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

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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

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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.
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 weaving 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.,...
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 & Asemov, 2018; Bolade, 2016; Idowu-Adeboyi 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), Ida ara (27 processors), Ila olohu (30 processors), Oniyelu 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...
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 Monilia spp) were identified and then described and classified based on conidia and colony morphology as described by Guoyin 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 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 Abusoro | Atosin | Okolo Ajemboboro | Mean value |
|---------------|--------|---------|----------|-------|-------|-----------|---------------------|--------|-----------------|------------|
| **Age**       |        |         |          |       |       |           |                     |        |                 |            |
| 21–30         | 2/20   | 0/0     | 0/0      | 1/10  | 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            | 25         |
| 41–50         | 2/20   | 2/20    | 3/30     | 5/50  | 4/40  | 6/60      | 2/20                | 5/50   | 6/60            | 40         |
| Above 50      | 2/20   | 5/50    | 6/60     | 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             | 8          |
| Female        | 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          |
| Married       | 9/90   | 10/100  | 8/80     | 8/80  | 9/90  | 10/100    | 10/100              | 9/90   | 7/70            | 90         |
| Divorced      | 0/0    | 0/0     | 0/0      | 1/10  | 0/0   | 0/0       | 0/0                 | 0/0    | 0/0             | 1          |
| Widowed       | 1/10   | 0/0     | 2/20     | 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          | 94         |
| Igbo          | 0/0    | 1/10    | 1/10     | 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       | 1/10                | 0/0    | 1/10            | 2          |

(Continued)
Table 1 (Continued)

| Education level | Mean value |
|-----------------|------------|
| Primary         | 4/40       |
| Secondary       | 5/50       |
| Tertiary        | 0/0        |
| Not educated    | 1/10       |

| Occupation      | Yes         |
|-----------------|-------------|
| Minor Occup      | 6/60        |
| Major Occup      | 5/50        |

| Aponmu          | Isinkan     |
|-----------------|-------------|
| Ita araba       | Odode       |
| Aloe Ajemiboro  | Oluju Aburo |
| Ita olerun      | Atoosi      |

| Education level | Mean value |
|-----------------|------------|
| Primary         | 4/40       |
| Secondary       | 5/50       |
| Tertiary        | 0/0        |
| Not educated    | 1/10       |

| Occupation      | Yes         |
|-----------------|-------------|
| Minor Occup      | 6/60        |
| Major Occup      | 5/50        |

Adenitan et al., *Cogent Food & Agriculture* (2022), 8: 2113205
https://doi.org/10.1080/23311932.2022.2113205
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(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 Olo euth, 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

| Experience in drying | Aponmu | Isinkan | Idi agba | Odode | Alade | Idi araba | Ita olorun | Oniyevu Abusoro | Atosin | Okolo Ajembamba | Mean value |
|-----------------------|--------|---------|----------|-------|-------|-----------|------------|-----------------|--------|----------------|------------|
| < 5 years             | 1/10   | 0/0     | 3/30     | 1/10  | 2/20  | 0/0       | 0/0        | 0/0             | 2/20   | 0/0            | (%)        |
| 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       | 2/20       | 0/0            | 3/30   | 8              |            |
| Above 20 years        | 2/20   | 3/30    | 0/0      | 3/30  | 1/10  | 3/30      | 1/10       | 2/20           | 1/10   | 19             |            |
| Variety used          |        |         |          |       |       |           |            |                 |        |                |            |
| Agbagbo               | 8/80   | 9/90    | 9/90     | 7/70  | 8/80  | 7/70      | 9/90       | 3/30           | 6/60   | 8/80           | 74         |
| Agbagbo and Panbo     | 2/20   | 1/10    | 1/10     | 3/30  | 2/20  | 3/30      | 1/10       | 5/50           | 4/40   | 2/20           | 24         |
| Agbagbo 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    | 2              |            |
| 4–5 days              | 1/10   | 1/10    | 0/0      | 1/10  | 1/10  | 1/10      | 0/0        | 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)
| Source of plantain | Mean value |
|--------------------|------------|
| Farm               | 0/0        |
| Market             | 0/0        |
| Farm and Market    | 0/0        |
| Materials for chips preservation | 0/0 |
| Dried pepper       | 0/0        |
| Prostoxin          | 0/0        |
| Nil                | 0/0        |

