Food Control 119 (2021) 107467

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Mycotoxin profiles of solar tent-dried and open sun-dried plantain chips

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ARTICLE INFO

Keywords:
Plantain chips
Open sun-drying
Solar tent-dryer
Mycotoxin metabolites
Regulated mycotoxins
Non-regulated mycotoxins
Food safety

ABSTRACT

Plantain is a popular dietary staple in Central and West African countries due to its versatility and excellent nutritional value. Mature unripe plantain finger is usually processed into dried chips by processors using open sun-drying method to reduce the moisture content and extends its shelf life, but without controlling the unit operations that affect product quality. Thus, this study aimed at assessing the mycotoxin profile of solar tent-dried and open sun-dried plantain chips in Nigeria. Fifty (50) dried plantain chips [10 samples produced from the solar tent-dried, 10 samples from open sun dried, and 30 samples from local processors (9 from Akure South and 21 from Idanre Local Governments)] were analyzed for constituent mycotoxins using Liquid Chromatography Tandem-Mass Spectrometry (LC-MS/MS). The result reveals that all the regulated mycotoxins (*Aflatoxin B1, B2, G1, G2, Ochratoxin A, Fumonisin B1, Fumonisin B2, Zearalenone, T-2 Toxin, HT-2 Toxin* and, *Deoxynivalenol*) were below the detectable limits in the dried plantain chips. *Aflatoxin B1* and G1, which were considered as the most regulated mycotoxin, were below the limits of detection (0.16–0.22 μg/kg) in all the samples. Only 23 analytes were detected at concentrations higher than their respective limits of detection (LOD) in 2% or more of the 50 dried plantain chips investigated, with reference to the prevalence of the non-regulated mycotoxins. Thus, all regulated mycotoxins produced by *Aspergillus, Penicillium* and *Fusarium* as stipulated by the Commission of the European Union were found at concentrations which are toxicologically acceptable in many other crops, particularly in the solar tent-dried plantain chips compared to those from the open sun-dried and local processors. Therefore, the use of a solar tent in drying plantain chips and other agricultural products is encouraged for the safety of human consumption. The outcome of this study provides useful information regarding the possible safety of plantain chips in Nigeria.

1. Introduction

Plantain (*Musa paradisiaca* L.) is a tropical fruit that constitutes a staple food crop in Central and West Africa (Akinsanmi, Oboh, Akinyemi, & Adefegha, 2015). It belongs to the genus *Musa* in the family Musaceae. Plantain is a popular dietary staple food due to its versatility and good nutritional value. It is widely consumed by the entire population in Nigeria as boiled, fried, or roasted. It is also consumed mainly as snacks in the form of chips, 'dodo Ikire' e.t.c. (Abioye, Ade-Omowaye, Babarinde, & Adesigbin, 2011). Mature unripe plantain is usually processed into dried chips by processors using traditional sun-drying methods to reduce the moisture content and extend product shelf life (Amusa, 2001), but without controlling the critical control points that affect product quality. The produced chips, which are prone to contamination during drying, maybe blanched for consumption after preparation (Amusa, 2001) or converted to flour for further use.

Traditionally, open sun-drying is a standard drying method to reduce the moisture content, which will retard the growth of microorganisms and increases the shelf life of the stored products. However, the technique is prone to contamination. Solar tent dryer is an advanced technology of sun drying. It is simple to build and consists of a frame of a wooden pole covered by a plastic sheet (Rwubatse, Akubor & Mugabo, 2014). It is an evaporative drying process with the greenhouse principle (Doe, 2002, pp. 350–359). After being set up in the sun, solar energy

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https://doi.org/10.1016/j.foodcont.2020.107467
Received 30 March 2020; Received in revised form 30 May 2020; Accepted 5 July 2020
Available online 10 July 2020
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passes through polythene and gets trapped inside; it leads to an increase in internal temperature (Logesh, Pravinkumar, Raffi, & Kalaiselvam, 2012) and dry faster (Mkoka, 2016). This gives protection against dirt, grits, rain, insect and rodents infestation and also prevents animals from the products.

In Nigeria, more than 200,000 people die annually of food poisoning, caused by food contaminated through improper farming, processing, preservation, storage (Premium Times, 2017). Ensuring food safety through the reduction of aflatoxin and other fungal metabolites contamination can contribute significantly to alleviating poverty, increasing food security, and improving nutrition. The reduction of aflatoxin in foods will impact positively on-farm productivity, conservation of natural resources, as well as promotion of economic growthby meeting standards in domestic, regional, and international trade (Pepple, 2017). As crucial as these processed chips are to the natives, the possible problem of food safety with mycotoxins and their metabolites should receive considerable attention.

