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Influence of drying methods on heavy metal composition and microbial load of plantain chips

Ayodele Adenitan[1,2], Wasiu Awoyale[1,3], Aisha B. Akinwande[2] and Busie Maziya-Dixon[1]*

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*Corresponding author: Busie Maziya-Dixon, International Institute of Tropical Agriculture, PMB 5320 Oyo Road, Ibadan, Oyo, Nigeria
E-mail: b.maziya-dixon@cgiar.org

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M. Lourdes Morales, Nutrition and Food Science, Toxicology and Legal Medicine, University of Seville: Universidad de Sevilla, Spain

Additional information is available at the end of the article

Abstract: Mature unripe plantain is usually processed into chips using the traditional sun-drying method without considering consumer safety. Thus, there is a need to assess the influence of solar tent and open sun drying on the heavy metal composition and microbial load of plantain chips. Thirty samples of dried plantain chips were collected randomly from 10 processing centers in Akure South and Idanre Local Government Areas of Ondo State, Nigeria. In addition, four popularly consumed plantain varieties (agbagba, bobby tannap, mbi egome, and pita 23) were processed to chips and dried using open sun and solar tent drying. The samples were analyzed for heavy metal compositions using an Inductively Coupled Plasma- Optical Emission Spectrometer (ICP-OES) and microbial loads using the serial dilution method. The heavy metal content of the dried plantain chips was in the range of 0.01–0.08 mg/kg for Cd, 0.01–0.07 mg/kg for Co, and 0.05–0.50 mg/kg for Pb. Seven fungi (Penicillium spp., Rhizopus spp., Aspergillus flavus, Aspergillus Niger, Aspergillus tamarii, Fusarium verticillioides, and Monilla spp.) of health importance were isolated. The drying methods had a significant effect on the Cd ($p < 0.01$), Co ($p < 0.001$), and Pb ($p < 0.01$) contents of the plantain chips, but with no significant effect ($p > 0.05$) on the bacterial, fungi, and total coliform counts. Since the heavy metal content and microbial loads were higher in the surveyed and open sun-dried samples, the solar tent-dryer may be more reliable in producing less contaminated plantain chips than the open sun drying methods.

ABOUT THE AUTHOR

Ayodele Adenitan (MSc) was a Graduate Research Fellow in the Food and Nutrition Sciences Laboratory of the IITA, Ibadan, Oyo State, Nigeria. Awoyale Wasiu (PhD) is a Lecturer in the Department of Food Science and Technology, Kwara State University, Malete, Kwara State, Nigeria, and a Postharvest Specialist (Consultant) in the Food and Nutrition Sciences Laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria. Aisha B. Akinwande (PhD) is a Professor of Food Science in the Department of Food Science, Ladoke Akintola University of Technology Ogbomoso, Nigeria. Busie Maziya-Dixon (PhD) is a Senior Food and Nutrition Scientist and Head of the Food and Nutrition Sciences Laboratory of IITA, Ibadan, Nigeria. The outcome of this study will assist the dried plantain chip processors in reducing microbial and heavy metal contamination of the product.

PUBLIC INTEREST STATEMENT

Mature unripe plantain is usually processed into dried chips using the traditional sun-drying method without considering the safety of the consumers through product contamination. It is envisaged that the solar tent-dryer may reduce microbial and heavy metals contamination of plantain chips. The information provided in this article may be of use to dried plantain chip processors in the production of contaminant-free products, and whose safety will be better than the open-sun dried plantain chips.

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Subjects: Agriculture & Environmental Sciences; Food Chemistry; Food Laws & Regulations

Keywords: Plantain chips; alternative drying; contamination; consumer safety

1. Introduction

Plantain (*Musa paradisiaca L.*) is a tropical fruit that constitutes an essential food crop in Central and West Africa (Akinsanmi et al., 2015). It is a popular nutritional staple due to its versatility and excellent nutritional value (Abioye et al., 2011). Plantain is a starchy, less sweet variety of banana that can be used either ripe or unripe and is an invaluable carbohydrate source (Amah et al., 2021). It is used as food, beverage, fermentable sugar, medicine, flavoring, and cooked food (Amah et al., 2021; Ayanwale et al., 2018) and is widely consumed in Nigeria. Mature plantain pulp is rich in iron, potassium, and vitamin A but low in protein and fat (Anajekwu et al., 2020). It has been reported and identified by some food consumption surveys in Nigeria that plantain is a food among the primary starch staples (Odenigbo & Inya-Osuu, 2012; Ogechi et al., 2017).

Mature unripe plantain is usually processed into plantain chips to be further processed to flour by local producers using the traditional sun-drying method. Drying reduces the moisture content, retards the development of microorganisms and increases the shelf life of the stored product. The chips, prone to contamination during drying, may be blanched for consumption after preparation or converted to flour for further use (Obidiegwu et al., 2020). This process is, however, gradually finding application in weaning food formulations and composite flour preparations and is recommended as an ideal diet for diabetic patients (Anajekwu et al., 2020).

The water content in green plantain is about 61% and increases in ripening to about 68%, making it highly perishable after harvest. The increase in water is due to the breakdown of carbohydrates during respiration (Pelissari et al., 2012). Drying is a common preservation practice, thus, making the plantain available throughout the year in different forms (Olorode and Ewuoso, 2017). Sun, oven, cabinet, and solar drying have been used to dry plantain. Sun drying is Nigeria's most popular method due to its simplicity (Olorode and Ewuoso, 2017). During sun drying, the slices of unripe fruit are usually spread out on bamboo frameworks or bare patches of earth, roofs, stones, crops, or sheets of corrugated iron. This drying method under hostile climatic conditions leads to severe losses in both quantity and quality of the dried produce. These losses may be due to contamination by dirt, dust, bird droppings, and infestation by insects, rodents, and animals. The quality of products is degraded due to uncontrolled heat, even to the extent that the food becomes inedible (Hii et al., 2012). Also, the chip's shape, size, and thickness influence how fast it dries and the subsequent quality. For instance, when chips are thick, the outer layer easily compacts, preventing unrestricted air movement through the mass. Thick slices may appear dry on the surface, however, their internal moisture content will still be high (Olowoyeye and Evbuomwan, 2014). Olowoyeye and Evbuomwan (2014) reported that when plantain chips of varying thicknesses (2 mm, 4 mm, 6 mm, and 8 mm) were subjected to natural sun drying (with an ambient temperature of 29 °C and artificial tray drying with a dry bulb temperature of 60 °C, wet bulb temperature of 48 °C, air flow rate of 2.0 m/s, and relative humidity of 52%), there was more moisture loss in the tray drying method than the sun drying. There were distinct differences in their respective moisture content. On the other hand, a solar tent dryer is an advanced open sun drying technology. It is simple to build and consists of a wooden pole frame covered by a plastic sheet (Rwubatse et al., 2014). It is an evaporative drying process with the greenhouse principle (Ayua, 2017). Solar energy passes through the polyethylene and gets trapped inside it, leading to increased internal temperature and faster drying (Logesh et al., 2012). This covered structure gives protection against exhaust fumes, dirt, grit, rain, and insect and rodent infestation. It also keeps animals from the products and may reduce heavy metals and microbial contamination.