| Plantain | 6-7 days | Isinkan | Odode | Alode | Ile araba |
|----------|----------|---------|-------|-------|-----------|
| Aponmu   | 0/0      | 0/0     | 0/0   | 0/0   | 0/0       |
| Olobo Ajeombambo | 0/0 | 0/0     | 0/0   | 0/0   | 0/0       |
| Oniyu Aburo | 0/0 | 0/0     | 0/0   | 0/0   | 0/0       |
| Atooso | 0/0      | 0/0     | 0/0   | 0/0   | 0/0       |

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https://doi.org/10.1080/23311932.2022.2113205
| Type of constraint/problem | Aponmu | Isinkan | Ibiagbo | Odade | Idi araba | Ita donum | Okoide | Ajembambo |
|---------------------------|--------|---------|---------|-------|-----------|-----------|--------|-----------|
| Mean Value (%)            | 91     | 91      | 96      | 91    | 100       | 100       | 99     | 100       |
| Time consuming and laborious | 9/90  | 5/50   | 7/70   | 10/100 | 10/100   | 10/100   | 9/90  | 9/90     |
| Tedious peeling and drying | 8/80  | 10/100 | 9/90 | 7/70   | 8/80      | 10/100   | 9/90  | 9/90     |
| Insects and weevil infestation during storage | 1/10  | 0/0    | 3/30  | 1/10  | 0/0       | 0/0       | 0/0  | 2/20     |
| Transportation from farm to processing point | 2/20  | 2/20   | 0/0   | 0/0   | 0/0       | 0/0       | 0/0  | 2/20     |
| Stressful process | 4/40  | 3/30   | 4/40  | 6/60  | 1/10      | 4/40      | 4/40  | 4/40     |
| Extended drying time during rainy season | 4/40  | 3/30   | 4/40  | 6/60  | 1/10      | 4/40      | 4/40  | 4/40     |
| Monitoring of dried materials to prevent contamination | 0/0   | 0/0    | 0/0   | 0/0   | 0/0       | 0/0       | 0/0  | 0/0      |
| Weather condition | 0/0   | 0/0    | 0/0   | 0/0   | 0/0       | 0/0       | 0/0  | 0/0      |