Mycotoxins are secondary fungal metabolites that may grow in almost any food or feedstuff during the growing season, at harvest, or during processing or storage, depending on the environment and method of handling. Ingestion of high concentrations of mycotoxins can cause sickness or death in humans and animals. There are three significant *genera* of fungi that produce mycotoxins: *Aspergillus, Fusarium* and *Penicillium* (Kaaya & Eboku, 2010; Patchimapon et al., 2018). Kaaya and Eboku (2010) reported that aflatoxins are naturally-occurring mycotoxins produced as secondary metabolites by many species of *Aspergillus* (*Aspergillus flavus, A. fumigatus, A. parasiticus, and A.niger*). These secondary metabolites include *aflatoxins B1, B2, G1 and G2.* There is a need for knowledge of the levels of mycotoxin contaminants in food products to assist regulatory food agencies in estimating possible exposure of consumers to such contaminants and in setting maximum allowable standards for food control purposes (Awoyale, Adebayo, Sulyok, & Alamu, 2017). Some studies have been done on the aflatoxin profile of plantain flour (Jonathan, Ajayi, & Omitade, 2011; Okafor & Eni, 2017) but little or none has been reported on the mycotoxin profile of plantain chips dried with solar tent-dryer and open sun-drying. Therefore, this study aimed at assessing the mycotoxin profile of solar tent-dried and open sun-dried plantain chips in Nigeria.

2. Materials and methods

2.1. Sampling of dried plantain chips and sample preparation

Thirty (30) samples of plantain chips were collected randomly from the local processors (Akure South and Idanre Local Government) in Ondo State to evaluate their mycotoxin profiles. Four popularly consumed plantain varieties; "*agbagba, bobby tannap, mbi egome, and pita 23*" were washed, sliced (3 mm), and dried into plantain chips using solar tent-dryer (5 m × 3 m) and open sun drying. They were compared with the dried plantain chips obtained from the local processors (surveyed samples). All the dried plantain chips were crushed with laboratory mortar and pestle and milled with the aid of stainless USHA mixer grinder (MG 2053 N model) to flour. The plantain flour samples were packaged in zip lock bags and transported to the Center for Analytical Chemistry Laboratory in the Department of Agrobiotechnology, University of Natural Resources and Life Sciences, Vienna, for analysis. Fifty (50) dried plantain chips were all analyzed for mycotoxin profiles: 10 plantain chips produced from solar tent dryer, 10 from open sun drying, 9 dried plantain chips from Akure South, and 21 dried plantain chips from Idanre Local Government).

2.2. Determination of mycotoxin profiling of dried plantain chips

2.2.1. Extraction and matrix effect

The mycotoxin profile of all the dried samples was determined using the Liquid Chromatography Tandem-Mass Spectrometry (LC-MS/MS) system reported by Malachova, Sulyok, Beltran, Berthiller, and Krska (2015). A QTrap 5500 LC-MS/MS System (Applied Biosystems, Foster City, CA, USA) equipped with a TurboIonSpray® electrospray ionization (ESI) source and a 1290 Series HPLC System (Agilent, Waldbronn, Germany) was used for the liquid chromatography-mass spectrometry/mass spectrometry (LC-MS/MS) screening of target microbial metabolites (Vishwanath, Sulyok, Labuda, Bicker, & Krska, 2009). About five (5) grams of ground samples were extracted through 50 ml polypropylene tubes (Sarstedt, Nümbrecht, Germany) with 20 ml of extraction solvent (acetonitrile/water/acetic acid 79:20:1, v/v/v). After 90 min of shaking within a GFL 3017 rotary shaker (GFL, Burgwedel, Germany), samples were transferred to vials and diluted with an equal volume of the dilution solvent (acetonitrile/water/acetic acid 20:79:1, v/v/v). About 5 μl of the diluted extracts were subsequently injected into the LC-MS/MS system (Gruber-Dorninger, Jenkins, & Schatzmayr, 2019). For the spiking experiment, 0.25g of five blank samples were spiked with a multi-component standard and extracted as described above. To allow evaporation of the solvent and to establish equilibration between the analytes and the matrix, the spiked samples were mixed and stored at room temperature overnight in the dark.