Heavy metals like cadmium, cobalt, copper, lead, and zinc are pollutants of environmental concern, and their bioaccumulation in the food chain is dangerous to humans (Lanlokun et al.,

2018). The intake of heavy metals by human populations through the food chain has been reported in many countries. This problem has received increasing attention from public and governmental agencies, particularly in developing countries (Iyama et al., 2022). Many studies have reported the toxicological implications of these metals in the human system. These metals like lead and cadmium in the human body can negatively affect mental development, particularly in children, an impact that persists into adulthood, and kidney damage (FAO/WHO, 2017; Iyama et al., 2022). Additionally, excessive consumption of metals like zinc, iron, and copper can cause diarrhea, pancreatitis, liver cell necrosis, heart failure, and liver and kidney damage (Ametepey et al., 2018; Armachius & Athanasia, 2018; Velu et al., 2014).

In Nigeria, more than 200,000 people die annually of food poisoning caused by food contamination through improper farming, processing, preservation, and storage (Premium Times, 2017). Microorganisms are microscopically small forms of life that occur as single-cell or multicellular organisms. They are ubiquitous in the natural environment, water, soil, air, etc. They can also naturally be found in foods or on the surfaces of raw materials as contaminants during the manufacturing process of food products (Aruwa et al., 2017). Some studies have been done on the microbiological assessment of sun-dried plantain chips (Adeyeye & Yildiz, 2016; Ajayi, 2016; Bolade, 2016), but none on the microbial quality of solar tent-dried plantain chips. In addition, different studies have been done on the chemical and heavy metal composition of roadside foods (Anhwange & Asemave, 2018; Bolade, 2016; Idowu-Adebayo et al., 2015). However, little has been reported on assessing heavy metals in plantain chips dried with a solar tent dryer and open sun drying. Therefore, this study aims to assess the influence of drying methods (solar tent and open sun drying) on the heavy metal composition and microbial load of plantain chips.

2. Materials and methods

2.1. Location of the study

Before constructing the solar tent dryer used for this study, and the subsequent laboratory assays, a survey was done to get baseline information on the usual traditional practices of the small-scale commercial producers of plantain chips in two Local Government Areas (LGAs) of Ondo State (Akure South and Idanre LGAs) based on many commercial plantain chips processors (Adenitan et al., 2021). The samples' heavy metal composition and microbial loads were carried out at the Analytical Service Laboratory and the Virology Laboratory, respectively, of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

2.1.1. Survey sampling

Information collected from the head of the processors on the number of persons involved in plantain chip processing was used to select plantain processors and marketers in ten communities in the LGAs: *Aponmu* (18 processors), *Isinkan* (18 processors), and *Idi agba* (20 processors) in Akure South LGA (56 processors), and *Alade* (28 processors), *Odode* (29 processors), *Atosin* (29 processors), *Idi araba* (27 processors), *Ita olohun* (30 processors), *Oniyeu Abusoro* (29 processors) and *Okolo Ajembamibo* (28 processors) in Idanre LGA (200 processors). Information on the socioeconomic and demographic characteristics of the processors, their current processing methods, and the problems/constraints encountered while processing plantain chips were obtained based on the willingness and availability of the respondents in each location. One hundred interviewer-administered questionnaires were used to collect data for this study, with 30 respondents from Akure South LGA and 70 from Idanre LGA. The high number of respondents from Idanre LGA was due to more processors than in Akure South LGA. Also, Idanre LGA is a rural settlement closer to the plantain farm, while Akure South is an urban settlement far away from the plantain farm. In addition, nine samples were collected from Akure South (3 samples from 3 communities), and 21 samples were collected from Idanre (3 samples from 7 communities) LGAs, making 30 samples. The 30 collected samples were analyzed in the laboratory with the solar tent dried (4 samples) and open sun-dried (4 samples) plantain chips produced from four different plantain varieties as described below. This gave 38 samples to compare the level of heavy metal composition and microbial load of the products (Adenitan et al., 2021).

2.2. Construction of solar tent dryer

The solar tent dryer was constructed using locally available materials of transparent plastic sheets, wood, plywood, cement, and sand; and black polyethylene was used on the U-shaped drying platform built inside the dryer. The size of the tent was 3 × 5 m (Plate 1). The tent was positioned in the prevailing wind path to allow air into the tent since the drying process combines air movement, temperature, and relative humidity (Adenitan et al., 2021).

2.3. Sample collection preparation for drying and laboratory analyses

Four popularly consumed plantain varieties, *agbagba, bobby tannap, mbi egome*, and *pita 23*, were used for the research. Bunches at the mature green stage were obtained from the research farm of IITA, Nigeria. The plantain fingers were cleaned with water, peeled using a stainless-steel knife, sliced to a round shape of about 3 mm thick to dry fast, and dried in thin layers on a black polyethylene sheet 200 µ thick, with a solar tent-dryer and in the open sun (as a check for the locally processed samples; Plate 1). The samples were dried under the open sun by spreading the sliced plantain finger thinly on the polyethylene sheet placed on a concrete floor. For the solar tent drying, the samples were spread thinly on the polyethylene sheet placed on a raised wooden platform inside the dryer (Plate 1). The temperature and relative humidity of the solar tent and open sun drying were measured using a thermohygrometer in 3 h intervals for the 5-day drying period between 8 am and 5 pm daily to dry to breakage and crispness. The average drying temperature and relative humidity of the solar tent dryer was 40 °C and 45%, while that of the open sun drying was 38 °C and 48%, respectively. The average initial moisture content of the plantain chips (before drying) was 65%. The average final moisture content of the plantain chips (after drying) using the solar dryer and open sun drying were 7% and 9%, respectively. The dried plantain chip samples (Plate 2) were crushed with a laboratory mortar and pestle and milled with a Stainless USHA mixer grinder (MG 2053 N model) to flour. The flour samples were packaged in zip lock bags before laboratory analyses, as reported by Adenitan et al. (2021).

2.3.1. Heavy metal composition

The heavy metal profiles of the samples were done using the Inductively Coupled Plasma- Optical Emission Spectrometer (ICP-OES Perkin Elmer Optima 8000; Bolade, 2016). The sample (0.5 g) was weighed into a clean ceramic crucible and recorded to the nearest 0.001 g. One empty crucible was included for a blank, and all were placed in a cold muffle furnace (VULCANTM furnace model



Plate 1. Use of the solar tent dryer and open sun for drying of plantain chips (Adenitan et al., 2021).

Plate 2. Original image of sun-dried (a) and solar tent-dried (b) plantain chips.



3–1750) and ramp temperature to 550 °C and heated for 2 h. It was allowed to remain at 550 °C for an additional 2 h to obtain a grey appearance, after which the sample was allowed to cool in the oven. The sample was removed from the oven, ensuring the environment was breeze-free. The ashed sample was poured into an already labeled 50 ml centrifuge tube, and the crucible was rinsed with 5 ml ultrapure water in the centrifuge tube. The crucible was rinsed again with 5 ml of modified aqua regia. The modified aqua regia solution was made with 1.2 L of distilled water with 400 ml conc. HCl and 133 ml of 70% Nitric acid and made up to 2 L with distilled water. Rinsing was repeated two more times to make a total of 20 ml. The sample was vortexed for proper mixing and then centrifuged for 5 min. The supernatant was then decanted into vials for heavy metal profiling determination using ICP-OES. The analysis was done in triplicate.