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https://doi.org/10.1080/23311932.2022.2113205
| 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** |                |                |                |              |                |              |                   |              |
| Agbagbo          | ND             | ND             | 0.27 ± 0.02\(^{bc}\) | 0.05 ± 0.05\(^{a}\) | 2.62 ± 0.42\(^{f}\) | 5.15 ± 0.90\(^{c}\) | 10.08 ± 5.41\(^{de}\) | 9.99 ± 1.00\(^{e}\) |
| Bobby tannap     | 0.03 ± 0.02\(^{de}\) | 0.01 ± 0.02\(^{bc}\) | 0.21 ± 0.02\(^{a}\) | ND           | 2.08 ± 1.49\(^{f}\) | 3.78 ± 1.01\(^{b}\) | 2.08 ± 0.19\(^{c}\) | 11.07 ± 1.29\(^{e}\) |
| Mbi egome        | 0.04 ± 0.00\(^{cd}\) | ND             | 0.21 ± 0.02\(^{a}\) | 0.11 ± 0.12\(^{a}\) | 1.29 ± 0.39\(^{f}\) | 3.62 ± 0.19\(^{b}\) | 2.18 ± 0.18\(^{c}\) | 9.41 ± 0.83\(^{e}\) |
| Rta 23           | 0.04 ± 0.01\(^{de}\) | ND             | 0.02 ± 0.02\(^{c}\) | 0.11 ± 0.02 \(^{a}\) | 4.42 ± 0.02\(^{df}\) | 4.83 ± 0.04\(^{b}\) | 5.85 ± 0.02\(^{bc}\) | 11.87 ± 0.25\(^{e}\) |
| **Open sun-dried** |                |                |                |              |                |              |                   |              |
| Agbagbo          | 0.07 ± 0.02\(^{bc}\) | 0.07 ± 0.02\(^{a}\) | 0.31 ± 0.06\(^{ab}\) | ND           | 5.00 ± 1.92\(^{c}\) | 4.83 ± 0.68\(^{c}\) | 9.87 ± 5.73\(^{de}\) | 10.25 ± 0.51\(^{e}\) |
| Bobby tannap     | 0.08 ± 0.00\(^{d}\) | 0.03 ± 0.02\(^{b}\) | 0.33 ± 0.17\(^{c}\) | 0.29 ± 0.08\(^{ab}\) | 3.00 ± 2.05\(^{f}\) | 5.27 ± 3.04\(^{b}\) | 2.19 ± 0.45\(^{c}\) | 9.83 ± 0.27\(^{e}\) |
| Mbi egome        | 0.07 ± 0.02\(^{cd}\) | ND             | 0.24 ± 0.00\(^{cd}\) | 0.45 ± 0.16\(^{ef}\) | 1.79 ± 0.48\(^{de}\) | 3.73 ± 0.34\(^{b}\) | 2.19 ± 0.29\(^{c}\) | 8.92 ± 1.53\(^{e}\) |
| Rta 23           | 0.04 ± 0.01\(^{de}\) | ND             | 0.23 ± 0.02\(^{c}\) | 0.50 ± 0.02\(^{a}\) | 4.77 ± 0.02\(^{a}\) | 4.27 ± 0.04\(^{b}\) | 6.24 ± 0.04\(^{c}\) | 10.95 ± 0.03\(^{de}\) |
| **Locally processed** |                |                |                |              |                |              |                   |              |
| Akure South LGA  |                |                |                |              |                |              |                   |              |
| Apomnu           | 0.05 ± 0.02\(^{bc}\) | ND             | 0.25 ± 0.02\(^{bc}\) | 0.32 ± 0.08\(^{cd}\) | 4.16 ± 1.89\(^{c}\) | 7.74 ± 5.07\(^{cd}\) | 12.11 ± 6.19\(^{d}\) | 25.75 ± 10.97\(^{c}\) |
| Isinkan          | 0.07 ± 0.02\(^{cd}\) | ND             | 0.21 ± 0.02\(^{c}\) | 0.32 ± 0.00\(^{cd}\) | 3.69 ± 0.49\(^{ef}\) | 4.64 ± 0.55\(^{b}\) | 10.19 ± 6.14\(^{de}\) | 16.62 ± 2.35\(^{e}\) |
| Idi agba         | 0.04 ± 0.00\(^{cd}\) | ND             | 0.24 ± 0.00\(^{cd}\) | 0.36 ± 0.00\(^{de}\) | 3.38 ± 0.39\(^{a}\) | 4.56 ± 0.49\(^{b}\) | 10.93 ± 1.71\(^{de}\) | 14.72 ± 0.89\(^{e}\) |
| Idanre LGA       |                |                |                |              |                |              |                   |              |
| Odode            | 0.05 ± 0.02\(^{bc}\) | ND             | 0.23 ± 0.02\(^{c}\) | 0.47 ± 0.15\(^{ab}\) | 3.80 ± 1.58\(^{cd}\) | 11.16 ± 7.40\(^{a}\) | 8.22 ± 2.43\(^{c}\) | 23.54 ± 6.60\(^{de}\) |
| Arole            | 0.04 ± 0.00\(^{cd}\) | ND             | 0.24 ± 0.04\(^{ac}\) | 0.40 ± 0.04\(^{dc}\) | 4.27 ± 1.17\(^{c}\) | 4.55 ± 0.47\(^{d}\) | 10.12 ± 3.03\(^{ab}\) | 17.32 ± 1.64\(^{e}\) |
| Idi araba        | 0.04 ± 0.02\(^{de}\) | ND             | 0.21 ± 0.02\(^{c}\) | 0.17 ± 0.06\(^{de}\) | 3.29 ± 0.26\(^{de}\) | 4.99 ± 1.57\(^{b}\) | 9.10 ± 2.06\(^{de}\) | 21.75 ± 6.17\(^{c}\) |
| Ito olahun       | ND             | ND             | 0.24 ± 0.04\(^{bc}\) | 0.09 ± 0.02\(^{a}\) | 4.25 ± 0.88\(^{c}\) | 4.60 ± 1.28\(^{c}\) | 8.70 ± 0.87\(^{ab}\) | 21.52 ± 6.87\(^{cd}\) |