2.2.1.1. LC/MS-MS parameters. Analyses were carried out via a developed multi mycotoxin LC/MS-MS method (EU, 2002; Gruber-Dorninger et al., 2019) that was updated and extended to cover 650 analytes (Sulyok, Berthiller, Krska, & Schuhmacher, 2006). Briefly, analyses were performed with a QTrap 5500 LCMS/MS System (Applied Biosystems, Foster City, CA, USA) equipped with a Turbo Ion Spray electrospray ionization (ESI) source and a 1290 Series HPLC System (Agilent, Waldbronn, Germany). Chromatographic separation was undertaken at 25 °C on a Gemini C18-column, 150X 4.6 mm, 5 μm particle size, equipped with a C18 4 × 3 mm security guard cartridge (Phenomenex, Torrance, CA, USA). ESI-MS/MS was performed in the time-scheduled multiple reaction monitoring (MRM) mode, both in positive and negative polarities, in two separate chromatographic runs per sample, by scanning two fragmentation reactions per analyte. The MRM detection window of each analyte was set to its expected retention time ±27s and ±48s in the positive and negative mode, respectively. Confirmation of positive analyte identification was obtained by the acquisition of two MRMs per analyte (except for moniliformin and 3-nitropropionic acid that exhibit only one fragment ion). This yielded 4.0 identification points, according to the European Union Commission decision 2002/657 (EU, 2002). Also, the LC retention time and the intensity ratio of the two MRM transitions agreed with the related values of an authentic standard within 0.1 min and 30% relative, respectively. Quantification was performed using an external calibration based on serial dilutions of a multi-analyte stock solution. Results were corrected for apparent recoveries determined by spiking experiments.

The expanded measurement uncertainty was determined to be 50%. Limits of quantification and limits of detection were determined using the EURACHEM guide. The accuracy of the method was verified on a routine basis by participation in inter-laboratory testing schemes, including a broad variation of matrices of grains, nuts, dried fruits, spices, baby food, and animal feed. Satisfactory z-scores between −2 and 2 were obtained for more than 94% of more than 1100 results submitted.

2.3. Statistical analysis

Data were statistically analyzed using the Statistical Analysis System (SAS) package version 9.3 (SAS, 2008).

3. Results and discussion

The samples of dried plantain chips were analyzed for >700 (mostly fungal) secondary metabolites, including all mycotoxins addressed by regulatory limits, "emerging mycotoxins" for which a basic risk

assessment exists. The results of the mycotoxin metabolites profiles of the 50 dried plantain chips are shown in Tables 1, 3–5. The results revealed that regulated mycotoxins (*Aflatoxin B1, B2, G1, G2, Ochratoxin A, Fumonisin B1, Fumonisin B2, Zearalenone, T-2 Toxin, HT-2 Toxin* and *Deoxynivalenol*) were all below the detectable limits in the dried plantain chips. *Aflatoxin B1* and *G1*, which were considered as the most regulated mycotoxin (Awoyale et al., 2017; IARC, 2002), were below the limits of detection (0.16–0.22 μg/kg) in all the dried plantain chips samples; thus, dried plantain chips may not be a suitable substrate for the biosynthesis of aflatoxin. Conversely, these regulated mycotoxins were reported to be present in cassava flour samples from the Republic of Benin (Ediage, Di Mavungu, Monbaliu, Van Peteghem, & De Saeger, 2011), and the sun-dried cassava samples from Madagascar and Tanzania (Abass et al., 2019).

3.1. Non-regulated microbial metabolites detected in solar tent dried and opened sun-dried plantain chips

As regards the prevalence of non-regulated mycotoxins in all the dried plantain chips, only 23 analytes were detected at concentrations higher than their respective limits of detection (LOD) in 2% or more of the 50 dried plantain chips investigated (Table 1). They were *Kojic acid* (10%), *3-Nitropropionic acid* (52%), *Oxaline* (2%), *Quinolactacin A* (40%), *Quinolactacin B* (6%), *Beauvericin* (2%), *Moniliformin* (18%), *Chrysogin* (58%), *Equisetin* (2%), *Monocerin* (20%), *Abscisic acid* (100%), *Anhydrofulvic acid* (34%), *Chloramphenicol* (20%), *Lecanoic acid* (44%), *Asperglaucide* (84%), *Asperphenamate* (60%), *Citreorosein* (20%), *Dihydroxymellein* (52%), *Cyclo (L-Pro-L-Tyr)* (36%), *Cyclo (L-Pro-Val)* (18%), *Emodin* (40), *Iso-Rhodoptilometrin* (14%), and *Tryptophol* (78%).

Kojic acid and *3-Nitropropionic acid* are metabolites associated with *Aspergillus* species. Aspergillus species are filamentous fungi that are frequently found in soil, decaying vegetation, and seeds and grains, where they thrive as saprophytes. Aspergillus species can be harmful to humans occasionally (Heitman, 2011; Pitt, 1994; Seyedmousavi et al., 2015). Most Aspergillus metabolites are found in a wide variety of environments and substrates on the earth throughout the year (Kwon-Chung & Sugui, 2013). They constitute an essential threat to human health, with their effects ranging from moderate allergies and severe asthma to disseminated infections. *Kojic acid* was below the detectable limits (20.4 μg/kg) in the solar tent-dried chips and open sun-dried plantain chips, but it was detected in samples obtained from Idanre Local Government (4/21 samples), and Akure South (1/9 sample) with a concentration of 855 and 2260 μg/kg respectively. Samples from Akure South had the highest level of *Kogic acid*, which might be attributed to possible fermentation of the plantain chips before or during drying (Balint, Forsthoffer, Brtko, & Dobias, 1988). Though poisoning from the consumption of oriental fermented foods containing *Kojic acid*, where its presence is common, has not been reported in humans, and there are still inconsistent and controversial results on *Kojic acid* toxicity (Wei, Huang, Fernando, & Chung, 1991). A s significant and robust correlation exists between *Kojic acid* and fungi counts ($r = 0.79$, $p < 0.01$) (Table 2). This might be an indication of high moisture content found in the open sun-dried plantain chips (Akure South and Idanre local governments), which may have contributed to the production of *Kojic acid* in the sample.