2.3.2. Microbiological load and identification

The microbiological investigation was carried out according to the method described by Yeleliere et al. (2017). One gram (1 g) of each sample was homogenized in 10 ml of sterile peptone water. Dilutions were made by mixing 1.0 ml of the homogenate in 9.0 ml of sterile peptone water to obtain 10^{-1} dilution. The dilution was then made to 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5}.

The bacteria's total viable counts were determined by enumerating the Colony Forming Units (CFU) by pour plating on nutrient agar plates and incubated at 28 °C for 24 h. Mold and yeast counts were determined by pour plating onto acidified potato dextrose agar plates and incubated at room temperature (28 ± 2 °C) for 3 days. The total coliform counts were determined by pour plating on MacConkey agar plates and incubated at 37 °C for 24 h. The analyses were done in triplicate.

The intercepted fungi were identified based on the colony and morphological characters to identify fungal pathogens. The isolated fungi were identified to the genus and species level, which was possible based on microscopic structures (Conidia, chlamydospores, etc.) and macromorphological characteristics using suitable media, slide cultures, and the most updated keys from identification guides, as stated below.

The plates were inspected again for growth and purity after three consecutive times of purifying the plates following the method of Saeed (2012). Some of the pure cultures obtained on Potato dextrose agar (PDA)

had colonies that were whitish to dark grey with thick to sparse lawns of aerial mycelium when viewed from the top of Petri dishes, similar to Awa et al. (2012) description. They were greenish to orange or dark brown at the center bordered by a creamy surrounding when viewed from the reverse side of the Petri dish.

When viewed under the microscope, conidia were observed to be hyaline, single-celled, and cylindrical with obtuse ends. Some plates exhibited similarities in morphological growth, so they were divided into groups. Eleven different groups with similar growth morphologies of isolates within each group were identified, and three distinct and morphologically different from any isolate were also identified. A maximum of three pure isolates with similar morphology were carefully selected from each group of eleven isolates and assumed to be the same. They were grouped according to their growth. Purification was done

for the various groups to ensure pure isolates were consistently obtained. Temporary slides from each group of plantain chips isolates were made after carefully selecting the purest and observed under an electronic microscope. Some unidentified spores were observed to be similar and were identified as such. A total of seven fungi (*Penicillium spp., Rhizopus spp., Aspergillus flavus, Aspergillus Niger, Aspergillus tamarii, Fusarium verticillioides*, and *Monilla spp*) were identified and were then described and classified based on conidia and colony morphology as described by Guo-yin et al. (2013) and Nyongesa et al. (2015).

2.4. Data analysis

The Statistical Package for Social Scientists (SPSS-version 21) was used for the descriptive analysis of the data collected from Akure South and Idanre LGAs. Data obtained in the laboratory were subjected to analysis of variance (ANOVA) using the Statistical Analytical System (SAS) package (SAS 9.3 version), and the means were separated using Least Significant Difference (LSD). The significance test was done at the 5% probability level ($p < 0.05$).

3. Results and discussion

3.1. Socioeconomic and demographic characteristics of local plantain chip producers

The results obtained from the socioeconomic and demographic characteristics of plantain processors in the study area are shown in Table 1. Results revealed that respondents in the 41–50-year age group had the highest percentage of 40, and 21–30 years had the least (3%). This implies that older people were significant processors of plantain chips in the study area, with women dominating (92%). The result for age group and sex obtained for this study was comparable to studies reported by Bolade (2016): 41–50 years (58%), women (100%), and Aina et al. (2012): women (84%), respectively. Thus, using the proposed solar tent may encourage the youth to produce plantain chips as a business. The marital status of the processors depicts that a higher value of 90% was married while 0%, 1%, and 9% were single, divorced, and widowed, respectively. The values obtained for marital status in this study were similar to the values reported by ; 69%), Aina et al. (2012) (86.7%), and Bolade (2016). This may imply that processing plantain chips is a reliable source of income for family upkeep and is viable for sustenance. A higher percentage of the processors (94%) was Yoruba, while 4% and 2% were Igbo and Urhobo, respectively. The result obtained by tribe in this study was comparable to studies reported by Bolade (2016) (Yoruba 79%). Most of the processors had secondary school education (58%), while 32% had primary, and 2% had tertiary education, and only 8% had no formal education. The values obtained for the level of education in this study were similar to those reported by Aina et al. (2012) (secondary 64% and primary education 24%). Thus, at least secondary-school-educated people are getting involved in plantain chip processing and could enhance their processing effectiveness and efficiency. The values obtained from the occupation of the processors showed that 55% of them had the processing of plantain chips as their primary occupation and 45% combined other products with plantain chips. This may imply that the respondents were engaged in other activities to improve their capital base and stabilize their income level.

3.2. Perception of local plantain chip producers to processing

Table 2 presents the result obtained from local processors' perception of drying. Most of the processors with 5–10 years of experience get their raw materials (plantain fingers/bunches) from farms and markets (43%) and farms only (40%). The results obtained for years of experience in plantain processing in this study are comparable to the values reported by Folayan and O (2011)

Table 1. Socioeconomic and demographic characteristics of local processors of plantain chips in some parts of Ondo state

	Aponmu	*Isinkan*	*Idi agba*	*Odode*	*Alade*	*Idi araba*	*Ita olorun*	*Oniyeu Abusoro*	*Atosin*	*Okolo Ajembamibo*	Mean value
	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	(%)
Age 21–30	2/20	0/0	0/0	1/10	0/0	0/0	0/0	0/0	0/0	0/0	3
31–40	4/40	3/30	1/10	1/10	3/30	1/10	3/30	4/40	1/10	4/40	25
41–50	2/20	2/20	3/30	5/50	4/40	6/60	2/20	5/50	6/60	5/50	40
Above 50	2/20	5/50	6/60	3/30	3/30	3/30	5/50	1/10	3/30	1/10	32
Sex											
Male	0/0	0/0	0/0	0/0	0/0	3/30	0/0	2/20	0/0	3/30	8
Female	10/100	10/100	10/100	10/100	10/100	7/70	10/100	8/80	10/100	7/70	92
Marital status											
Single	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
Married	9/90	10/100	8/80	8/80	9/90	10/100	10/100	9/90	7/70	10/100	90
Divorced	0/0	0/0	0/0	1/10	0/0	0/0	0/0	0/0	0/0	0/0	1
Widowed	1/10	0/0	2/20	1/10	1/10	0/0	0/0	1/10	3/30	0/0	9
Ethnic group											
Yoruba	10/100	9/90	9/90	10/100	10/100	10/100	9/90	8/80	10/100	9/90	94
Igbo	0/0	1/10	1/10	0/0	0/0	0/0	1/10	1/10	0/0	0/0	4
Others (Urobo)	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/10	0/0	1/10	2

(*Continued*)

Table1. (*Continued*)