(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 ± 0.02ef  | ND             | 0.25 ± 0.02bc | 0.08 ± 0.07g | 3.98 ± 0.64c  | 8.02 ± 6.11b  | 12.04 ± 3.24b    | 25.96 ± 10.0b |
| Atosin            | ND             | ND             | 0.31 ± 0.05d  | ND          | 3.83 ± 0.52c  | 3.95 ± 0.43c   | 8.50 ± 3.05b     | 23.21 ± 8.02b  |
| Okeki Ajebomibo   | ND             | ND             | 0.20 ± 0.04c  | 0.24 ± 0.21e | 2.74 ± 0.59f  | 4.70 ± 1.66c   | 11.71 ± 7.71b    | 23.53 ± 17.13b |

$p$ Varieties  | NS                  | **             | ***            | 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 mbì egóme 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 × 10⁶ CFU/g. Solar tent-dried samples had the lowest bacteria counts, between 0.20 × 10⁶ CFU/g and 2.15 × 10⁶ CFU/g. Open sun-dried samples had values between 1.13 × 10⁶ CFU/g and 2.80 × 10⁶ CFU/g, and samples obtained from the local processors had the highest bacteria count of 0.89–3.09 × 10⁶ 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 × 10⁶ 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 × 10⁶ 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 × 10⁵ CFU/g. The solar tent-dried plantain chips had the lowest values (0–0.06 × 10⁵ CFU/g). Open sun-dried samples ranged from 0 to 0.13 × 10⁵ CFU/g, and the samples obtained from the local processors had the highest fungal counts of 0.01–0.07 × 10⁵ 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 × 10⁵ 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, Monilia 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 (mi’gbe egobe) dried in the solar tent-dryer and open sun. One of the samples was collected from the local processors (Idi Araba, Idenre 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 mycobiota 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.
| 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                | 4.15×10^4 ± 1.41 j           | Penicillium spp, Aspergillus flavus, Aspergillus tamarii, Aspergillus Niger |
| Bobby tannap                | 0.96 ± 0.01k                    | 0.10 ± 0.04 f               | 1.97×10^3 ± 2.12 l           | Penicillium spp                        |
| Mbi egome                   | 0.20 ± 0.03 m                   | 0.00 ± 0.03 g               | 2.03×10^3 ± 2.83kl           | Nil                                    |
| Pita 23                     | 2.15 ± 0.01d                    | 0.60 ± 0.04c                | 2.10×10^3 ± 16.26kl          | Rhizopus spp                           |
| **Open sun-dried chips**    |                                 |                             |                              |                                        |
| Agbagba                     | 2.15 ± 0.01d                    | 0.20 ± 0.02e                | 2.20×10^4 ± 212.13 f         | Penicillium spp, Rhizopus spp, Fusarium verticillioides, Aspergillus Niger |
| Bobby tannap                | 2.80 ± 0.07b                    | 1.30 ± 0.01a                | 2.80×10^4 ± 70.71d           | Aspergillus Niger, Rhizopus spp,       |
| Mbi egome                   | 2.01 ± 0.01 f                   | 0.00 ± 0.01 g               | 2.01×10^4 ± 70.71 g          | Nil                                    |
| Pita 23                     | 1.13 ± 0.01 j                   | 0.20 ± 0.01e                | 1.30×10^4 ± 141.62 h         | Rhizopus spp, Penicillium spp          |