Table 2
The correlation between moisture content, fungi counts, the total microbial counts, and the mycotoxin metabolites.

Metabolites	Moisture Content	Fungi counts	Total microbial counts
Kojic acid	0.39	0.79**	−0.50
3-Nitropropionic acid	−0.50	−0.33	−0.56
Oxaline	0.12	−0.05	0.76*
Quinolactacin A	0.38	−0.05	0.04
Quinolactacin B	0.39	0.05	0.39
Beauvericin	0.30	−0.25	−0.48
Moniliformin	0.21	−0.02	0.05
Chrysogin	0.41	0.83*	0.08
Equisetin	0.55	0.02	0.12
Monocerin	0.49	−0.06	−0.22
Abscisic acid	0.23	0.01	0.04
Anhydrofulvic acid	0.16	0.91***	−0.27
Chloramphenicol	0.24	0.70*	−0.49
Lecanoric	−0.36	0.18	−0.23
Asperglaucide	−0.19	−0.43	0.32
Asperphenamate	0.01	−0.08	−0.38
Citreorosein	0.08	0.79*	−0.19
cyclo(L-Pro-L-Tyr)	−0.02	−0.07	−0.22
cyclo(L-Pro-L-Val)	0.25	−0.03	0.77*
Dihydroxymellein	−0.22	0.02	−0.31
Emodin	−0.37	−0.67	0.13
Iso-rhodoptilometrin	−0.42	−0.42	0.18
Tryptophol	−0.72*	−0.38	−0.33

*P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.

The concentration of *3-Nitropropionic acid*, a natural environmental toxin obtained from various plants and fungi ranged from 8.82 to 241 μg/kg in all the dried plantain chips. Solar tent-dried chips (3/10 samples) (18.84 μg/kg), open sun-dried chips (3/10 samples) (8.82 μg/kg), dried chips collected from Idanre (13/21 samples) (64.59 μg/kg), while the one from Akure South had the highest concentration (7/9 samples) with a value of 241 μg/kg (Table 1). The variations in the result may be due to the fungi isolated (*Rhizopus* spp, *Aspergillus niger, Aspergillus flavus, Rhizopus)* from the dried chips obtained from the processors that predispose them to moulds growth of the toxin and which may be the significant factor for the high level in samples collected from Akure South than others. It might also be from extreme weather, stressed crop conditions, and environmental conditions.

Table 1
Number of non-regulated microbial metabolites detected at or above the limit of detection in the solar tent-dried and open sun-dried plantain chips.

S/N	Analytes	P/N	Prevalence (%)	LOD (μg/kg)	R (%)	S/N	Analytes	P/N	Prevalence (%)	LOD (μg/kg)	R (%)
1	*Kojic acid*	5/50	10	20	70	16	*Asperphenamate*	30/50	60	0.39	103
2	*3-Nitropropionic acid*	26/50	52	0.74	38	17	*Citreorosein*	10/50	20	0.74	71
3	*Oxaline*	1/50	2	0.08	82	18	*cyclo(L-Pro-L-Tyr)*	18/50	36	1.17	55
4	*Quinolactacin A*	20/50	40	0.01	79	19	*cyclo(L-Pro-L-Val)*	9/50	18	1.17	70
5	*Quinolactacin B*	3/50	6	0.03	78	20	*Dihydroxymellein*	26/50	52	0.51	90
6	*Beauvericin*	1/50	2	0.02	87	21	*Emodin*	20/50	40	0.11	89
7	*Moniliformin*	9/50	18	1.52	91	22	*Iso-Rhodoptilometrin*	7/50	14	0.03	79
8	*Chrysogin*	29/50	58	0.56	76	23	*Tryptophol*	39/50	78	3.86	77
9	*Equisetin*	1/50	2	0.69	122	24	*N-Benzoyl-Phenylalanine*	50	0.00	0.15	84
10	*Monocerin*	10/50	20	0.06	82	25	*Citrinin*	50	0.00	0.73	121
11	*Abscisic acid*	50/50	100	15	100	26	*Mycophenolic acid*	50	0.00	1.10	84
12	*Anhydrofulvic acid*	17/50	34	4.00	83	27	*Sterigmatocystin*	50	0.00	0.08	76
13	*Chloramphenicol*	10/50	20	0.03	82	28	*Chanoclavin*	50	0.00	0.18	76
14	*Lecanoic acid*	22/50	44	0.15	78	29	*Alternariol*	50	0.00	0.10	36
15	*Asperglaucide*	42/50	84	0.07	85	30	*Alternariol methyl ether*	50	0.00	0.11	73

P: Positive samples, N: total number of samples, R: apparent recovery, LOD: Limits of detection.