	Aponmu	*Isinkan*	*Idi agba*	*Odode*	*Alade*	*Idi araba*	*Ita olorun*	*Oniyeu Abusoro*	*Atosin*	*Okolo Ajembamibo*	**Mean value**
Education level Primary	4/40	5/50	3/30	4/40	2/20	0/0	5/50	4/40	1/10	4/40	32
Secondary	5/50	4/40	6/60	5/50	7/70	9/90	4/40	5/50	7/70	6/60	58
Tertiary	0/0	1/10	0/0	0/0	0/0	0/0	1/10	0/0	0/0	0/0	2
Not educated	1/10	0/0	1/10	1/10	1/10	1/10	0/0	1/10	2/20	0/0	8
Minor Occupation											
Yes	4/40	5/50	6/60	5/50	5/50	2/20	5/50	4/40	6/60	3/30	45
No	6/60	5/50	4/40	5/50	5/50	8/80	5/50	6/60	4/40	7/70	55
Major Occupation											
Yes	6/60	5/50	4/40	5/50	5/50	8/80	5/50	6/60	4/40	7/70	55
No	4/40	5/50	6/60	5/50	5/50	2/20	5/50	4/40	6/60	3/30	45

(41.3%) and Bolade (2016) (58%) for 6–10 years' experience. They constantly process the *agbagba* variety (74%) to chips within 5 days (36%; Table 2). The percentage of other plantains used by the local processors was 24%, and 2% for *agbagba* and *panbo*, and *agbagba*, and *paranta*, respectively. This means that *agbagba* is the standard variety planted by the farmers in the study area for processing into chips. The use of 5 days for sun-drying was employed by the highest number of processors (36%), while others (1%) dry for 3–4 days. Overall, 82% of the plantain processors sun-dried between 5 and 6 days. This implies that drying for more than 6 days may affect the quality of the plantain chips. It was observed that 40% of the processors sourced the plantain fingers directly from the farm, 17% sourced it from the market only, while 43% sourced from both farm and market. The implication is that the farmers are the major suppliers of plantain fingers to the processors in the study area. The values obtained for the source of plantain for processing in this study are comparable to the study reported by Folayan and O (2011) (direct from farmers 70%). Types of preservatives used by the local processors in the study area were discovered to range from non-toxic (pepper) (21%) to toxic (phostoxin) (2%).

3.3. Challenges encountered during the processing and storage of dried plantain chips

Table 3 shows the challenges faced by the local processors during the processing and storage of the plantain chips. Most (91%) local processors reported that processing plantain fingers into dried chips is time-consuming, stressful, and tedious when peeling and drying, especially during the rainy season. Moreover, 14% reported weevil and insect infestation during storage, and 18% had transportation from the farm to the processing point, especially during the rainy season. About 40% of the local processors reported weakness in the body system, and 8% complained of staying close to the drying point to ensure animals did not have access to the product to reduce contamination. Only 1% of the local processors reported that it took several days to dry during the rainy season and the weather condition, which affects the quality of the plantain chips. This indicates that the quality and safety measures of the chips may be affected by these constraints, and the use of a solar tent may be a perfect alternative for drying to reduce product contamination. Similar challenges encountered by processors in this study were reported by Folayan and O (2011).

3.4. Heavy metals composition of dried plantain chips

The results of the heavy metals in the samples are shown in Table 4. The varieties have a significant effect on the Cobalt (Co) ($p < 0.001$), Nickel (Ni) ($p < 0.05$), Lead (Pb) ($p < 0.05$), Copper (Cu) ($p < 0.05$) and Manganese (Mn) ($p < 0.01$) contents of the plantain chips, but no significant effect ($p > 0.05$) was observed in the Cadmium (Cd), Zinc (Zn), and the Iron (Fe) contents of the plantain chips. The drying methods (open sun drying, solar tent-drying, and traditional sun drying) do not have significant effects ($p > 0.05$) on all the heavy metals composition of the plantain chips except the Cd ($p < 0.01$), Co ($p < 0.001$), and Pb ($p < 0.01$) content. Also, the interactions between the varieties and the drying methods have no significant effect ($p > 0.05$) on all the heavy metals composition of the plantain chips except the Co content ($p < 0.001$; Table 4).

The solar tent-dried plantain chip Cd levels ranged from 0.03 to 0.04 mg/kg, while those dried in the open sun ranged from 0.04 to 0.08 mg/kg, and those collected from the local processors in Ondo State ranged from 0.01 to 0.07 mg/kg. However, Cd was not detected in the solar tent dried *agbagba* variety, and the plantain chips collected from *Ita Olohun, Atosin*, and *Okolo Ajebamibo* communities of Idanre LGA. There were significant differences ($p < 0.05$) in the Cd level of the solar tent-dried and open sun-dried plantain chips. Also, a significant difference ($p < 0.01$) exists in the Cd content of the open sun-dried plantain chips produced from the Pita 23 variety compared to the other varieties. The variations in the levels may be due to varietal and environmental differences, soil, or land where the plantain was planted. The health effects of exposure to Cd include the gastrointestinal tract, pulmonary, hepatic, or renal injuries, and pancreatic and thyroid cancer (Buha et al., 2017; Lanlokun et al., 2018). It is imperative to add that the Cd level in solar tent-dried plantain chips was lower than the recommended maximum limit of 0.05 mg/kg (FAO/WHO, 2017),

Table 2. Perception of local processors on plantain chip processing

	Aponmu	*Isinkan*	*Idi agba*	*Odode*	*Alade*	*Idi araba*	*Ita olorun*	*Oniyeu Abusoro*	*Atosin*	*Okolo Ajembamibo*	Mean value
	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	(%)
Experience in drying < 5 years	1/10	0/0	3/30	1/10	2/20	0/0	0/0	0/0	2/20	0/0	9
5–10 years	5/50	2/20	4/40	5/50	2/20	3/30	2/20	5/50	4/40	4/40	36
11–15 years	1/10	5/50	1/10	1/10	5/50	4/40	5/50	2/20	2/20	2/20	28
16–20 years	1/10	0/0	2/20	0/0	0/0	0/0	0/0	2/20	0/0	3/30	8
Above 20 years	2/20	3/30	0/0	3/30	1/10	3/30	3/30	1/10	2/20	1/10	19
Variety used											
Agbagba	8/80	9/90	9/90	7/70	8/80	7/70	9/90	3/30	6/60	8/80	74
Agbagba and *Panbo*	2/20	1/10	1/10	3/30	2/20	3/30	1/10	5/50	4/40	2/20	24
Agbagba and *Paranta*	0/0	0/0	0/0	0/0	0/0	0/0	0/0	2/20	0/0	0/0	2
Drying time											
3–4 days	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/10	0/0	1
4 days	1/10	0/0	1/10	0/0	0/0	0/0	0/0	0/0	0/0	0/0	2
4–5 days	1/10	1/10	0/0	0/0	1/10	1/10	1/10	0/0	3/30	2/20	10
5 days	5/50	4/40	8/80	1/10	5/50	2/20	4/40	1/10	6/60	0/0	36
5–6 days	3/30	3/30	1/10	4/40	3/30	5/50	3/30	1/10	0/0	1/10	24
6 days	0/0	1/10	0/0	5/50	1/10	1/10	1/10	7/70	0/0	6/60	22

(*Continued*)

