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Occurrence of zearalenone in maize and millet grains and their derived porridges marketed in Abidjan (Côte d'Ivoire)

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ABSTRACT

Zearalenone is an endocrine-disrupting mycotoxin commonly found in cereals. The objective of this work was to evaluate zearalenone levels in maize and millet grains, and their porridges to measure the impact of the preparation processes of these porridges on the occurrence of zearalenone. The sampling was realized according to the regulation (EC) No 401/2006 of the European commission. Zearalenone concentration in commodities was determined using HPLC/UV. Zearalenone concentrations were compared with the Maximum Tolerable Limits (MTLs) of zearalenone established by European Union (EC) No1881/2006. The average zearalenone levels in the grains were 82.83 µg/Kg (maize) and 141.88 µg/Kg (millet). These levels were below the MTL in the case of maize, and above the MTL concerning millet. Average zearalenone levels in porridges were 11.70 µg/Kg < MTLs (maize) and 36.16 µg/Kg > Infant Maximum Tolerable Limit (IMTL) of millet. Zearalenone concentrations in millet grains were higher than in maize grains. Zearalenone levels in maize and millet-based porridges were low compared with their respective basic commodities. The processing techniques used for porridges, removed 85.88-93.67% of zearalenone from maize, and 74.51-76.66% of zearalenone from millet. Despite this significant reduction, the average zearalenone content in millet-based porridge was above the IMTL (20 µg/Kg).

Keywords: Zearalenone; Maize; Millet; Porridge; Abidjan.

INTRODUCTION

Zearalenone or Toxin F-2, is a mycotoxin produced by *Fusarium* species such as *Fusarium graminearum*, *Fusarium oxysporum*, *Fusarium equisetum*, and *Fusarium nivalis* (Abbasian et al., 2018; Han et al., 2022). It is a macrocyclic lactone derived from resorcyclic acid, with the molecular formula $C_{18}H_{22}O_5$ (Gaumy et al., 2001; EFSA, 2016). This mycotoxin is common in maize, but it can also be found in many cereals such as wheat, barley, sorghum, and rye (Zinedine et al., 2007; EFSA, 2011; Boevre et al., 2012). Although it is not classified among carcinogen compounds by the International Agency for Research on Cancer (IARC, 2021),

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zearalenone is an endocrine disruptor (Bennett and Klich, 2003; Kowalska et al., 2016; Balló et al., 2023). When the mycotoxin is taken in mammals, the ketone group at the C-8' position of zearalenone may be reduced and zearalenone becomes α- and β-zearalenol, both of which have estrogen hormone-like structures (Han et al., 2022). These substances may bind to human estrogen receptors (ER-α and ER-β) in competition with 17-β-estradiol (Gaumy et al., 2001; AFSSA, 2006; Tekamura et al., 2007). Some studies show a relationship between central precocious puberty or the incidence of endometrial adenocarcinomas and the concentration of zearalenone in serum, tissues, and food, in humans (Massart et al., 2008; Pajewska et al., 2018; Ropejko and Twaruzek, 2021). Therefore, the presence of this mycotoxin in foodstuffs needs continuous monitoring because endocrine disruptors are potential reproductive impediments. Maize (*Zea mays*) and millet (*Pennisetum glaucum*) are part of the staple diet of Africans and particularly in Sub-Saharan populations (N'DA et al., 2013; Galati et al., 2014). These cereals are used in several processed products (Tankoano, 2017; Saubade et al., 2018; Loba et al., 2019). In Côte d'Ivoire, adults consume maize and millet based-porridges called "Baca" as breakfast. These porridges are a complementary food for young children (Brou et al., 2008). Despite the toxicity of zearalenone, and its frequent occurrence in cereals (maize, millet), very few studies relating to the occurrence of zearalenone in cereals have been realized in Côte d'Ivoire. In addition, data on the zearalenone occurrence in cereal-based foods such as porridges are non-existent, whereas zearalenone can persist in cooked foods due to the thermostability of this mycotoxin (Ryu et al., 2003; Khaneghah et al., 2018). The studies conducted by Sangaré-Tigori et al. (2007) revealed 50 µg/Kg of zearalenone in raw maize. However, this work involved only ten maize samples and did not take into account raw millet and cereal-based porridges. With climate change that is likely to increase the development, and modify the behavior of mycotoxigenic fungi, zearalenone levels in foods, may be increased (Zingales et al., 2022). Bamba et al. (2020), detected zearalenone at levels ranging from 8.48 µg/Kg to 341.84 µg/Kg in maize grains, cobs, and spathes. Because of the limited data related to zearalenone occurrence in raw cereals and their by-products (porridges), further investigations should be done to reinforce data highlighting the presence of zearalenone in raw cereals and their derivative products. These data might be an important asset for decision-making in the context of food security in Côte d'Ivoire, and even in the sub-region. In this context, the objective of the current study was to evaluate the level of zearalenone in raw cereals (maize and millet) and their porridges.

MATERIALS AND METHODS

Identification of porridges preparation and cooking processes

A survey was conducted in Port-Bouët and Abobo, two communes of Abidjan. The target population of the survey was made of porridge sellers. This population was chosen because they produce porridges themselves.

Sampling

Three markets of Port-Bouet (Abattoir, Wharf, and Petit Bassam) as well as two markets in the commune of Abobo (Anador and Abobo Gare), were visited during the survey. The sampling of raw cereals (millet and maize) was realized flowing European Commission Regulation (EC) No. 401/2006 (CE, 2006). As the batch size of foodstuffs was less than 50 kg, the sample weight was 1 kg. To prevent contamination, the samples were transferred into bags (STOMACHER), and then transported to the laboratory where they were stored at -6°C before analysis.

