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CYANOGENIC ANALYSIS, MOISTURE ASSESSMENT, AND COLOR EVALUATION IN CASSAVA PRODUCTS FROM ZAMBIA

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Abstract: Cassava (Manihot esculenta Crantz) stands out as one of the most widely cultivated root crops worldwide, playing a vital role as a primary calorie source for a significant portion of the African population. In 2014 alone, over 145 million tonnes of cassava were harvested from approximately 17 million hectares of land across Africa, highlighting its immense agricultural significance. Recognized for its high dietary carbohydrate content, cassava exhibits exceptional adaptability to various ecological conditions, making it a resilient and versatile food crop. This paper provides an overview of cassava cultivation, emphasizing its importance in African agriculture and its nutritional contributions to food security.
Keywords: Cassava, Manihot esculenta, root crop, food security, Africa.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the most extensively cultivated root crop globally, serving as a significant calorie source for approximately two-fifths of the African population (Nweke et al., 2002). The year 2014 witnessed the harvesting of more than 145 million tonnes of cassava across 17 million hectares of land on the African continent (FAOSTAT, 2017). Renowned for its substantial dietary carbohydrate content, this notable food crop demonstrates remarkable adaptability to diverse ecological conditions (Alamu et al., 2019).

In Zambia, it is the second most important crop for food security, after maize (Abass, 2008). According to the CODEX (FAO/WHO, 2020), the recommended moisture content for cassava roots is 10 to 13%. However, due to their high moisture content, cassava root has a low postharvest life of less than 72 h. Among various contributing factors, a primary factor promoting mould contamination of cassava flour is initial high relative humidity or an increase in moisture level during storage (Chukwu and Abdullahi, 2015).

The processing of cassava root into various forms, such as flour, chips, and pellets, not only extends its shelf life but also promotes trade and encourages commercial use, as highlighted by Gacheru et al. (2015). High-quality cassava flour (HQCF) is distinguished by its white appearance, unfermented state, and inherent gluten-free nature. These defining characteristics hold significance in the food industry, particularly in pasta and confectionery production, as noted by Taiwo (2006) and Shittu et al. (2008). The color of food plays a critical role that many consumers consider when assessing quality, and it can be influenced by the various methods employed in the preparation of dried cassava products, such as chips and flour (Gacheru et al., 2015). Cassava naturally contains two cyanogenic glucosides (CNGs), lotaustralin (methyl linamarin), and linamarin, which function as defense mechanisms against herbivores or in response to damage to cassava tissue. These compounds, upon hydrolysis, transform into hydrocyanic acid (HCN), associated with cases of acute cyanide poisoning, goiter, and chronic pancreatitis in humans (JECFA, 2010). The primary cyanogen in cassava is linamarin, also referred to as cyanogenic glucoside. These cyanogenic glucosides are widely distributed throughout the plant, with higher

concentrations in the outer root layer (root cortex) and lower concentrations in the inner root (root parenchyma) (Cardoso et al., 2005). Cyanogenic glycosides have the potential to induce acute poisoning in humans and contribute to various chronic conditions linked to the consumption of poorly processed cassava products.

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established health-based guidance values (HBGVs) for cyanogenic glycosides, which include an Acute Reference Dose (ARfD) of 0.09 mg kg^{-1} body weight in cyanide equivalents and a Provisional Maximum Tolerable Daily Intake (PMTDI) of 0.02 mg kg^{-1} body weight as cyanide (JECFA, 2010). Cyanide obstructs cellular respiration in aerobic organisms by impeding oxygen uptake (Marziaz et al., 2013). To ensure safety, the World Health Organization (WHO) has set the acceptable limit for cyanide in dried cassava products at 10 mg kg^{-1} (FAO/WHO, 2020). The East African Standards EAS 739:2010 and 740:2010 also establish the hydrogen cyanide (HCN) limit at 10 mg kg^{-1} (EAS, 2010). Additionally, JECFA (2010) has specified that edible cassava flour is considered suitable for direct human consumption only if the "total hydrocyanic acid" level in the flour remains below 10 mg kg^{-1}. Hydrogen cyanide (HCN) poisoning can manifest in both acute and chronic forms. Acute exposure to low cyanide levels, whether through inhalation, skin contact, or ingestion, results in rapid breathing, increased heart rate, restlessness, dizziness, weakness, headache, and nausea/vomiting within minutes (Mburu, 2013). On the other hand, chronic exposure to low cyanide levels can lead to breathing difficulties, eye irritation, chest or heart pain, vomiting, appetite loss, headaches, nosebleeds, goiter, and potential fatalities. Tropical Ataxic Neuropathy (TAN) is a progressive syndrome associated with dietary cyanide exposure from poorly processed cassava, primarily affecting older adults (CCDN News, 2008). Survivors of chronic cyanide exposure may experience brain and heart damage, and in some cases, central nervous system injury due to prolonged oxygen deprivation (Baskin et al., 2004). An increase in ataxic polyneuropathy cases was reported in Ososa, Southwest Nigeria: 22/1000 in 1969, 60/1000 in 1998, and 64/1000 in 2003; linked to cyanide poisoning from cassava products (Oluwole et al., 2013). In the town of Zaria in the metropolis of Nigeria, insufficient processing of cassava roots into garri has been associated with vision impairment due to prolonged cyanide consumption, contributing to elevated rates of blindness and severe visual impairment (Yusuf et al., 2014). A study conducted by Siddiqi et al. (2020) identified 32 cases of Konzo, a neurological disorder resulting from the impact of HCN on the nervous system, leading to paralysis (WHO, 1996). These cases were observed in the western and northwestern regions of Zambia, primarily affecting children between the ages of 6 and 14, with a higher prevalence among females above 14 years old. Among the affected individuals, cassava consumption was identified as the most prevalent dietary factor (Siddiqi et al., 2020). Konzo has also been documented in Tanzania, the Democratic Republic of the Congo, the Central African Republic, and Cameroon, as reported in studies by Howlett et al. (1990), Tylleskar et al. (1992, 1994), and Lantum (1998). Investigations from these regions consistently link Konzo to prolonged intake of cyanogens from cassava flour and chips at sub-lethal levels. Another study conducted in Zambia's Luapula province, Mansa district, by Chisenga et al. (2019), revealed that various cassava root and flour varieties had HCN content ranging from 27.60 to 238.12 mg kg^{-1}.