Table 3
Penicillium metabolites detected in the solar tent-dried and open sun-dried plantain chips.

	N	Penicillium Metabolites				
		Kojic acid	*3-Nitropropionic acid*	*Oxaline*	*Quinolactacin A*	*Quinolactacin B*
Apparent recovery (%)		70	38	82	79	77
LOD (μg/kg)		20.40	0.74	0.08	0.01	0.03
Solar tent-dried chips	10	<LOD	18.84	<LOD	<LOD	<LOD
Open sun-dried chips	10	<LOD	8.82	<LOD	<LOD	<LOD
Akure South chips	09	2260	241	<LOD	0.83	0.21
Idanre chips	21	855	64.6	5.19	0.14	0.08

The calculation of means was based on positive values. LOD: limits of detection N: Total number of samples.

Table 4
The *Fusarium* metabolites and metabolites from other fungal genera detected in the solar tent-dried and open sun-dried plantain chips.

	N	*Fusarium* metabolites				Metabolites from other fungal genera				
		Beauvericin	*Moniliformin*	*Chrysogin*	*Equisetin*	*Monocerin*	*Abscisic acid*	*Anhydrofulvic acid*	*Chloramphenicol*	*Lecanoic acid*
Apparent recovery (%)		87	91	76	122	82	100	83	82	78
LOD (μg/kg)		0.02	1.52	0.56	0.69	0.06	15.07	4.00	0.03	0.15
Solar tent-dried chips	10	<LOD	6.81	16.03	<LOD	<LOD	528.19	26.01	<LOD	4.69
Open sun-dried chips	10	<LOD	7.92	49.38	<LOD	<LOD	499.03	29.13	<LOD	3.44
Akure South chips	09	0.57	<LOD	56.90	6.78	9.03	1100.44	25.86	0.40	16.65
Idanre chips	21	<LOD	9.23	33.76	<LOD	2.81	1355.11	24.70	0.93	13.05

The calculation of means was based on positive values. LOD: limits of detection N: Total number of samples.

Table 5
Unspecific metabolites of the solar tent-dried and open sun-dried plantain.

		Unspecific metabolites									
	N	*Asperglaucide*	*Asperphe-Namate*	*Citreorosein*	*cyclo(L-Pro-L-Tyr)*	*cyclo(L-Pro-L-Val)*	*Dihydroxymellein*	*Emodin*	*Iso-Rhodoptilometrin*	*N-Benzoyl-Phenylalanine*	*Tryptophol*
Apparent recovery (%)		85	103	71	55	70	90	89	79	84	77
LOD (μg/kg)		0.07	0.39	0.74	1.17	1.17	0.51	0.11	0.03	0.15	3.86
Solar tent dried chips	10	0.36	<LOD	<LOD	<LOD	<LOD	9.68	0.60	<LOD	<LOD	61
Opened sun-dried chips	10	0.46	<LOD	<LOD	<LOD	<LOD	10.11	0.60	<LOD	<LOD	86
Akure South chips	09	364	146	8.84	7.81	5.43	469	1.58	0.46	<LOD	35.2
Idanre chips	21	379	323	6.21	7.86	6.16	75	0.94	0.24	<LOD	40.3

The calculation of means was based on positive values. LOD: limits of detection N: Total number of samples.

3.2. Penicillium metabolites present in solar tent dried and opened sun-dried plantain chips

Oxaline, Quinolactacin A, and *B* are metabolites associated with *Penicillium* species (Table 3). *Penicillium* can be found practically anywhere in air, soil, compost, grains. The health effects of these *Penicillium* metabolites include respiratory problems, which can lead to damage to internal organs, cancer, fever, e.t.c (De Hoog, Guarro, Figueras, & Gené, 2000, p. 1126; Haubrich, 2003, p. 175). *Oxaline* compounds were detected only in one chip obtained from Idanre Local Government (1/21 samples) with a value of 5.19 μg/kg but were below the limits (0.08 μg/kg) of detection in all other samples (solar tent-dried, opened sun-dried chips, and Akure South chips). *Quinolactacin A* was below the limits of detection (0.01 μg/kg) in the solar tent-dried and open sun-dried plantain chips and was detected in dried chips obtained from Akure South (6/9 samples) and Idanre Local Government (14/21samples) with a concentration of 0.83 μg/kg and 0.14 μg/kg respectively. Also, *Quinolactacin B* exhibits below the detectable limits (0.03 μg/kg) in the solar tent-dried and open sun-dried plantain chips but was detected in dried plantain chips obtained from Akure South (2/9 samples) and Idanre Local Government (1/21) with concentrations of 0.21 μg/kg and 0.08 μg/kg respectively. The variations in the values may be as a result of environmental conditions (temperature, relative humidity, and insect infestation), which may be conducive to fungal colonization and mycotoxin production. The method of handling during the processing of the plantain chips may also be responsible for the variations in the *Quinolactacin B* values.