Extraction and purification

The extraction was performed according to method RP91/RP90 described by R-BIOPHARM, the manufacturer of the immunoaffinity column (R-BIOPHARM 2021).

To 25 g of sample (ground grain or porridge) introduced in 500 mL Erlenmeyer flask, 125 mL of the extraction solvent consisting of acetonitrile/ultrapure water (75/25, v/v) was added, and then the whole was vigorously homogenized for 2 minutes using mixer OMNI INTERNATIONAL (Kennesaw

GA, USA). The extract was filtered through a filter (No.4) FISHER SCIENTIFIC (Paris, France) to remove solid residues. An aliquot of 20 mL of filtrate was diluted with 80 mL of phosphate buffer VWR INTERNATIONAL (Pennsylvania, USA). The pH of this diluted solution was adjusted to pH 7.4 using 2 M sodium hydroxide MERCK (Darmstadt, Germany). A quantity of 25 mL (equivalent to 1 g of sample) of the diluted filtrate, was passed through the zearalenone-specific immunoaffinity column EASI-EXTRACT®, R-BIOPHARM (Darmstadt, Germany) at a flow rate of 2 mL/min under gravity. The column was washed at a flow rate of approximately 5 mL/min, using 20 mL of PBS. After drying the column using a vacuum pump VACUUBRAND (Vertheim, Germany), zearalenone was eluted with 1.5 mL of HPLC-gradient acetonitrile CHEM-LAB (Zedelgem, Belgium) under gravity. The eluate was collected in an amber vial and then injected into the SHIMADZU chromatographic system (Tokyo, Japan) consisting of a reservoir (TRAY), a degasser (DGU-20A5), a pump (LC-20AT), an oven (CTO- 20A), an UV/VIS detector (SPD-20A) and an auto-sampler (SIL-20A). This HPLC system was coupled to a computer Dell (Texas, USA) equipped with LAB solution software.

Zearalenone quantification

Calibration of the chromatographic system was performed using six solutions of 0 µg/L; 0.25 µg/L; 2.5 µg/L; 25 µg/L; 50 µg/L; 125 µg/L; and 250 µg/L, made of zearalenone standard (100 µg/mL) whose purity was >99.99%, SUPELCO (St Louis, USA). These solutions were injected into the chromatographic system equipped with Kromasil column 100 ODS 5µm (L= 250 cm x ID=4.6 mm) maintained at 40°C. The mobile phase consisted of acetonitrile and ultrapure water in the ratio of 80/20 (v/v) with an isocratic elution flow rate of 1mL/min. The analysis duration was set at 10 minutes while the absorption wavelength and injection volume were 274 nm and 10 µL respectively. Simple linear regression between the concentrations of the calibration solutions and their peak areas was used to establish the calibration curve and to obtain the coefficient of determination (R^2) and the probability associated with Fisher's test. The equation of the calibration curve was (**Equation 1**):

$$Y = a X + b$$

where Y: peak area;
X: concentration of zearalenone (µg/L);
a: slope ;
b: y-intercept.
Zearalenone concentrations (C0) expressed in µg/L, were determined according to **Equation 2**:

$$C_0 = (Y-b) / a$$

The recovery rate (Tr) was determined by the method of dosed additions. Indeed, 25 g of the commodity was spiked with 1 mL of the standard zearalenone (50 µg/L). After 30 min, the mycotoxin was extracted and quantified. The recovery rate was calculated according to **Equation 3** (Kpan et al., 2019):

$$\mathbf{Tr}\ (\%) = \frac{\mathbf{Cr - C_{nf}}}{\mathbf{Cest}} \times \mathbf{100}$$

where T_r: recovery rate (%);
C_r: effective zearalenone content of the fortified sample (µg/Kg);
C_{nf}: zearalenone content of the non-fortified sample (µg/Kg);
C_{est}: theoretical zearalenone content of the fortified sample (µg/Kg).
The final zearalenone concentration of each sample was determined using the **Equation 4**:

$$C_{Zea} = (C_0 \times V_f \times F) / (M \times T_r)$$

where
C_{Zea}: zearalenone content (µg/Kg);
C_0: zearalenone content (µg/L);
V_f: final volume of the extract (L);
F: dilution factor of the eluted extract;
M: mass of the test sample (Kg);
T_r: recovery rate (%).

The limit of detection (LOD) and limit of quantification (LOQ) were determined using the signal-to-noise ratio (S/N) method. Thus, the LOD was obtained through the S/N=3 ratio while LOQ was determined from the S/N=10 ratio (ICH, 2005; Shrivastava and Gupta,

2011). The fidelity of the zearalenone analytical method was evaluated through the coefficient of variation relative to the repeatability and reproducibility, performed on the zearalenone solution (50 µg/L). This coefficient of variation was determined according to Equation 5 (Feinberg 2019):

$$CV = \frac{\sigma_{n-1}}{\bar{\chi}} \times 100$$

where
CV: coefficient of variation (%);
σ_{n-1} : standard deviation ;
$\bar{x}$: average

Evaluation of zearalenone level in commodities

Zearalenone levels in the samples were compared to the European Commission's Maximum Tolerable Limits (MTLs) (EC, 2006). According to Regulation (EC) No. 1881/2006, the maximum amount of zearalenone allowed in raw maize was set at 200 µg/Kg regardless of the age of the consumer. For raw millet, the MTL of zearalenone was set at 100 µg/Kg for all consumer age groups. For maize or millet-based porridges, the infant MTL is 20 µg/Kg and the adult MTL is 50 µg/Kg.