Table 2. (*Continued*)

	Aponmu	*Isinkan*	*Idi agba*	*Odode*	*Alade*	*Idi araba*	*Ita olorun*	*Oniyeu Abusoro*	*Atosin*	*Okolo Ajembamibo*	**Mean value**
6–7 days	0/0	1/10	0/0	0/0	0/0	1/10	1/10	1/10	0/0	1/10	5
Source of plantain											
Farm	6/60	1/10	2/20	5/50	1/10	8/80	1/10	7/70	0/0	9/90	40
Market	1/10	3/30	3/30	1/10	3/30	0/0	3/30	0/0	3/30	0/0	17
Farm and Market	3/30	6/60	5/50	4/40	6/60	2/20	6/60	3/30	7/70	1/10	43
Materials for chips preservation											
Dried pepper	4/40	1/10	2/20	1/10	1/10	3/30	1/10	0/0	3/30	5/50	21
Phostoxin	0/0	0/0	2/20	0/0	0/0	0/0	0/0	0/0	0/0	0/0	2
Nil	6/60	9/90	6/60	9/90	9/90	7/70	9/90	10/100	7/70	5/50	77

Table 3. Constraints and problems encountered during processing and storage of plantain chips

Type of constraint/ problem	Aponmu	Isinkan	Idi agba	Ododе	Alade	Idi araba	Ita olorun	Oniyeu Abusoro	Atosin	Okolo Ajembamibo	Mean Value (%)
	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	Freq/%	
Time consuming and laborious	9/90	5/50	7/70	10/100	10/100	10/100	10/100	10/100	10/100	10/100	91
Tedious peeling and drying	8/80	10/100	9/90	7/70	8/80	10/100	10/100	10/100	9/90	9/90	91
Insects and weevil infestation during storage	1/10	3/30	1/10	0/0	6/60	0/0	1/10	0/0	2/20	0/0	14
Transportation from farm to processing point	2/20	5/50	4/40	2/020	2/20	0/0	0/0	0/0	3/30	0/0	18
Monitoring of drying process to prevent contamination	1/10	0/0	3/30	1/10	0/0	0/0	0/0	0/0	0/0	2/20	8
Stressful process	4/40	3/30	4/40	6/60	1/10	8/80	4/40	4/40	1/10	6/60	40
Extended drying time during rainy season	1/10	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1
Weather condition	0/0	0/0	0/0	0/0	0/0	0/0	1/10	0/0	0/0	0/0	1

Table 4. Heavy metals composition of dried plantain chips

Samples	Cadmium (mg/kg)	Cobalt (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
Solar tent-dried								
Agbagba	ND	ND	$0.27 \pm 0.02^{a-c}$	0.05 ± 0.05^{fg}	$2.62 \pm 0.42^{c-f}$	5.15 ± 0.90^{b}	10.08 ± 5.41^{ab}	9.99 ± 1.00^{e}
Bobby tannap	0.03 ± 0.02^{de}	0.01 ± 0.02^{bc}	0.21 ± 0.02^{c}	ND	$2.08 \pm 1.49^{d-f}$	3.78 ± 1.01^{b}	2.08 ± 0.19^{c}	$11.07 \pm 1.29^{c-e}$
Mbi egome	0.04 ± 0.00^{cd}	ND	0.21 ± 0.02^{c}	0.11 ± 0.12^{fg}	1.29 ± 0.39^{f}	3.62 ± 0.19^{b}	2.18 ± 0.18^{c}	9.41 ± 0.83^{e}
Pita 23	$0.04 \pm 0.01^{c-e}$	ND	$0.02 \pm 0.02^{a-c}$	0.11 ± 0.02^{fg}	4.42 ± 0.02^{ab}	4.83 ± 0.04^{b}	5.85 ± 0.02^{bc}	$11.87 \pm 0.25^{c-e}$
Open sun-dried								
Agbagba	0.07 ± 0.02^{ab}	0.07 ± 0.02^{a}	0.31 ± 0.06^{ab}	ND	5.00 ± 1.92^{a}	4.83 ± 0.68^{b}	9.87 ± 5.73^{ab}	10.25 ± 0.51^{e}
Bobby tannap	0.08 ± 0.00^{a}	0.03 ± 0.02^{b}	0.33 ± 0.17^{a}	$0.29 \pm 0.08^{c-e}$	$3.00 \pm 2.05^{b-f}$	5.27 ± 3.04^{b}	2.19 ± 0.45^{c}	9.83 ± 0.27^{e}
Mbi egome	0.07 ± 0.02^{ab}	ND	0.24 ± 0.00^{bc}	0.45 ± 0.10^{ab}	1.79 ± 0.48^{ef}	3.73 ± 0.34^{b}	2.19 ± 0.29^{c}	8.92 ± 1.53^{e}
Pita 23	$0.04 \pm 0.01^{c-e}$	ND	0.23 ± 0.02^{c}	0.50 ± 0.02^{a}	4.77 ± 0.02^{a}	4.27 ± 0.04^{b}	$6.24 \pm 0.04^{a-c}$	10.95 ± 0.03^{de}
Locally processed								
Akure South LGA								
Aponmu	0.05 ± 0.02^{bc}	ND	0.25 ± 0.02^{bc}	0.32 ± 0.08^{cd}	$4.16 \pm 1.89^{a-c}$	7.74 ± 5.07^{ab}	12.11 ± 6.19^{a}	25.75 ± 10.97^{a}
Isinkan	0.07 ± 0.02^{ab}	ND	0.21 ± 0.02^{c}	0.32 ± 0.00^{cd}	$3.69 \pm 0.49^{a-d}$	4.64 ± 0.55^{b}	10.19 ± 6.14^{ab}	$16.62 \pm 2.35^{a-e}$
Idi agba	0.04 ± 0.00^{cd}	ND	0.24 ± 0.00^{bc}	$0.36 \pm 0.00^{b-d}$	$3.38 \pm 0.39^{a-e}$	4.56 ± 0.49^{b}	10.93 ± 1.71^{ab}	$14.72 \pm 0.89^{b-e}$
Idanre LGA								
Odode	0.05 ± 0.02^{bc}	ND	0.23 ± 0.02^{c}	0.47 ± 0.15^{ab}	$3.80 \pm 1.58^{a-d}$	11.16 ± 7.40^{a}	$8.22 \pm 2.43^{a-c}$	23.54 ± 6.60^{ab}
Alade	0.04 ± 0.00^{cd}	ND	0.24 ± 0.04^{bc}	$0.40 \pm 0.04^{a-c}$	$4.27 \pm 1.17^{a-c}$	4.55 ± 0.47^{b}	10.12 ± 3.03^{ab}	$17.32 \pm 1.64^{a-e}$
Idi araba	0.04 ± 0.02^{de}	ND	0.21 ± 0.02^{c}	0.17 ± 0.06^{ef}	$3.29 \pm 0.26^{a-e}$	4.99 ± 1.57^{b}	9.10 ± 2.06^{ab}	$21.75 \pm 6.17^{a-c}$
Ita olohun	ND	ND	0.24 ± 0.04^{bc}	0.09 ± 0.02^{fg}	$4.25 \pm 0.88^{a-c}$	4.60 ± 1.28^{b}	8.70 ± 0.87^{ab}	$21.52 \pm 8.67^{a-d}$