3.3. Fusarium metabolites and metabolites from other fungal genera detected in solar tent dried and opened sun-dried plantain chips

Beauvericin, moniliformin, chrysogin, and equisetin are associated with Fusarium metabolites (Table 4). *Fusarium* metabolites are worldspread contaminants that occur naturally in food, and feed. *Beauvericin* and *moniliformin* have been categorized as emerging mycotoxin. *Moniliformin* compounds exhibit below the detectable limits (1.52 μg/kg) in all dried chips from Akure South Local Government, but was detected in the solar tent-dried (5/10 samples), open sun-dried chips (3/10 samples) and only one chip obtained from Idanre Local Government (1/21 sample) with trace concentrations of 6.81, 7.92, and 9.23 μg/kg respectively. There were traces of *Beauvericin* in all the dried chips, and which was found below the detectable limits in all the samples (0.02 μg/

kg), except in only one sample from Akure South Local Government (1/9) with a concentration of 0.57 μg/kg. *Chrysogin* was below the detectable limits (0.56 μg/kg) in some of the dried samples, and was detected in solar tent-dried chips (2/10 samples), open sun-dried chips (5/10 samples), Akure South chips (7/9 samples) and Idanre Local Government (15/21 samples) with a concentration of 16.03, 49.38, 56.90 and 33.76 μg/kg respectively. Solar tent-dried chips had the least concentration and plantain chips from Akure South had the highest level. A strong and significant correlation was observed between fungi counts and *Chrysogin* ($r = 0.83$, $p < 0.05$), but moisture content was positively correlated with *Chrysogin* though not significant ($r = 0.41$, $p > 0.05$) (Table 5). This might be an indication that in regards to the level of moisture content and the number of fungi counts present, there maybe a release of *Chrysogin*. There were also traces of *Equisetin* in all the dried chips and was found below the limits of detection (0.69 μg/kg) in all the samples except only in one samples from Akure South Local Government (1/9) with a concentration of 6.78 μg/kg. The variations in the result may be a result of inadequate drying during processing below optimal conditions often or weather condition, which encourages contamination by fungi.

Metabolites from other fungal genera include *Monocerin, abscisic acid, Anhydrofulvic acid, Chloramphenicol*, and *Lecanoric acid*. *Monocerin* is a polyketide metabolite isolated from several fungal species showing antifungal, phytotoxic, insecticidal, and plant pathogenic properties (Nichea, Palacios, & Chiacchiera, 2015). *Monocerin* compounds were below the detectable limits (0.06 μg/kg) in all the dried plantain chips from the solar tent-dried and open sun-dried samples but were detected in dried chips collected from Akure South (4/9 samples) and Idanre (6/21 samples) Local Government with a concentration of 9.03 and 2.81 μg/kg respectively. Akure South had the highest level of the *Monocerin* compounds. *Abscisic acid*, which is a *phytotoxin* (product of plant pathogens), was detected in all the dried chips with concentrations ranging from 499 to 1355 μg/kg (Akure South plantain chips has the lowest and that of Idanre the highest). *Abscisic acid* is a naturally occurring compound known in its roles in various aspects of plant growth, development, and responses to environmental stresses (Himmelbach, Yang, & Grill, 2003; Hirayama & Shinozaki, 2007). Thus, the *Abscisic acid* content in foods may not necessarily be of fungal origin. *Anhydrofulvic acid* was detected in solar tent-dried chips (3/10 samples), open sun-dried chips (7/10 samples), samples obtained from Akure South (2/9 samples), and Idanre (5/21 samples) with a concentration of 26.01, 29.13, 25.86, and 24.70 μg/kg respectively. Open sun-dried plantain chips had the highest value. There is a significant positive correlation between fungi count and *Anhydrofulvic* ($r = 0.91$, $p < 0.005$) (Table 2). This might leads to the production of *Anhydrofulvic* in regards to the number of fungi counts and level of moisture content in the samples. *Chloramphenicol* compounds (a bacterial metabolite) exhibits below the detectable limits (0.03 μg/kg) in all solar tent-dried and open sun-dried plantain chips, but was detected in samples obtained from Akure South (1/9 sample) and Idanre (9/21 samples) with a concentration of 0.40 and 0.93 μg/kg respectively. Moisture content, fungi counts and *Chloramphenicol* were positively correlated, but only fungi counts and *Chloramphenicol* were significantly correlated ($r = 0.24$ and 0.70, $p < 0.05$) (Table 2). This might be an indication of high moisture content found in the open sun-dried plantain chips (Akure South and Idanre Local Governments), which might have contributed to the production of *Chloramphenicol* in regards to fungi counts. *Lecanoric acid* (produced by lichens) was detected in solar tent-dried chips (3/10), open sun-dried chips (3/10), samples obtained from Akure South (7/9 samples) and Idanre (9/21 samples) with a concentration of 4.69, 3.44, 16.65, and 13.05 μg/kg respectively. Dried plantain chips obtained from Akure South had the highest level. The variations may be a result of poor hygienic practices, which may facilitate fungal growth and may subsequently lead to toxin production in the dried chips.