The primary objective of this study was to assess the visual attributes, moisture content, and cyanogenic glucoside concentration of cassava products commonly consumed in Zambia. Anticipating variations in visual attributes, moisture content, and cyanogenic glucoside concentration among different product types and regions due to differences in processing and storage conditions, this study is, to our knowledge, the first to compare samples collected from both significant cassava-growing and consuming areas throughout Zambia.

MATERIALS AND METHODS

Study sites

This study was conducted in seven districts in Zambia, including Mansa, Samfya, Kabompo, Serenje, Kaoma, Lusaka, and Kasama. These districts were selected based on high cassava farming activities and consumption. The choice of these districts was guided by data from the Central Statistics Office (CSO) and insights from Postharvest Surveys conducted in 2014 and the Smallholder Enterprise and Marketing Program (SMEMP) report from 2004. Both sources identified these specific regions as exhibiting the highest levels of cassava production within Zambia. Lusaka district was included because it is a significant consumer of processed cassava products and receives them from all provinces (CSO, 2014; SHEMP, 2003).

Sampling

One hundred and two samples of cassava products were collected from the seven selected districts of Zambia. These samples were randomly collected from households, processors, and markets to represent all study sites comprehensively. Thirty samples were cassava chips, while the remaining 72 were cassava flour. A minimum of 250 g of each sample were collected. After collection, samples were sealed in labeled sterile brown paper bags and stored in insulated cooler boxes at room temperature to prevent contamination and moisture uptake. Samples were transported to the International Institute of Tropical Agriculture (IITA) laboratory in Lusaka, Zambia, within 24 to 48 h of collection.

The dried cassava chips were pulverized into powder using a grinder sample mill (Model: RM/519, Ramtons, China). The milled cassava flour samples were not subjected to further processing. Before analysis and storage, the samples were blended using the quartering method (Osuret et al., 2015), sealed in the labeled polyethylene bag (Ziploc), and stored at 4°C.

Determination of chemical composition

The samples' moisture content and color properties were analyzed at the International Institute of Tropical Agriculture (IITA) Laboratories, Lusaka – Zambia. However, the analyses of hydrogen cyanide were analyzed at the Food and Drugs Control Laboratories (FDCL).

Determination of moisture content

Moisture content in the dried cassava chips and flour was determined following the procedures outlined in the Association of Official Analytical Chemists (AOAC, 2012) Official method 925.10.

The infrared drying was conducted using an analyzer, the PCE-MB C Series, manufactured by Bioevopeak in Lixia district, China. Test portions were arranged in a single layer within aluminium dishes, positioned on the balance pan of the integrated balance unit with a resolution of 1 mg. The computation of moisture content was performed automatically employing Equation 1:

$$Moisture\ Content\ (\%) = \frac{\text{Initial weight (m0)} - \text{Dry weight (m)}}{\text{Initial weight (m0)}} \times 100 \quad (1)$$