(*Continued*)

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Table 4. (*Continued*)

Samples	Cadmium (mg/kg)	Cobalt (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
Oniyeu Abusoro	0.01 ± 0.02^{ef}	ND	0.25 ± 0.02^{bc}	0.08 ± 0.07^{fg}	3.98 ± 0.64^{a-c}	8.02 ± 6.11^{ab}	12.04 ± 3.24^{ab}	25.96 ± 10.10^{a}
Atosin	ND	ND	0.31 ± 0.05^{ab}	ND	3.83 ± 0.52^{a-c}	3.95 ± 0.43^{b}	8.50 ± 3.05^{ab}	23.21 ± 8.02^{ab}
Okolo Ajembamibo	ND	ND	0.20 ± 0.04^{c}	0.24 ± 0.21^{de}	2.74 ± 0.59^{b-f}	4.70 ± 1.66^{b}	11.71 ± 7.71^{ab}	23.53 ± 17.13^{ab}
p Varieties	NS	***	*	*	*	NS	**	NS
p Treatment	**	***	NS	**	NS	NS	NS	NS
p Varieties x Treatment	NS	***	NS	NS	NS	NS	NS	NS

Mean values with the same superscript within a column is not significantly different ($p > 0.05$)

ND: Not detected, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, NS-Not significant ($p > 0.05$); LGA- Local Government Area

implying that there was little or no possible interaction of the plantain fingers with vehicular emission during processing (Iyama et al., 2022; Lanlokun et al., 2018). Also, Bolade (2016) investigated the level of metallic pollutants in roadside, sun-dried plantain chips, and Lanlokun et al. (2018) studied heavy metal assessment of unripe plantain flour. They reported high levels of Cd ranging from 0.0081 to 0.0131 mg\100 g and 0.50–4.51 mg/kg for Bolade (2016) and Lanlokun et al. (2018), respectively, disagree with the recommended limit (0.05 mg/kg) according to FAO/WHO (2017).

The Co levels in the samples ranged from 0.01 to 0.07 mg/kg ($p < 0.05$). Co was detected in only one variety (*bobby tannap*) dried in the solar tent (0.01 mg/kg) and two varieties (*bobby tannap* and *agbagba*) dried in the open sun (0.03 mg/kg and 0.07 mg/kg, respectively). No Co was detected in the local processor samples collected from Ondo State. The differences could be influenced by environmental factors such as soil or land where the plantains are planted (Dolara, 2014). In addition, there was a significant difference ($p < 0.05$) in the Co content of the open sun-dried chips produced from the *agbagba* and *bobby tannap* varieties. No permissible limit was established for Co (Mehjbeen & Nazura, 2013). However, Dolara (2014) reported that the ingestion of 3 µg/kg/d (0.003 mg/kg/d) could be safe throughout a lifetime for healthy individuals. This implies that the Co level of the open sun-dried *agbagba* plantain chips may not be safe for consumption. The health exposure of Co includes lung cancer and fibrosing alveolitis (Nordberg et al., 2014).

The Ni level of the plantain chip samples ranged from 0.02 to 0.33 mg/kg, with solar tent-dried samples having lower values of between 0.02 mg/kg and 0.27 mg/kg. The open sun-dried samples had higher Ni values of 0.23–0.33 mg/kg. Samples collected from the local processor's Ni content ranged from 0.20 to 0.31 mg/kg. The low level of Ni obtained in solar tent-dried chips may be because of a controlled environment devoid of vehicular movement. In contrast, the higher values in the open sun-dried samples could reflect high traffic volume with a simultaneous release of vehicular emission in the study area (Bolade, 2016; Lanlokun et al., 2018). The Ni level in the samples was lower than the maximum limit of 6.7 mg/100 g in vegetables as prescribed by FAO/WHO (2017). Also, in another report where the metallic pollutants were investigated in roadside, sun-dried plantain chips by Bolade (2016), the results revealed high levels of nickel (0.0043–0.0098 mg/100 g) comparable to the study. A large quantity of Ni ingestion may result in gastrointestinal disease, cancer, heart disorders, respiratory failure, and chronic bronchitis (Mehjbeen & Nazura, 2013).

The Pb content of the samples ranged from 0.05 to 0.50 mg/kg, with no detection in one sample dried in the solar tent (*bobby tannap*), open sun (*agbagba*), and the local processor sample (Idanre LGA). Solar tent-dried chips had the least Pb values (0.05–0.11 mg/kg), followed by the samples collected from the local processors (0.08–0.47 mg/kg). The samples dried in the open sun had the highest Pb values of 0.29–0.50 mg/kg. The Pb level in the solar tent-dried samples was generally lower than the International standard maximum limit of 0.2 mg/kg, as indicated by the Food and Agricultural Organization (FAO/WHO, 2017). Also, the Pb content of the Open sun-dried plantain chips produced from the *bobby tannap* and *mbi egome* varieties was significantly different ($p < 0.05$). Varietal and environmental differences may influence the variations in the levels of the metal. Furthermore, Bolade (2016) reported low levels of lead (0.0024–0.0083 mg/100 g) in the study of the level of metallic pollutants in roadside sun-dried plantain chips, which is comparable to the levels reported for solar tent-dried plantain chips (0.05–0.11 mg/kg). Lead accumulation in humans can cause brain damage, kidney damage, gastrointestinal diseases, and adverse effects on blood and the central nervous system (FAO/WHO, 2017).

Cu was detected in the plantain chips with a range of 1.20–5.00 mg/kg. Solar tent-dried chips had the lowest values of Cu ranging from 1.29 to 4.42 mg/kg. Open sun-dried samples had Cu values between 1.79 mg/kg and 5.00 mg/kg, while those obtained from local processors were within 2.74–4.27 mg/kg. There were significant differences ($p < 0.05$) in the Cu content of all the samples. The Cu content of the open sun-dried plantain chips produced from the *agbagba* and the *bobby tannap* was significantly different. The high Cu content in the samples from the local

processors might be attributed to mechanical abrasion and normal wear and tear of vehicular components such as tires and alloy rims (Bolade, 2016). Cu is an important trace metal and has some nutritional benefits for human life. It is present naturally in foodstuff but toxic when consumed in excess (Awoyale et al., 2017; Magomya et al., 2013). According to FAO/WHO (2017), the recommended limit of Cu in vegetables is 7.3 mg/100 g, which is higher than the Cu content of the samples. High doses of Cu can cause nausea, vomiting, stomach cramps, or diarrhea (FAO/WHO, 2017). Moreover, in another report (Bolade, 2016), where the metallic pollutants were investigated in roadside sun-dried plantain chips, the results revealed slightly lower levels of copper (2.91–3.42 mg/100 g) than this report, which is comparable to the study.