Statistical analyses

Descriptive statistics, Fisher's F test, and the linear regression model (calibration curve) were performed using Microsoft Excel version 2016 and XLSAT 7.5 software (Addinsoft). The threshold of the Fisher F test was set at 5%.

RESULTS

Analytical parameters

The comparison of the chromatograms of the zearalenone standards with that of the blank (acetonitrile), led to the identification of the zearalenone peak at 3.96 ± 0.20 min (Figure 1). The equation of the linear regression line between concentrations and peak areas was y = 608.44x-172.62, and the associated Fisher test probability was less than 5% ($p<0.0001$). The coefficient of determination (R^2) of the calibration curve was 0.9999. The detection method of zearalenone is therefore linear in the range of 0-250 µg/L (Figure 2).

Porridges preparation and cooking processes

A total of 40 porridge sellers were interviewed during the survey at a rate of 20 porridge sellers per commune. Three methods of preparing foodstuffs before cooking were identified in the survey. The most common method (95% of the women) consists of cleaning the grains (washing), then soaking them in water at room temperature for two days. The grains are then drained and germinated in the shade for two to three days. The humidity of the grains is maintained through small periodic waterings. After germination, the grains are sun-dried for 4 days (maize) and 6 days (millet). After drying, the grains are stripped of their rootlets before being ground and sieved to collect the flour. The other two methods are minor, as they are each practiced by 2.5% of porridge sellers. One of them consists of cleaning the grains, then spreading them in the shade at room temperature. The grains are watered 3-6 times by day for about 48 hours. Finally, the grains are crushed without sieving to obtain gruel. The other method consists of cleaning the grains, soaking them in water for 3-4 days, and grinding them to get the paste. Three cooking durations were identified, namely the durations of 60 min (CD1), 30 min (CD2), and 15 min (CD3). In the commune of Abobo, 50% of porridge sellers observed CD1, 40% of observed CD2, and CD3 observed by 10% of porridge sellers. In Port-Bouët, the CD1 was adopted by 80% of the preparers against 20% of the preparers who adopted the (CD2).

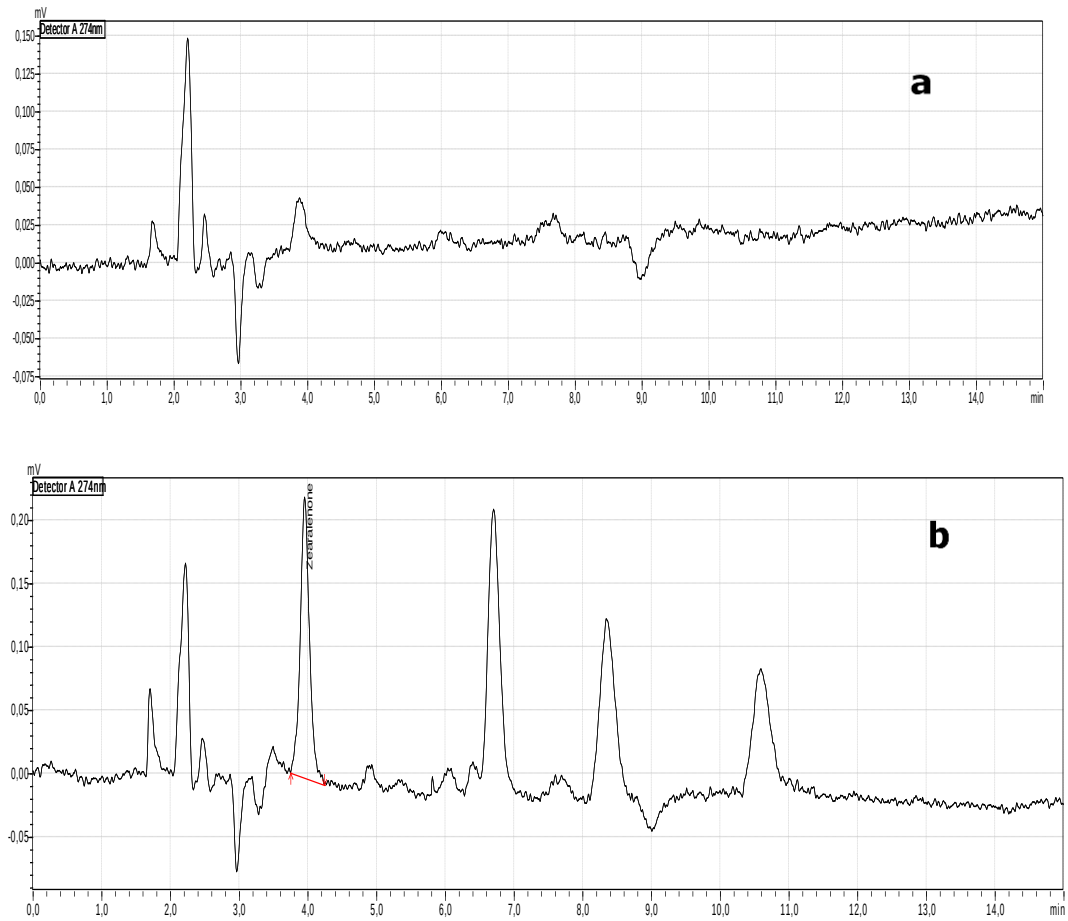
Zearalenone concentration in commodities (grains and porridges)

A total of 160 samples were analyzed at the rate of 40 samples for each type of commodity, namely maize grains, millet grains, maize-based porridge, and millet-based porridge. The results of these analyses are shown in Table 1.