| **Locally processed chips** |                                 |                             |                              |                                        |
| Akure South LGA             |                                 |                             |                              |                                        |
| Aponmu                      | 2.58 ± 0.01c                    | 0.70 ± 0.03b                | 2.70×10^4 ± 212.13e          | Rhizopus spp, Aspergillus flavus, Aspergillus tamarii, Aspergillus Niger |
| Isinkan                     | 2.08 ± 0.01e                    | 0.40 ± 0.01d                | 2.85×10^4 ± 3.54jk           | Rhizopus spp, Aspergillus flavus       |
| Idi agba                    | 3.09 ± 0.01a                    | 0.20 ± 0.02e                | 3.10×10^4 ± 141.62c          | Rhizopus spp                           |
| Idanre LGA                  |                                 |                             |                              |                                        |
| Odode                       | 0.89 ± 0.02 l                   | 0.20 ± 0.02e                | 9.50×10^3 ± 14.14i           | Rhizopus spp                           |
| Alade                       | 1.34 ± 0.01 h                   | 0.20 ± 0.01e                | 9.00×10^3 ± 70.71a           | Rhizopus spp                           |
| Idi araba                   | 1.38 ± 0.01 gh                  | 0.20 ± 0.02e                | 7.00×10^3 ± 141.21b          | Aspergillus flavus                     |
| Ita olohu                   | 1.19 ± 0.01i                    | 0.20 ± 0.03e                | 2.86×10^3 ± 3.54jk           | Nil                                    |
| Oniyeu Abusoro              | 2.21 ± 0.01d                    | 0.20 ± 0.01e                | 1.79×10^3 ± 2.83 l           | Aspergillus tamarii, Aspergillus flavus, Rhizopus spp |
| Atosin                      | 1.39 ± 0.01g                    | 0.20 ± 0.02e                | 1.49×10^3 ± 2.12 l           | Aspergillus Niger, Aspergillus spp, Aspergillus tamarii, Rhizopus spp |
| Oko o Ajembamibo            | 1.37 ± 0.01gh                   | 0.10 ± 0.02f                | 3.00×10^3 ± 141.62 j         | Manila 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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No potential conflict of interest was reported by the author(s).

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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References
Abiyo, Y. F., Ade-Omowaye, B. I. O., Babarinde, G. O., & Adesigbin, M. K. (2011). Chemical, physicochemical, and sensory properties of soy-plantain flour. African Journal of Food Science, 5(4), 176–180. https://doi.org/10.5897/AJFS2011.0870
Adenitan, A. A., Awoyale, W., Akinwande, B. A., Maziya-Dixon, B., & Sulyok, M. (2021). Mycotoxin profiles of

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solar tent-dried and open sun-dried plantain chips. Food Control, 119(4), 107–467. https://doi.org/10.1016/j.foodcont.2020.107467

Adeeye, S., & Yildiz, F. (2016). Fungal mycotoxins in foods: A review. Cogent Food and Agriculture, 2(1), 1–11. https://doi.org/10.1080/23311932.2016.1179161

Aina, O. S., Ajiola, S., Bappah, M. T., Ibrahim, L., & Musa, I. A. (2012). Economic analysis of plantain marketing in ogibo local government area of Ondo State, Nigeria. Global Advanced Research Journal of Agricultural Science, 1(5), 104–109. http://garj.org/garjas/index.htm

