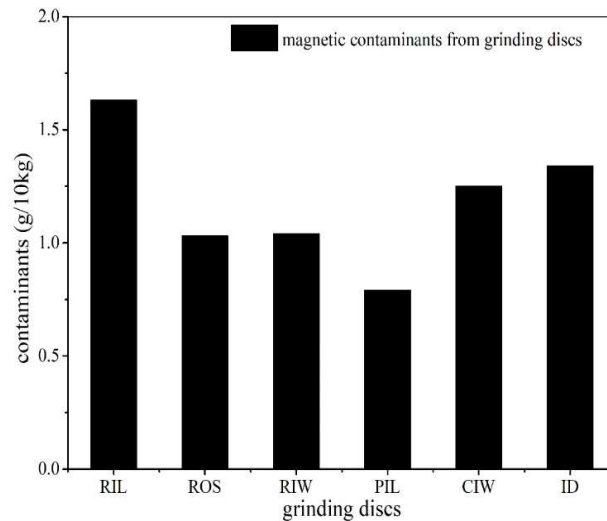


Figure 3. Magnetic contaminants generated from different locally sourced discs during dry grinding for 18.25 minutes.

3.3 Analysis of heavy metals in magnetic contaminants from ground food prepared using various grinding discs

There are about twenty-three heavy metals that in large quantities will be harmful to humans (Jaishankar *et al.*, 2014). Heavy metal toxicity can impair the functionality of some important organs such as the brain, lungs, kidneys and liver (Järup, 2003; Jaishankar *et al.*, 2014). Long-term exposure to them can cause neurological degenerative processes that can lead to multiple sclerosis, Parkinson's disease, Alzheimer's disease and muscular dystrophy while their compounds may be carcinogenic (Järup, 2003).

Table 2 shows AAS results for different samples of recovered magnetic contaminants. The results showed that food processed using locally fabricated grinding machines can be a contributory source of heavy metal intake in humans. Consequently, attention must be given to the processing of food grains with such machines having cast iron grinding discs installed in them. More so, the recovered metallic contaminants are not present in mineral or dietary form and may therefore constitute a major health hazard. Nevertheless, the analysis and comparison in this study were based on information available regarding the consumption of such heavy metals in their dietary form. Regarding this study, the presence of lead (Pb) was detected in contaminants generated from the usage of CIW, RIL and ROS discs. RIL contaminants presented the highest Pb value of about 0.3169 mg/kg. Sub-Saharan Africans consumed up to 450 g/person/day of maize (Ekpa *et al.*, 2019). Consequently, an adult in Nigeria may consume about 3.2 kg in a week. Based on earlier results (section 3.1), 0.5216 g of magnetic contaminants were recovered when 3.2 kg of maize grains were ground using RIL discs. This quantity of contaminants contained about 0.00016 mg of Pb. The tolerable weekly intake of Pb has been reported as 0.025 mg/kg body weight (Witkowska *et al.*, 2021). The average body weight of an adult in Nigeria is 72 kg, which implied that the maximum tolerable intake of Pb per week is 1.8 mg. This indicates that the detected Pb quantity is within the permissible limit. However, it must be noted that this is only coming from a single food source. Cadmium is another heavy metal that was detected during the analysis of contaminants recovered from food processed using all the investigated grinding discs. The maximum value of this metal was recorded in contaminants recovered from food processed using RIL discs. The tolerable weekly intake value of Cd has been reported as 0.007 mg/kg body weight (Witkowska *et al.*, 2021). According to the earlier submission, the detected value will imply a weekly consumption of 1.25×10^{-5} mg of Cd, which is within the permissible weekly consumption value. Chromium can exist in trivalent or hexavalent form in the environment and its hexavalent form has been reported to be toxic and carcinogenic (Gürkan *et al.*, 2017; Witkowska *et al.*, 2021). Nevertheless, the tolerable upper intake level of chromium has not been established. In this study, 0.01612 mg/kg and 0.00950 mg/kg of Cr were detected in ID and ROS contaminants, respectively. The recommended maximum daily intake of copper for adults, which is based on liver damage protection is 70 mg/week (Trumbo *et al.*, 2001). Similarly, the recovered contaminants will only contribute 0.00042 mg when an adult consumed 3.2 kg of maize ground under dry conditions using RIL discs whose contaminants contained the highest quantity of copper in this study. Compared to the permitted intake, copper consumption through food processed with the grinding machine that has these installed cast-iron discs is not significant. Manganese is another heavy metal that was detected in the recovered magnetic contaminants. This element was discovered in all the analyzed samples and the highest quantity was found in those recovered from food processed using ID discs. The tolerable intake level of zinc in the human body is 40 mg/day (Saper and Rash, 2009). This element was only detected in magnetic contaminants recovered from maize grains processed using ID discs and its value was not significant.