Zearalenone was found in all raw commodity samples (maize grains and millet grains). The quantity of zearalenone in maize

grains fluctuated between 1.69±0.06 µg/Kg and 233.49±1.07 µg/Kg with an average content of 82.83 ± 10.07µg/Kg. The concentration of zearalenone in raw millet ranged between 10.22 ± 10.22 ± 0.08 µg/Kg and 515.59 ± 1.12 µg/Kg with an average concentration of 141.88 ± 13.78 µg/Kg. According to Friedman's test, samples of millet grains contain more zearalenone than those of maize grains ($p<0.0001$). Although, the average concentrations of zearalenone in the raw commodities were below the TMLs, it is important to underline that 5% of the maize grains samples and 70% of the millet grains samples had zearalenone concentrations higher than the TMLs. In the case of porridges, zearalenone was found in 80% of maize-based porridge samples, and in 100% of millet-based porridge samples. Zearalenone concentrations between 0.31±0.02 µg/Kg and 59.15±0.32 µg/Kg with an average of 11.70 ± 2.48 µg/Kg, were recorded in the maize-based porridge. Zearalenone concentration in millet-based porridge ranged from 2.03±0.02 µg/Kg to 102.02±0.72 µg/Kg, with an average concentration of 36.16 ± 3.89 µg/Kg. The average concentration of zearalenone in maize-based porridge was lower than the MTLs, while in the case of millet-based porridge, the concentration of zearalenone was above infant MTL (20 µg/Kg) In addition, 2.5% of maize-based porridge samples, and 27.5% of millet-based porridge samples were above the MTLs. In the same way, 25% of maize-based porridge samples, and 67.5% of millet-based samples exceeded infant MTL (Table 2).

Moreover, the zearalenone concentrations in porridges were statistically lower than those of the raw foodstuffs ($p<0.0001$). The average zearalenone contents of raw maize and millet were reduced by 85.87% and 74.51% respectively (Table 3).



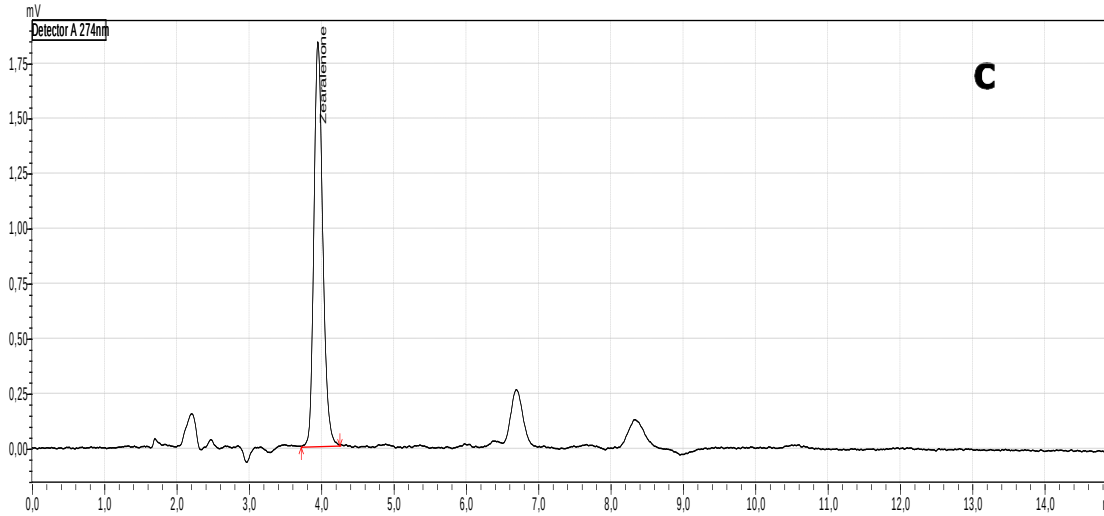


Figure 1: Chromatograms of blank and zearalenone standard a: Chromatogram of blank, b: Chromatogram of zearalenone standard (2.5 µg/L), c: Chromatogram of zearalenone (25 µg/L).

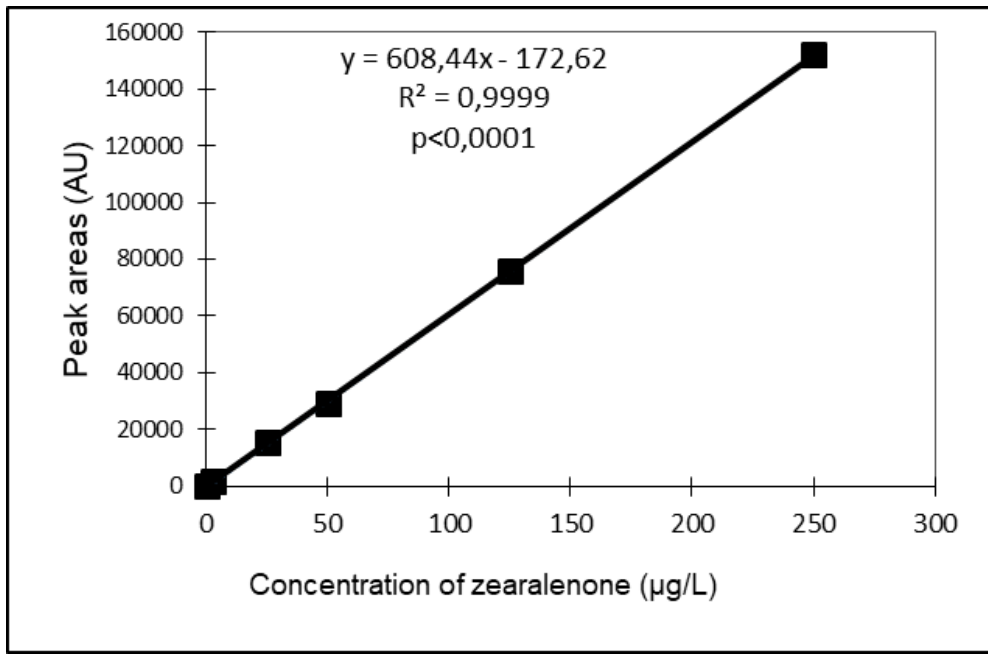


Figure 2: Calibration curve of zearalenone.