Zn was detected in the dried samples with a range of 3.62–11.16 mg/kg. Solar tent-dried chips had the lowest Zn content with a range of 3.62–5.15 mg/kg. Open sun-dried chips had values between 3.73 mg/kg and 5.27 mg/kg, while those obtained from the local processors ranged from 3.95 to 11.16 mg/kg. A significant difference ($p < 0.05$) exists in the Zn content of the samples. Zinc levels in the samples were generally below the FAO/WHO permissible limit of 40.0 mg/kg and the European Union acceptable dietary limits (FAO/WHO, 2017; Nordberg et al., 2014). The results obtained for Zn in the study are like the values (3.41–5.41 mg/100 g) reported by Bolade (2016), who worked on metallic pollutants in roadside sundried food products. However, unripe plantain naturally contains some level of Zn, as reflected in the solar tent-dried samples (Oyeyinka & Afolayan, 2019). The levels reported by Bolade (2016) were higher than the FAO/WHO permissible limits. High zinc ingestion may cause anemia, damage the pancreas, and decreased levels of high-density lipoprotein (HDL) cholesterol (FAO/WHO, 2017).

The Fe content of the samples ranged from 8.92 to 25.96 mg/kg. Open sun-dried chips had the least values in the range of 8.92–10.95 mg/kg, followed by solar tent-dried chips (9.41–11.87 mg/kg), while the highest values were found in the samples obtained from the local processors (14.72–25.96 mg/kg) ($p < 0.05$). Although, the Fe content of the open sun-dried and solar tent-dried plantain chips was not significantly different ($p > 0.05$). The result is comparable to studies reported by Bolade (2016), which ranged from 15.81 to 24.13 mg/kg. As observed in the samples, the Fe level was lower than the recommended maximum limit of 42.5 mg/100 g in vegetables (FAO/WHO, 2017). However, Fe is one of the nutritionally essential metals found naturally in plantain (Oyeyinka & Afolayan, 2019) but is toxic when consumed in excess. The high Fe content in some of the samples collected from the local processors might be attributed to contamination from the atmosphere, possibly from the wear and tear of motor vehicle tires (Bolade, 2016). A high dose of Fe can result in gastrointestinal effects, especially constipation, nausea, diarrhea, and vomiting (Mehjbeen & Nazura, 2013).

Mn composition of the dried samples ranged from 2.08 to 12.11 mg/kg. Solar tent-dried plantain chips had the lowest values in the 2.08–10.08 mg/kg range. Open sun-dried samples had values between 2.19 and 9.87 mg/kg, while those obtained from the local processors were within 8.22–12.11 mg/kg. The difference in the Mn content of the locally processed plantain chips compared to those of the open sun-dried and solar tent-dried may be attributed to the drying of the plantain fingers in places burning fossil fuels (Tóth et al., 2016). The Mn content of the solar tent-dried and open sun-dried plantain chips produced from the *agbagba* and *bobby tannap* varieties was significantly different ($p < 0.05$). Mn is also an important trace metal and has some nutritional benefits for human life; this metal is a coenzyme essential for growth and respiration. They are present naturally in foodstuff but toxic when consumed in excess (Awoyale et al., 2017; Magomya et al., 2013). A high level of Mn can cause lung, liver, and vascular disturbances and declines in blood pressure (Mehjbeen & Nazura, 2013).

It is imperative to add that the variations in the levels of heavy metal contamination may be attributed to the planting soil, fertilizers, air, closeness of the plantain farm to vehicular movements, plantain variety, and materials of construction of the drying platform, among others (Bolade, 2016).

3.5. Microbial load and identification in dried plantain chips

Table 5 shows the total bacterial and fungal counts in the dried plantain chips. The varieties have a significant effect on the fungi counts ($p < 0.01$) of the plantain chips, but with no significant effect ($p > 0.05$) on the bacterial and total microbial counts. The drying methods, on the other hand, have no significant effect ($p > 0.05$) on the bacterial, fungi, and total microbial counts of the plantain chips. However, the interactions between the varieties and the drying methods have a significant effect on the bacterial ($p < 0.01$) and fungi ($p < 0.001$) counts, but with no significant effect ($p > 0.05$) on the total microbial counts of the plantain chips (Table 5).

The bacterial counts of the samples ranged from 0.20 to 3.09 × 10^4 CFU/g. Solar tent-dried samples had the lowest bacteria counts, between 0.20 × 10^4 CFU/g and 2.15 × 10^4 CFU/g. Open sun-dried samples had values between 1.13 × 10^4 CFU/g and 2.80 × 10^4 CFU/g, and samples obtained from the local processors had the highest bacteria count of 0.89–3.09 × 10^4 CFU/g. The lower bacteria count recorded for the solar tent dryer may result from an enclosed medium that uses greenhouse principles to dry agricultural products. However, WF (2012) stated that bacterial counts should not exceed 1.0 × 10^4 CFU/g in foods. It is imperative to add that processing the plantain chips into flour and subsequent cooking of the flour to *amala* in boiled water may reduce the bacterial counts before consumption. However, some studies reported microbial counts and pathogens higher than international stipulated limits (1.0 × 10^2 CFU/g) in commercial and conventionally produced fresh and dried fruits and vegetables (Alimi & Workneh, 2016). A significant difference ($p < 0.05$) exists in the bacteria count of the solar tent-dried and open sun-dried plantain chips produced from different varieties.

The fungal count of the dried plantain chips ranged from 0 to 0.13 × 10^4 CFU/g. The solar tent-dried plantain chips had the lowest values (0–0.06 × 10^4 CFU/g). Open sun-dried samples ranged from 0 to 0.13 × 10^4 CFU/g, and the samples obtained from the local processors had the highest fungal counts of 0.01–0.07 × 10^4 CFU/g. The variation in the fungal counts of the locally processed samples may be due to incomplete drying for several days, environmental conditions, and handling methods during processing by the local processors (Rani & Saxena, 2022). The dried plantain chips are below the recommended guidelines for dried foods, which should not exceed 1.03 × 10^4 CFU/g (Nutli et al., 2016). The fungal count of the solar tent-dried plantain chips produced from the different varieties was significantly different ($p < 0.05$). There was no significant difference ($p > 0.05$) in the fungal count of the open sun-dried plantain chips produced from the *Agbagba* and Pita 23 varieties.

Seven fungi (*Penicillium* spp., *Rhizopus* spp., *Aspergillus flavus, Aspergillus Niger, Aspergillus tamarii, Fusarium verticillioides, Monilla* spp) were isolated from the dried plantain chips (Table 5). One or more fungi were found in the dried plantain chips except in one variety (*mbi egome*) dried in the solar tent-dryer and open sun. One of the samples was collected from the local processors (*Idi Araba*, Idanre LGA). The fungi isolated could be present in the atmosphere because most of these fungi (*Aspergillus, Fusarium, Rhizopus, and Penicillium*) are surface pollutants of most agricultural products that induce deterioration and can grow inside dried products (Adeyeye & Yildiz, 2016). The fungi isolated in this study differed slightly in solar tent dryers and open sun-drying due to varietal and environmental differences.

The fungi intercepted in this study (*Aspergillus flavus, Aspergillus Niger, Rhizopus* spp, and *Penicillium* spp) were similar to studies reported by some authors on the microorganisms associated with the preparation of plantain pudding in Western Nigeria (Adeyeye & Yildiz, 2016; Jonathan et al., 2017). Nutritional and mycoflora changes during storage of plantain chips and the health implications, and the nutritional compositions, fungi, and aflatoxins detection in stored *gbodo* and *elubo ogede* from southwestern Nigeria (Adeyeye & Yildiz, 2016; Jonathan et al., 2017). However, *Aspergillus* spp. are the common fungi isolated in this study, agreeing with Jonathan et al. (2017) and Okafor and Eni (2017), who reported *Aspergillus* spp. as the commonly isolated fungi.