Ajayi, A. O. (2016). Microbiological quality of plantain (Musa paradisiaca). Nigerian Journal of Microbiology, 30(2), 3611–3618. https://www.semanticscholar.org/paper/Microbiological-Quality-of-Plantain-MUSA-Ajajy-A-O.-/0cb0950b6e5d76e4b3388f4c95d8f023475d385c

Akinyemi, A. O., Oboh, G., & Adedegha, A. S. (2015). Assessment of the nutritional, anti-nutritional, and antioxidant capacity of unripe, ripe, and overripe plantain (Musa paradisiaca) peels. International Journal of Advanced Research, 3(2), 63–72. http://www.sciencedr.com

Alimi, B. A., & Worlneh, T. S. (2018). Consumer awareness and willingness to pay for safety of street foods in developing countries: A review. International Journal of Consumer Studies, 40(2), 242–248. https://doi.org/10.1111/jics.12248

Amah, D., Stuart, E., Mignouna, D., Swennen, R., & Teekens, B. (2021). End-user preferences for plantain food products in Nigeria and implications for genetic improvement. International Journal of Food Science and Technology, 56(3), 1148–1159. https://doi.org/10.1111/1749-0939.16780

Ametepey, S. T., Cobbina, S. J., Akpabey, F. J., Abudu, B. D., & Zita, N. A. (2018). Health risk assessment and heavy metal contamination levels in vegetables from Tamale Metropolis, Ghana. Food Contamination, 5(5), 1–8. https://doi.org/10.1186/s40550-018-0067-0

Anajekwu, E. O., Maziya-Dixon, B., Akinoso, R., Awoyale, W., & Alamu, E. O. (2020). Physicochemical properties and total carotenoid content of high-quality unripe plantain flour from varieties of hybrid plantain cultivars. Journal of Chemistry, 2(4), 1–7. https://doi.org/10.11152/20960346

Anhwange, B. A., & Asemave, K. (2018). Assessment of some heavy metals content of roadside vended foodstuffs in Keffi metropolis. The International Journal of Science and Technology, 6(4), 24–27. www.theijst.com

Armachis, J., & Athanasia, M. (2018). Formulation of a novel mixed dried vegetable product for improved iron, zinc and vitamin A accessibility. Cogent Food & Agriculture, 4(1), 1531806. https://doi.org/10.1080/23311932.2018.1531806

Aruwo, C. E., Akindusaye, A. J., & Awala, S. I. (2017). Socio-demographic characteristics and food hygiene level. assessment of food handlers in cafeterias around a federal university in Nigeria. Journal of Scientific Research and Reports, 14(4), 1–9. https://doi.org/10.9734/JISR/2017/33273

Awoyale, W., Asiedu, R., K wai l o w a, W. K. C., M aziya-Dixon, B., Abass, A., Edet, M., & Adejumobi, M. O. (2017). Assessment of heavy metals and microbial contamination of gari from Liberia. Food Science and Nutrition, 5(1), 62–66. https://doi.org/10.1002/fsn3.527

Ayarwale, A. B., Fatunbi, A. O., & Ojo, M. P. (2018). Baseline analysis of plantain (Musa sp.) value chain in Southwest of Nigeria. FARA Research Report, 3(1), 84. http://www.farafro ngo.co/
Nordberg, G., Fowler, B., & Nordberg, M. (2014). Handbook on the toxicology of metals (4th ed.). Academic Press publisher.