Table 1: Zearalenone levels in raw commodities and porridges.

Zearalenone in raw foodstuffs (µg/Kg)				Zearalenone in porridges (µg/Kg)			
Maize	**Millet**	**Maize**	**Millet**	**Maize**	**Millet**	**Maize**	**Millet**
89.83±0.69	82.99±0.74	162.33±0.70	84.88±0.45	26.42±0.19	23.27±0.17	6.47±0.12	21.3±0.13
39.19±0.15	73.43±0.45	169.09±0.83	81.02±0.56	59.16±0.32	32.84±0.22	4.99±0.06	86.61±0.62
62.75±0.58	57.08±0.36	1.69±0.06	87.06±0.45	29.83±0.15	55.66±0.35	5.16±0.07	102.02±0.72
82.54±0.62	53.53±0.25	17.50±0.11	120.00±0.77	2.89±0.07	55.64±0.32	0.71±0.02	63.29±0.34
174.37±0.85	106.67±0.66	50.85±0.33	138.08±0.75	17.09±0.12	17.80±0.13	1.04±0.03	20.46±0.15
78.66±0.73	116.40±0.73	14.82±0.10	10.22±0.08	10.44±0.08	13.23±0.10	1.12±0.04	22.52±0.18
74.88±0.55	137.39±0.82	7.94±0.07	142.43±0.75	ND	17.76±0.16	2.19±0.05	41.62±0.26
59.13±0.41	93.66±0.64	17.91±0.13	139.17±0.64	13.36±0.05	28.14±0.17	3.56±0.04	63.47±0.35
35.80±0.17	108.61±0.77	4.56±0.04	515.59±1.12	ND	83.59±0.64	1.33±0.03	45.54±0.33
30.48±0.11	184.92±0.83	36.29±0.15	127.87±0.65	7.27±0.04	12.14±0.07	3.68±0.02	79.11±0.42
32.40±0.17	127.05±0.86	50.19±0.31	29.83±0.15	45.10±0.22	12.93±0.08	46.01±0.22	47.09±0.22
107.13±0.74	184.66±0.87	30.22±0.14	211.24±0.83	27.43±0.16	57.49±0.28	40.45±0.24	19.42±0.19
67.01±0.36	235,47±0,91	56.48±0.36	173.94±0.74	ND	36.85±0.21	0.79±0.04	45.92±0.31
38.35±0.19	176.70±0.87	12.95±0.10	211.24±0.85	ND	10.20±0.05	1.47±0.06	15.11±0.12
105.81±0.72	213.25±0.85	75.96±0.64	116.96±0.69	32.03±0.24	7.48±0.04	2.33±0.05	48.21±0.35
170.46±0.83	90.60±0.63	91.21±0.68	240.03±0.78	22.57±0.19	9.21±0.06	ND	39.64±0.32
70.02±0.51	126.61±0.76	183.59±0.75	248.52±0.89	10.57±0.06	11.31±0.08	ND	53.67±0.29
145.12±0.64	142.94±0.79	224.83±0.79	240.47±0.76	ND	31.06±0.17	5.92±0.04	52.71±0.27
233.49±1.07	112.03±0.68	157.62±0.76	209.52±0.88	ND	2.03±0.02	5.48±0.04	23.81±0.17
170.03±0.89	112.24±0.57	79.85±0,54	10.79±0.08	30.92±0.21	11.43±0.14	0.31±0.02	24.59±0.15

LD=0,25 µg/Kg; LQ= 0,75 µg/Kg; the uncertainty on each value was calculated for three (03) repetitions (n=3)
Uncertainty = Standard deviation /$(n)^{1/2}$ **;** ND : not detected

Tableau 2: comparison of zearalenone levels in foodstuffs with MTLs.

Zearalenone (µg/kg)	**Maize grain (n=40)**	**Millet grain (n=40)**	**Maize-based porridge (n=40)**	**Millet-based porridge (n=40)**
Minimum	1.69	10.22	0.31	2.025
Median	68.51	126.83	4.34	29.60
Average	82.83< (IMTL= AMTL=200)	141.88< (IMTL = AMTL =100)	11.70<(AMTL =50 IMTL =20)	(AMTL =50)<36.16 > IMTL =20
Maximum	233.49	515.59	59.15	102.02
Occurrence (n ; %)	40(100)	40(100)	32(80)	40(100)
Sample (n ; %) > AMTL[1] EU*	2(5)	28(70)	1(2.5)	11(27.5)
Sample (n ; %) > IMTL[2] UE*			10(25)	27(67.5)

* European Union; [1]Maximum Tolerable Level of zearalenone in infant foods;
[2] Maximum Tolerable Level of zearalenone in infant foods

Table 3: comparison of zearalenone levels in grains and porridges.