3.4. Unspecific mycotoxin metabolites of solar tent dried and opened sun-dried plantain chips

The unspecific metabolites [*Asperglaucide, Asperphenamate, Citreorosein, Dihydroxymellein, Cyclo (L-Pro-L-Tyr), Cyclo (L-Pro-Val), Emodin, Iso-rhodoptilometrin, N-benzoyl-phenylalanine, and tryptophol*] (Table 5), are known to be produced by microbes and plants.

Asperglaucide was found in the solar tent-dried chips (7/10 samples) and had the least value (0.36 μg/kg) while that of Idanre Local Government (21/21 samples) had the highest values (379 μg/kg) of all the unspecified metabolites. *Asperglaucide* was also found in the open sun-dried chips (5/10 samples) with a concentration of 0.46 μg/kg and all the dried chips from Akure South (9/9 samples) with a level of 364 μg/kg. *Asperglaucide* is reported to have an anti-inflammatory effect and the ability to inhibit cysteine peptidase (Nilsson et al., 2015). *Asperphenamate* was below the limits of detection (0.39 μg/kg) in the solar tent-dried and open sun-dried plantain chips but was detected in all the samples obtained from Akure South (9/9 samples) (146 μg/kg) and Idanre (21/21 samples) (323 μg/kg) Local Governments. *Citreorosein* compound also exhibits below the detectable limits (0.74 μg/kg) in a solar tent-dried and open sun-dried plantain chips, but was detected in some of the samples obtained from Akure South (5/9 samples) with a concentration of 8.84 μg/kg, and had the highest value, and Idanre (5/21 samples) (6.21 μg/kg). Thus, a significant positive correlation exists between fungi counts and *Citreorosein* and was significant ($r = 0.79$, $p < 0.05$) (Table 2). The significant correlation between the fungi counts and *Citreorosein* might be attributed to an increase in moisture content found in the dried plantain chips (obtained from Akure South and Idanre Local Governments), which might have contributed to the production of *Citreorosein*.

Dihydroxymellein was detected in some of the chips from the solar tent-dried (2/10), open sun dried (3/10), samples obtained from Akure South (7/9 samples), and Idanre (14/21 samples) with a concentration of 9.68, 10.11, 469 and 75 μg/kg respectively. However, solar tent-dried chips had the least concentration followed by open sun-dried chips, while Akure South had the highest level. *Cyclo (L-pro-L-Tyr)* and *Cyclo (L-pro-Val)* compounds were predominant of *Alternaria* spp, which exhibits below the detectable limits (1.17 μg/kg) in all the solar tent-dried and open sun-dried chips. *Cyclo (L-Pro-L-Tyr)*, or *Maculosin*, is a *diketopiperazine* formed by the fusion of tyrosine and proline that has been reported as a secondary metabolite of various fungi and bacteria on knapweed (Stierle, Cardellina, & Strobel, 1998). *Cyclo (L-pro-L-Tyr)* was detected in some of the samples collected from Akure South (5/9 samples) and Idanre (13/21 samples) with a concentration of 7.81 and 7.86 μg/kg, respectively. Related to *Cyclo (L-Pro-L-Tyr)* is another *diketopiperazine* known as *Cyclo (L-Pro-L-Val)*, which is formed by the fusion of valine and proline (Capon, Stewart, Ratnayake, Lacey, & Gill, 2007). *Cyclo (L-pro-Val)* compounds were found in Akure South (3/9 samples) and Idanre (6/21 samples) with a concentration of 5.43 and 6.16 μg/kg, respectively. Thus, a strong significant positive correlation ($r = 0.77$, $p < 0.05$) exists between *Cyclo (L-pro-Val)* and total microbial counts (Table 2). This might be attributed to the high level of moisture present in the dried plantain chips, which might have contributed to the production of *Cyclo (L-pro-Val)*.