Nutli, V., Chattanga, P., Kwiri, R., Gadega, H. T., Gere, J., Matsepo, T., & Potloane, R. P. (2016). Microbiological quality of selected dried fruits and vegetables in Masera, Lesotho. African Journal of Microbiology Research, 11(5), 185–193. https://doi.org/10.5897/ AJMR2016.8130

Obidiegwu, O. E., Lyons, J. B., & Chiloka, C. A. (2020). The Dioscorea Genus (Yam)—An appraisal of nutritional and therapeutic potentials. Foods, 9(9), 1304. https://doi.org/10.3390/foods9091304

Odenigbo, M. A., & Inya-Osue, J. (2012). Knowledge, attitudes and practices of people with type 2 diabetes mellitus in a tertiary health care centre, Umuahia, Nigerian. Journal of Diabetes & Metabolism, 3(3), 187–191. https://doi.org/10.4172/2155-6156.1000187

Ogechi, U. P., Akhokhio, O. I., & Ugwunna, U. A. (2017). Nutritional status and energy intake of adolescents in Umuahia urban, Nigeria. Pakistan Journal of Nutrition, 6(6), 641–646. https://doi.org/10.3923/pjn.2007.641.646

Okafor, S. E., & Eni, A. O. (2017). Microbial quality and the occurrence of aflatoxins in plantain/yam and wheat flours in Ado-Odo Ota. IOP conference series: earth and environmental science https://doi.org/10.1088/1755-1315/210/1/012017.

Olorode, O. O., & Evwuoso, L. M. (2017). Effect of different Sun drying Surfaces on the Functional Properties and Microbial Loads of Unripe Plantain Flours. Frontiers in Environmental Microbiology, 3(3), 50–55. https://doi.org/10.11648/j.fem.20170303.12

Olwayoye, O. I., & Evbuomwan, B. O. (2014). Comparative Analysis of the Effect of Size Reduction on the Drying Rate of Cassava and Plantain Chips. International Journal of Geology, Agriculture and Environmental Sciences, 2(4), 20–27.

Oyejinka, B., & Afolayan, A. (2019). Comparative evaluation of the nutritive, mineral, and antinutritive composition of musa sinensis l. (banana) and musa paradisiaca l. (plantain) fruit compartments. Plants, 8 (12). https://doi.org/10.3390/plants8120598

Pelissari, F. M., Andrade Mahecho, M. M., Sobral, P. J., & Menegalli, F. C. (2012). Isolation and characterization of the flour and starch of plantain bananas (Musa paradisiaca). Starch - Stärke, 64(5), 382–391. https://doi.org/10.1002/star.201100133

Premium Times. (2017). 200,000 people die of food poison annually in Nigeria-Prof. Ihenkuronye” –Premium Times accessed 11 October 2017. www.premiumtimesng.com/news/96700-200000-people-die-of-food-poison-annually-in-nigeria-prof-facinguronye.html>

Rani, S. K., & Saxena, N. (2022). Fungal contamination of some common spices. Journal of Plant Science Current Research, 5(1), 1–4. https://doi.org/10.24966/ PSR-3743/100014

Rwubatse, B., Akubor, P. I., & Mugabo, E. (2016). Traditional drying techniques for fruits and vegetable loss alleviation in Sub-Saharan Africa. Journal of Environmental Science, Toxicology and Food Technology, 8(9), 52–56. https://doi.org/10.9790/2402-08945256

Toth, G., Hermann, T., De Silva, M. R., & Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International, 88, 299–309. https://doi.org/10.1016/j.envint.2015.12.017

Velu, G., Ortiz-Monasterio, J., Cakmak, I., Hao, Y., & Singh, R. P. (2014). Biofortification strategies to increase grain zinc and iron concentrations in wheat. Journal of Cereal Science, 59(3), 365–372. https://doi.org/10.1016/j.jcs.2013.09.001

WF, P. (2012). Update on world food program (WFP) safety nets policy: the role of food assistance in social protection. World Food Program. https://documents.wfp.org/stellent/groups/public/documents/resources/wfp24575Y

Yeeliere, E., Cobbin, S. J., & Abubakari, Z. I. (2017). Review of microbial food contamination and food hygiene in selected capital cities of Ghana. Cogent Food & Agriculture, 3(1), 1395102. https://doi.org/10.1080/23311932.2017.1395102