Table 5. Microbial assessment of dried plantain chips

Samples	Bacterial count (cfu/g × 10^4)	Fungi count (cfu/g × 10^3)	Total Microbial count (cfu/g)	Fungi intercepted
Solar tent-dried chips				
Agbagba	0.86 ± 0.01 l	0.20 ± 0.01e	$4.15x10^3$ ± 1.41 j	*Penicillium* spp, *Aspergillus flavus*, *Aspergillus tamarii*, *Aspergillus Niger*
Bobby tannap	0.96 ± 0.01k	0.10 ± 0.04 f	$1.97x10^3$ ± 2.12 l	*Penicillium* spp
Mbi egome	0.20 ± 0.03 m	0.00 ± 0.03 g	$2.03x10^3$ ± 2.83kl	*Nil*
Pita 23	2.15 ± 0.01d	0.60 ± 0.04c	$2.10x10^3$ ± 16.26kl	*Rhizopus* spp
Open sun-dried chips				
Agbagba	2.15 ± 0.01d	0.20 ± 0.02e	$2.20x10^4$ ± 212.13 f	*Penicillium* spp, *Rhizopus* spp, *Fusarium verticillioides*, *Aspergillus Niger*
Bobby tannap	2.80 ± 0.07b	1.30 ± 0.01a	$2.80x10^4$ ± 70.71d	*Aspergillus Niger*, *Rhizopus* spp,
Mbi egome	2.01 ± 0.01 f	0.00 ± 0.01 g	$2.01x10^4$ ± 70.71 g	Nil
Pita 23	1.13 ± 0.01 j	0.20 ± 0.01e	$1.30x10^4$ ± 141.42 h	*Rhizopus* spp, *Penicillium* spp
Locally processed chips				
Akure South LGA				
Aponmu	2.58 ± 0.01c	0.70 ± 0.03b	$2.70x10^4$ ± 212.13e	*Rhizopus* spp, *Aspergillus Niger*, *Aspergillus flavus*, *Rhizopus*
Isinkan	2.08 ± 0.01e	0.40 ± 0.01d	$2.85x10^3$ ± 3.54jk	*Rhizopus* spp, *Aspergillus flavus*
Idi agba	3.09 ± 0.01a	0.20 ± 0.02e	$3.10x10^4$ ± 141.42c	*Rhizopus* spp
Idanre LGA				
Odode	0.89 ± 0.02 l	0.20 ± 0.02e	$9.50x10^3$ ± 14.14i	*Rhizopus* spp
Alade	1.34 ± 0.01 h	0.20 ± 0.01e	$9.00x10^4$ ± 707.11a	*Rhizopus* spp
Idi araba	1.38 ± 0.01 gh	0.20 ± 0.02e	$7.00x10^4$ ± 1414.21b	*Aspergillus flavus*
Ita olohun	1.19 ± 0.01i	0.20 ± 0.03e	$2.86x10^3$ ± 3.54jk	*Nil*
Oniyeu Abusoro	2.21 ± 0.01d	0.20 ± 0.01e	$1.79x10^3$ ± 2.83 l	*Aspergillus tamarii*, *Aspergillus flavus*, *Rhizopus* spp
Atosin	1.39 ± 0.01g	0.20 ± 0.02e	$1.49x10^3$ ± 2.12 l	*Aspergillus Niger*, *Aspergillus* spp, *Aspergillus tamarii*, *Rhizopus* spp
Okolo Ajembamibo	1.37 ± 0.01gh	0.10 ± 0.02f	$3.00x10^3$ ± 141.42 j	*Monilla* spp, *Aspergillus Niger*, *Penicillium* spp
p Varieties	NS	**	NS	
p Treatment	NS	NS	NS	
p Varieties × Treatment	**	***	NS	

Each value represents the mean of triplicate samples; CFU/g: Colony Forming Unit/gram, LGA: Local Government Area

The health implications of fungi ingestion may cause urinary tract infections, gastrointestinal infections, pulmonary and disseminated infections, cutaneous infections, keratitis, and damage to blood vessels and nerves, among others (Deutsch et al., 2019). The microbial contamination of the plantain chips may be reduced by using contaminant-free water for processing under strict hygienic conditions and drying under the solar tent dryer. However, the dried plantain chips of the present study will be milled into flour and reconstituted in hot water to form a thick paste (*amala*) eaten with the preferred soup, reducing microbial contamination.

4. Conclusions

The drying methods significantly affected the cadmium, cobalt, and lead content of the plantain chips but with no significant effect on the bacterial, fungi, and total microbial counts. However, the interactions between the plantain varieties and the drying methods significantly affected the cobalt content and the bacterial and fungi counts of the plantain chips. The heavy metal content and microbial load were higher in the surveyed and open sun-dried samples than in the solar tent-dried samples. Therefore, this research showed that a solar tent dryer might be a perfect alternative for drying agricultural commodities. This would reduce heavy metal accumulation and microbial contamination since a solar tent dryer produced a lower concentration of heavy metal and microbial load than open sun drying. Therefore, enlightenment and awareness of solar-tent dryers should be created to improve the safety of food preservation, processing, and nutritional value among the local processors in the study areas and Nigeria as a whole.

Additionally, the microbial contamination of the plantain chips may be reduced by using contaminant-free water for processing under strict hygienic conditions and drying under the solar-tent dryer. However, the dried plantain chips of the present study will be milled into flour and reconstituted in hot water to form a thick paste (*amala*) eaten with the preferred soup, thus, reducing microbial contamination. Other drying methods like freeze drying, vacuum drying, and oven drying methods should be carried out with the open sun and solar tent drying to enable effective comparison of heavy metals and microbial load composition and the drying kinetics of the plantain chips.

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Author details
Ayodele Adenitan[1,2]
Wasiu Awoyale[1,3]
ORCID ID: http://orcid.org/0000-0002-3635-1414
Aisha B. Akinwande[2]
Busie Maziya-Dixon[1]
E-mail: b.maziya-dixon@cgiar.org
[1] Food and Nutrition Sciences laboratory, International Institute of Tropical Agriculture, Ibadan, Nigeria.
[2] Department of Food Science, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
[3] Department of Food Science & Technology, Kwara State University Malete, Ilorin, Nigeria.

Author contributions
Conceptualization, all authors.; methodology, A.A.A., W.A. and A.B.A.; formal analysis, A.A.A, W.A. and B.M.D.; investigation, A.A.A and W.A.; resources, B. M. D.; data curation, A.A.A and W.A.; writing—original draft preparation, A.A.A. and W.A.; writing—review and editing, all authors; supervision, W.A., A.B.A. and B.M.D.; funding acquisition, B.M.D. All authors have read and agreed to the published version of the manuscript.

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Data availability
All data will be deposited into the IITA data repository and can be accessed through http://data.iita.org. The data will also be made available on request from the corresponding author.

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