Emodin is a natural compound belonging to the *Anthraquinone* family, which occurs naturally either in a free state or combined with sugar in a glucoside, and other plants (Ma et al., 2012). *Emodin* compound was found in some of the solar tent-dried chips (2/10 samples), open sun-dried chips (3/10 samples), and dried chips collected from Akure South (7/9 samples) and Idanre (8/21 samples) with a concentration of 0.60, 0.60, 1.58, and 0.94 μg/kg respectively. However, dried chips from Akure South had the highest concentration. *Emodin* has been found to have many health benefits, including antitumor effects on human cells (Ma et al., 2012). So, *Emodin* content in foods may not necessarily be of fungal origin (Mueller et al., 1999). *Iso-rhodoptilometrin* compound exhibits below the limits of detection (0.03 μg/kg) in all the solar

tent-dried and open sun-dried chips but was detected in some of the dried chips collected from Akure South (4/9 samples) and Idanre (3/21 samples) with a concentration of 0.46 and 0.24 μg/kg respectively. *N-benzoyl-phenylalanine* was below the limits of detection (0.15 μg/kg) in all the dried chips,including the samples from the processors (Akure South and Idanre Local Governments). *Tryptophol* compound is an aromatic alcohol that induces sleep in humans and is produced by many microbial species (Cornford, Bocash, Braun, Crane, & Oldendorf, 1979). This compound was detected in some of the chips from the solar tent-dried (5/10 samples), open sun-dried chips (4/10 samples), and all samples obtained from Akure South and Idanre Local Government with a concentration of 61, 86, 35.19, and 40.32 μg/kg respectively. Open sun-dried chips had the highest concentration, while samples from Akure South had the least concentration. The variations in the concentration may be a result of process handling, and environmental conditions (temperature, relative humidity, insect infestation), which may be conducive for mycotoxin production in samples.

The selection of other metabolites (*Ochratoxin A, Fumonisin B1, Fumonisin B2, Zearalenone, T-2 Toxin, HT-2 Toxin, Deoxynivalenol, Mycophenolic acid, Sterigmatocystin, Chanoclavin, Citrinin, Alternariol,* and *Alternariolmethylether*) limit of detections ranged from 0.08 to 2.40 μg/kg. The regulated mycotoxins are *Ochratoxin A, Fumonisin B1, Fumonisin B2, Zearalenone, Citrinin,* the type *A and B Trichothecenes* which are *T-2* and *HT-2* toxins and *Deoxynivalenol* respectively, while *Mycophenolic acid*, *Sterigmatocystin*, *Chanoclavin*, *Alternariol*, and *Alternariolmethylether* are considered as non-regulated mycotoxins (Gruber-Dorninger et al., 2019; Panasiuk, Jedziniak, Pietruszka, Piatkowska, & Bocian, 2019). They were all below the detectable limits with the equipment used in all the dried chips. This implies that consumers of dried plantain chips in the study area might not be exposed to regulated mycotoxin contamination.

4. Conclusions

This study showed that the consumers of dried plantain chips in Nigeria (Ondo State) might not be too exposed to aflatoxin contamination. Despite that Idanre Local Government of Ondo State is a rural area, lower levels of some of the mycotoxin metabolites were found on the plantain chips obtained from their processors when compared to plantain chips from Akure south Local Government, which is an urban area. The solar tent-dryer is safe in terms of mycotoxin profiling since it provides plantain chips with less concentration for the emerging and other non-regulated mycotoxins than the opened sun-drying. As considers mycotoxins addressed by regulatory limits, the contamination of the investigated samples is remarkably low in comparison to some numerous studies on grains, nuts, cassava, and processed foodstuffs from Sub-Saharan Africa. However, plantain chips are much safer than many other agricultural commodities as considers mycotoxins. Thus, this study recommends the enlightenment and awareness of solar tent-dryer in drying plantain chips and other agricultural products to improve the safety of food during processing and preservation for human consumption among the local processors in the study areas and Nigeria as a whole.

Funding

This work was supported by the Consultative Group for International Agricultural Research (CGIAR) Roots, Tubers, and Bananas Project.

CRediT authorship contribution statement

A. Adenitan Ayodele: Conceptualization, Data curation, Investigation, Methodology, Writing - original draft. **Awoyale Wasiu:** Conceptualization, Data curation, Investigation, Methodology, Writing - review & editing. **A. Akinwande Bolanle:** Conceptualization, Data curation, Investigation, Methodology, Writing - review & editing, Conceptualization, Data curation, Investigation, Methodology, Funding acquisition, Project administration, Resources, Writing - review & editing. **Sulyok Michael:** Formal analysis, Investigation, Methodology, Data curation, Validation, Writing - review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgments

The authors will like to acknowledge the Food and Nutrition Sciences Laboratory staffs of the International Institute of Tropical Agriculture (IITA), for their contribution to sample preparation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2020.107467.

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