Concentration of zearalenone (µg/Kg) n = 40		
	Maize	Millet
Raw commodity (grain)	82.83± 10.07	141.88±13.78
Porridge	11.7±2.48	36.16± 3.89
p value of Friedman test	<0.0001	<0.0001
Reduction rate (%)	85.88	74.51

DISCUSSION

Analytical parameters

The relatively short retention time of 3.96 ± 0.20 min compared to that of 6.4 min (Ok et al., 2014), saves solvent and maximizes the quantity of sample that can be analyzed in a short time. The recovery rate (109.42%), the LOD (0.25 µg/Kg), and LOQ (0.75 µg/Kg) were suitable for zearalenone determination since MTLs (CE, 2006) were above the LOD and LOQ. In addition, the LOD and LOQ were low compared with the values of LOD = 2.5 µg/Kg and LOQ =8.3 µg/Kg obtained by Ok et al. (2014) in their works related to the determination of zearalenone in noodles, cereal snacks, and infant formula, using HPLC. The coefficients of variation (CV) related to repeatability and reproducibility were 1.44% and 1.09%, respectively. These coefficients of variation are within the 5% margin recommended by the European Commission (CE, 2002).

Porridges preparation and cooking processes

The cooking duration is not linked to the nature of the porridge. It is not also related to the porridge processing method used. It only varies according to the porridge makers. These preparation methods are similar to those mentioned by Brou et al. (2008).

Zearalenone concentration in commodities (Grains and porridges)

Concerning the occurrence of zearalenone in raw maize, two major studies had been carried out in Côte d'Ivoire (Sangaré-Tigori et al., 2006; Bamba et al., 2020). In the investigations of Sangaré-Tigori et al. (2006), 50 µg/Kg of zearalenone was found in each of the ten (10) samples of raw maize analyzed. Compared with our data, the concentrations of zearalenone we found where higher than those of Sangaré-Tigori and collaborators. The difference in concentration might be due to the small size of the samples (n=10) used by Sangaré-Tigori and collaborators whereas our studies were carried out on 40 samples. Furthermore, our results corroborate those of Bamba et al. (2020) who indeed reported the presence of zearalenone in maize grains collected in the regions located in the Center, North, Center-North, East, and North-East of Côte d'Ivoire, with zearalenone concentrations between 8.48±0.25 µg/Kg and 173.10±7.75 µg/Kg. The presence of zearalenone in these foodstuffs could be explained by the development of molds caused by the bad agricultural practice observed by actors involved in the cereal sector. Indeed, one study carried out in three major maize production areas in Côte d'Ivoire showed that the majority of producers (97%) use traditional storage methods. This study also established a correlation between these storage methods and the development of mycotoxin-secreting fungi (Niamketchi et al., 2015). The reduction in the quantities of zearalenone in the porridges might be explained by the effect of grain washing and cooking. The preliminary washing of the grains before the other stages of the porridge manufacturing process was

observed by 95% of the actors. By removing coarse and fine waste from grains, zearalenone might probably be eliminated. Concerning cooking, many authors present zearalenone as a heat-stable mycotoxin. However, this stability is not absolute. It depends on factors such as the nature of the medium (aqueous or organic), the heating temperature range, the pH of the medium, and the duration of heating (Bullerman and Bianchini, 2007; Numanoglu et al., 2013; Gauthier, 2016). For example, in an aqueous medium, the degradation rate of zearalenone fluctuates between 23% and 92% when the temperature is 150°C and 225°C respectively at pH (4.7 and 10), with heating time ranging from 30 min to more than 60 min (Ryu et al., 2003). Since 50-80% of porridge makers fulfilled some of these conditions such as aqueous media and cooking duration (60 min); so cooking may have contributed to a reduction in the concentration of zearalenone. The simultaneous presence of zearalenone in raw commodities (maize grains and millet grains) and their porridges confirms that the processes of transforming raw commodities into directly consumable products can contribute to a reduction in the concentration of zearalenone in processed products. Nevertheless, zearalenone concentration in products might be sufficient to affect negatively the sanitary quality and market value of processed foods. That was the case of millet-based porridge whose average concentration of zearalenone was higher than the infant MTL defined by the European Commission

Conclusion

Zearalenone was found in both raw foodstuffs (maize gains and millet grains) and porridges. The prevalence of mycotoxin was 100% for raw commodities. In addition, 5% to 70% of these commodities had zearalenone levels exceeding the European Commission's MTLs. Concerning porridges, the occurrence of zearalenone was 80% for maize-based porridge and 100% for millet-based porridge. Moreover, zearalenone concentration in 2.5% of maize-based porridge, and 27.5% of millet-based porridge were higher than the adult MTL. In 25% maize-based porridge and 65.5% millet-based porridge, zearalenone concentration exceeded the infant MTLs. In both grain and porridge, zearalenone levels were higher in millet compared to maize. There was a considerable reduction in zearalenone levels when the raw commodities were transformed into porridge. Nevertheless, the quantities of zearalenone found in many of the porridge samples, especially in the millet-based porridge were higher than the MTLs. This situation might be problematic for consumers in general, and especially children.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

KKGK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing review & editing; PM: Conceptualization, Data curation, Formal analysis, Methodology; YBBDH: Writing original draft, Visualization; MO: Data collection, writing original draft; ST: Conceptualization, Methodology, Supervision; AD: Conceptualization, Methodology, Supervision.