Table 2. Heavy metals present in recovered magnetic contaminants from ground food

Sample Code	Pb	Cd	Cr	Cu	Mn	Zn
	mg/kg					
CIW	0.08182	0.018182	0.00000	0.880165	0.20992	0.00000
ID	0.0000	0.021901	0.01612	0.607851	0.62479	0.00661
PIL	0.0000	0.014463	0.00000	0.715702	0.48760	0.00000
RIL	0.31694	0.023967	0.00000	0.80124	0.49298	0.00000
ROS	0.00579	0.018182	0.00950	0.564463	0.42314	0.00000
RIW	0.0000	0.021074	0.00000	0.500413	0.41901	0.00000

4. CONCLUSION

The presence and characteristics of magnetic contaminants recovered from maize processed under wet and dry grinding conditions using a locally fabricated grinding machine installed with cast iron grinding discs were investigated in this study. The results showed that the use of cast iron discs in food processing led to the introduction of metallic contaminants containing heavy metals such as lead, cadmium, chromium, manganese and zinc into the ground maize grains, which may be detrimental to human health. The presence of these contaminants was also found to be independent of the disc types, which were manufactured based on different production routes. More so, different quantities of contaminants were introduced into the processed food depending on the grinding conditions and type of discs. The highest quantity of contaminants was recovered from maize ground under dry conditions due to the lack of lubrication provided by wet grinding. Consequently, the study point to the need to regulate the production of cast iron discs that are used in food processing. Currently, there is no stipulation guiding important steps such as scrap selection and choice of melting furnace in the manufacturing of such grinding discs. The lack of regulation can constitute a major health hazard, which may hinder the realization of SDG No. 9 in developing nations like Nigeria.

ACKNOWLEDGEMENT

The funding of this research by the Nigeria National Research Fund (NRF) under the grant reference number TETF/DR&D-CE/NRF/2020/SETI/85/VOL.1, is duly acknowledged by the authors. The authors also appreciate the Department of Materials and Metallurgical Engineering for providing the spacing and some tools used in this experimental work.

REFERENCES

- Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V., and Linnemann, A. R. (2019). Sub-Saharan African Maize-Based Foods - Processing Practices, Challenges and Opportunities. *Food Reviews International*, 35(7), 609-639. DOI:10.1080/87559129.2019.1588290
- Gao, W., Chen, F., Wang, X., and Meng, Q. (2020). Recent advances in processing food powders by using superfine grinding techniques: A review. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 2222-2255. DOI:<https://doi.org/10.1111/1541-4337.12580>
- Gürkan, R., Ulusoy, H. İ., and Akçay, M. (2017). Simultaneous determination of dissolved inorganic chromium species in wastewater/natural waters by surfactant sensitized catalytic kinetic spectrophotometry. *Arabian Journal of Chemistry*, 10, S450-S460. DOI:<https://doi.org/10.1016/j.arabjc.2012.10.005>
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol*, 7(2), 60-72. DOI:10.2478/intox-2014-0009
- Järup, L. (2003). Hazards of heavy metal contamination. *Br Med Bull*, 68, 167-182. DOI:10.1093/bmb/ldg032
- Kwofie S., and Chandler H. D. (2006). Potential health effects of locally-manufactured corn-mill grinding plates. *Journal of Science and Technology (Ghana)*, 26(2), 137-147. DOI:10.4314/just.v26i2.32995
- Normanyo, E., Esiam, E. K., Amankwa-Poku, K., and Adetunde, I. A. (2010). *Redesign Of A Grinding Mill For The Minimisation Of Iron Filing Production*.
- Oduote J. K., G. A. S. I. I. A. S. A. K. A. A. (2017). Assessment of Metallic Contaminants in Grinded Millet using Domestic Grinding Machine. *Nigerian Journal Of Technological Development*, 14(1), 13-17.
- Oluwole, O. O., Olorunniwo, O.E., Ogundare, O.O., Atanda P.O. and Oridota, O.O. (2007). Effect of Magnesium and Calcium as Spheroidizers on the Graphite Morphology in Ductile Cast Iron. *Journal of Minerals & Materials Characterization & Engineering*, 6(1), 25-37.
- Saper, R. B., and Rash, R. (2009). Zinc: an essential micronutrient. *Am Fam Physician*, 79(9), 768-772.
- Trumbo, P., Yates, A. A., Schlicker, S., and Poos, M. (2001). Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *J Am Diet Assoc*, 101(3), 294-301. DOI:10.1016/s0002-8223(01)00078-5

Wirojanupatump, S., and Shipway, P. H. (1999). A direct comparison of wet and dry abrasion behaviour of mild steel. *Wear*, 233-235, 655-665. DOI:[https://doi.org/10.1016/S0043-1648\(99\)00208-2](https://doi.org/10.1016/S0043-1648(99)00208-2)

Witkowska, D., Słowik, J., and Chilicka, K. (2021). Heavy Metals and Human Health: Possible Exposure Pathways and the Competition for Protein Binding Sites. 26(19). DOI:10.3390/molecules26196060