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REFERENCES

Abbasian N, Momtaz S, Baeeri M, Navaei-Nigjeh M, Hosseini R, Abdollahi M. 2018. Molecular and Biochemical Evidence on the Role of Zearalenone in Rat Polycystic Ovary. *Toxicon.*, **154**: 7-14. DOI: https://doi.org/10.1016/j.toxicon.2018.07.022

Balló A, Busznyákné SK, Czétány P, Márk L, Török A, Szántó Á, Máté G. 2023. Estrogenic and Non-Estrogenic Disruptor Effect of Zearalenone on Male Reproduction: A Review. *International Journal of Molecular Sciences*, **24**(2):

1578. DOI: https://doi.org/10.3390/ijms24021578

Bamba S, Biego HMG, Ake AY, Coulibaly A. 2020. Assessment of the Health Quality related to the presence of Ochratoxin A, fumonisin B1 and zearalenone in maize (*Zea mays* L.) produced in Côte d'Ivoire. *Asian Journal of Research in Crop Science*, **5**(3): 41-51. DOI: https://doi.org/10.9734/AFSJ/2021/v20i730323

Bennett JW, Klich M. 2003. Mycotoxins. *Clinical Microbiology Reviews*, **16**: 497-516. DOI: http://dx.doi.org/10.1128/CMR.16.3.497-516.2003

Boevre M, Mavungu JD, Landshchoot S, Audenaert K, Eeckhout M, Maene P. 2012. Natural Occurrence of Mycotoxins and their Masked Forms in Food and Feed Products. *World Mycotoxin Journal*, **5**: 207–219. DOI: https://doi.org/10.3920/WMJ2012.1410

Brou K, Gbogouri A, Ocho A, Djéni NT, Koné Y, Gnakri D. 2008. Assessment of some Chemical and Nutritional Properties of Maize, Rice and Millet Grains and their Weaning Mushes. *Pakistan Journal of Nutrition*, **7**(6): 721-725. DOI: https://doi.org/10.3923/pjn.2008.721.725

Bullerman LB, Bianchini A. 2007. Stability of mycotoxins during food processing. *International Journal of Food Microbiology*, **119**: 140-146. DOI: https://doi.org/10.1016-/j.ijfoodmicro.2007.07.035

Commission Européenne (CE). 2002. Décision de la Commission du 12 août 2002 portant modalités d'application de la directive 96/23/ce du conseil en ce qui concerne les Performances des Méthodes d'analyse et l'Interprétation des Résultats (2002/657/CE). *Journal officiel des Communautés Européennes*, p. 29.

Commission Européenne (CE). 2006. Règlement (CE) No 1881/2006 de la commission du 19 décembre 2006 portant fixation de Teneurs Maximales pour certains Contaminants dans les Denrées Alimentaires. *Journal officiel de l'Union européenne*, L 364/5, p. 20.

Commission Européenne (CE). 2006. Règlement (CE) No 401/2006 de la Commission du 23 février 2006 portant fixation des modes de prélèvement d'échantillons et des méthodes d'analyse pour le Contrôle Officiel des Teneurs en Mycotoxines des Denrées Alimentaires. *Journal officiel de l'Union Européenne*, 9.3.2006, p. 23.

EFSA. 2016. Appropriateness to set a Group Health-Based Guidance Value for Zearalenone and Its Modified Forms. EFSA Panel on Contaminants in the Food Chain (CONTAM). *EFSA Journal*, **14**(4): 4425. DOI: https://doi.org/10.2903/j.efsa.2016.4425

EFSA. 2011. Scientific Opinion on the Risks for Public Health Related to the Presence Of Zearalenone in Food. EFSA Panel on Contaminants in the Food Chain, *EFSA Journal*. **9**(6): 2197. DOI: https://doi.org/10.2903/j.efsa.2011.2197

Feinberg M. 2019. *Validation interne des méthodes d'analyse, qualité au laboratoire.* Technique Ingénieur, p. 174.

Galati A, Oguntoyinbo FA, Moschetti G, Crescimanno M. Settanni L. 2014. The Cereal Market and the Role of Fermentation in Cereal-Based Food Production in Africa, *Food Reviews International*, **30**(4): 317-337. DOI: https://doi.org/10.1080/87559129.2014.929143

Gaumy JL, Bailly JD, Burgat V, Guerre P. 2001. Zéaralénone : propriétés et toxicité expérimentale. *Revue de Médecine Vétérinaire*, **152**(3): 219-234.

Gauthier A. 2016. Les Mycotoxines dans l'Alimentation et leur incidence sur la santé. Sciences Pharmaceutiques, Thèse de l'Université de Bordeaux, France, p. 123. URL: https://du-mas.ccsd.cnrs.fr/dumas- 01315198

Han X, Huangfu B, Xu T, Xu W, Asakiya C, Huang K, He X. 2022. Research Progress of Safety of Zearalenone: A Review. *Toxins*, **14**(6): 1-19. DOI: https://doi.org/10.3390/toxins140-60386

IARC. 2021. Agents Classified by the IARC Monographs, Volumes 1-132, p. 41.

ICH. 2005. Validation of analytical procedures: text and methodology Q2 (R1), ICH Harmonised tripartite guideline, p. 18.

Khaneghaha AM, Fakhrib Y, Raeisic S, Armoon B, Sant'Ana AS. 2018. Prevalence and Concentration of Ochratoxin A, Zearalenone, Deoxynivalenol and Total Aflatoxin in Cereal-Based Products: A systematic review and meta-analysis. *Food and Chemical Toxicology*, **118**: 830-848. DOI: https://doi.org/10.1016/j.fct.2018.06.037

Kowalska K, Habrowska-Górczynska ED, Piastowska-Ciesielska WA. 2016. Zearalenone as an Endocrine Disruptor in humans. *Environmental Toxicology and Pharmacology*, **48**(2016): 141-149. DOI: http://dx.doi.org/10.1016/j.etap.2016.10.015

Kpan KKG, Kouacou KWD, Kouakou KJ-M, Yao BL, Trokourey A, Dembele A. 2019. Validation of HPLC-UV patulin determination method in traditional juices from Côte d'Ivoire. *European Scientific Journal*, **15**(36): 253-266. DOI: http://dx.doi.org/10.19044/esj.2019.v15n36p253

Loba SE, Gbakayoro JB, Kouame KA, Grodji GA, Brou K. 2019. Formulations de Farines Composées dont l'une à base de riz (*Oryza sativa*) et l'autre à base de maïs (*Zea Mays*) pour enfants en âge de sevrage. *European Scientific Journal*, **15**: 100-116. DOI: http://dx.doi.org/10.19044/esj.2019.v15n33p100

Massart F, Meucci V, Saggese G, Soldani G. 2008. High growth rate of girls with Precocious Puberty Exposed to Estrogenic Mycotoxins. *Journal of Pediatrics*, **152**(5): 690-695. DOI: http://dx.doi.org/10.1016/j.jpeds.2007.10.020

Niamketchi L, Chatigre O, Amane D, Nyamien Y, N'Tchobo F, Ezoua P, Kouame D, Biego G.H. 2015. Descriptive study of Maize Storage Methods (*Zea Mays*) used in Rural Environment in three zones of Côte d'Ivoire. *Global Advanced Research Journal of Agricultural Science*, **4**(10): 663-672. URL: https://www.researchgate.net/profile/Godi-Biego/publication/283212337.

N'Da H A, Akanvou L, Kouakou CK. 2013. Gestion Locale de la Diversité Variétale du maïs (*Zea mays* L.) violet par les Tagouana au Centre-Nord de la Côte d'Ivoire, *International Journal of Biological and Chemical Sciences*, **7**(5): 2058-2068. DOI: http://dx.doi.org/10.4314/ijbcs.v7i5.23

Numanoglu E, Yener S, Gökmen V, Uygun U, Koksel H. 2013. Modelling Thermal Degradation of Zearalenone in Maize Bread during baking. *Food Additives & Contaminants, Part A*, **30**(3): 528-533. DOI: http://dx.doi.org/10.1080/19440049.2012.751629

Ok HE, Choi S-W, Kim M, Chun HS. 2014. HPLC and UPLC methods for the Determination of Zearalenone in Noodles, Cereal Snacks and Infant Formula. *Food Chemistry*, **163**(15): 252-257. DOI: https://doi.org/10.1016/j.foodchem.2014.04.111

Pajewska M, Lojko M, Cendrowski K, Sawicki W, Kowalkowski T, Buszewski B, Gadzała-Kopciuch R. 2018. The Determination of Zearalenone and its Major Metabolites in Endometrial Cancer Tissues. *Analytical and Bioanalytical Chemistry*, **410**: 1571-1582. DOI: https://doi.org/10.1007/s00216-017-0807-7

R-BIOPHARM. 2021. Immunoaffinity columns (EASI-EXTRACT® ZEARALENONE) for use in Conjunction with HPLC or LC-MS/MS. 91RP90/V21/01.10.21, p.16.

Ropejko K, Twaruzek M. 2021. Zearalenone and its Metabolites-General Overview, Occurrence and Toxicity. *Toxins*, **13**(35): 1-12. DOI: https://doi.org/10.3390/toxins1301-0035

Ryu D, Hanna MA, Eskridge KM, Bullerman LB. 2003. Heat Stability of Zearalenone in an Aqueous Buffered Model System. *Journal of Agricultural and Food Chemistry*, **51**: 1746-1748. DOI: https://doi.org/10.1021/jf0210021

Sangaré-Tigori B, Moukha S, Kouadio HJ, Betbeder A-M, Dano DS, Creppy EE. 2006. Co-occurrence of Aflatoxin B1, Fumonisin B1, Ochratoxin A and Zearalenone in Cereals and Peanuts from Côte d'Ivoire, *Food Additives & Contaminants*, **23**(10): 1000-1007. DOI: https://doi.org/10.1080/02652030500415686

Saubade F, Humblot C, Hemery YM, Guyot J-P. 2017. PCR Screening of an African Fermented Pearl-Millet Porridge Metagenome to Investigate the Nutritional Potential of its Microbiota. *International Journal of Food Microbiology*, **244**: 103-110. DOI: https://doi.org/10.10-16/j. ijfoodmicro.2016.12.020.

Shrivastava, A., & Gupta, B.V., (2011). Methods for the Determination of Limit of Detection and Limit of Quantitation of the Analytical Methods. *Chronicles of Young Scientists*, **2**(1): 21-25. DOI: https://doi.org/10.4103/2229-5186.79345

Takemura H, Shim J-Y, Sayama K, Tsubura A, Zhu BT, Shimoi K. 2007. Characterization of the Estrogenic Activities of Zearalenone and Zeranol Invivo and Invitro. *The Journal of Steroid Biochemistry and Molecular Biology*, **103**: 170-177. DOI: https://doi.org/10.10-16/j.jsbmb.2006.08.008

Tankoano A, Diop MB, Sawadogo-Lingani H, Kaoré D, Savadogo A. 2017. Les Aspects Technologiques, Microbiologiques et Nutritionnels des Aliments Fermentés à base de lait et de mil en Afrique de l'Ouest. *International Journal of Advanced Research*, **5**(8): 1509-1526. DOI: https://doi.org/10.21474/IJAR01/5211

Zinedine A, Miguel SJ, Carlos MJ, Jordi M. 2007. Review on the Toxicity, Occurrence, Metabolism, Detoxification, Regulations and Intake of Zearalenone: An oestrogenic mycotoxin. *Food and Chemical Toxicology*, **4**: 1-18. DOI: https://doi.org/10.10-16/j.fct.2006.07.030

Zingales V, Taroncher M, Martino, PA., Ruiz, MJ, Caloni, F. 2022. Climate Change and Effects on Molds and Mycotoxins. *Toxins (Basel)*, **14**(7): 1-13. DOI: https://doi.org/10.3390-/oxins14070445