Determination of color parameter

The CIE L*a*b* method was used to measure the color parameter of cassava products. The surface testing colorimeter used (CSM 1, PCE Instruments UK Ltd., Old Trafford, Manchester, United Kingdom) quantified L*, representing lightness, with values closer to 100 indicating a whiter color. Color readings from various locations on dried cassava samples were measured in duplicate, and the average value was recorded. The meter was calibrated using a standard white background (L* = 99.98, a* = +24.73, and b* = +0.79*). The total color

difference from the standard was defined using the guidelines provided (Morrison and Laignelet, 1983) as ΔE. The computation of ΔE is articulated by Equation 2:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}. \quad (2)$$

Furthermore, the determination of the whiteness index followed the methodology established by Zhu et al. (2016), with its calculation defined by Equation 3:

$$\text{White Index (WI)} = 100 - [(100 - L)^2 + a^2 + b2]^{1/2} \quad (3)$$

Hydrogen cyanide content

Both qualitative and quantitative methods were applied to assess the HCN content of the dried processed cassava products, using the AOAC method (2019), where qualitative methods were used for the detection of HCN presence, while quantitative methods allowed for the precise measurement of HCN concentration.

Qualitative method (Quiacum test): A strip of filter paper was dipped into a 0.2% alcoholic solution of quiacum resin and then immediately into a 0.1% solution of copper sulphate. The filter paper was held over the cassava sample, suspended in a vessel containing at least 20 g of the sample. The presence of HCN in the cassava samples produced an immediate bluish-violet color on the filter paper. Results were recorded as positive or negative, depending on the color change.

Quantitative method: A total of 20 g of the cassava sample was mixed with 200 ml of distilled water in a distillation flask and left to stand for at least 4 h. The mixture was then distilled, and approximately 160 ml of the distillate was collected in a volumetric flask containing 250 ml of a 25% NaOH solution. To 200 ml of the distillate, 8 ml of a 5% KI solution was added before titration against a 0.02 N silver nitrate ($AgNO_3$) solution. The endpoint was indicated by a faint but persistent turbidity.

The measurements were repeated twice, and the average value was recorded. The HCN levels were calculated, with 1 ml of 0.02 N $AgNO_3$ equivalent to 1.08 mg of HCN per 20 g of the sample, and expressed as HCN mg kg^{-1}. All reagents used in this experiment were supplied by Merck Chemicals (Pty) Ltd., located at 259 Davidson Road, Wadeville, Gauteng, RSA, and were obtained through an authorized local distributor, Kansma Ltd. The blank sample was prepared following the same procedure as the actual sample. As a control, a certified standard solution of Potassium Thiocyanate (KSCN) with a concentration of 20 ppm was prepared. This solution underwent a precise titration process against silver nitrate ($AgNO_3$), resulting in a concentration of 21 ppm.

Statistical analysis

The data were analyzed using R software (Team R Core, 2021).

Analysis of variance (ANOVA) was conducted to assess differences

Table 1. Moisture content, color parameters, and hydrogen cyanide in dried cassava chips and cassava flour.

Location	Product	N	Moisture content (%)	L*	a*	b*	White Index ΔE	
Kabompo	Chips	4	12.50 ± 0.08	22.33 ± 11.80	6.13 ± 2.87	9.55 ± 2.00	27.28	126.68
			ab					61.02 ± 39.81
Kaoma	Chips	4	11.75 ± 0.06	19.04 ± 10.82	6.73 ± 1.38	9.86 ± 6.85	25.54	120.17
			ab					101.25 ± 80.26
Kasama	Chips	3	10.78 ± 0.58	13.98 ± 14.66	0.31 ± 0.24	10.16 ± 1.87	18.97	114.46
			a					89.64 ± 99.97
Lusaka	Chips	4	11.00 ± 0.82	9.25 ± 4.65	6.29 ± 1.02	11.96 ± 1.54	18.60	112.05
			ab					48.60 ± 57.15
Mansa	Chips	5	10.80 ± 1.92	22.49 ± 11.60	4.72 ± 2.56	8.78 ± 0.86	25.89	123.16
			ab					72.36 ± 16.47
Samfya	Chips	6	10.67 ± 1.63	16.52 ± 10.48	7.93 ± 0.58	10.39 ± 0.74	23.07	117.70
			ab					31.64 ± 34.15
Serenje	Chips	4	14.00 ± 0.82	9.80 ± 1.21	0.39 ± 0.44	9.19 ± 0.04	14.05	112.18
								40.50 ± 19.09
Kabompo	Flour	11	12.81 ± 0.66	42.55 ± 2.17	12.59 ± 2.76	8.14 ± 2.22	43.25	143.77
								79.29 ± 81.65
Kaoma	Flour	11	10.64 ± 0.63	45.04 ± 9.89	14.61 ± 1.01	7.84 ± 0.70	49.09	146.36
								70.32 ± 69.72
Kasama	Flour	10	13.70 ± 0.34	42.17 ± 10.18	14.27 ± 0.98	6.51 ± 0.47	46.07	143.41
								121.93 ± 90.40
Lusaka	Flour	12	12.00 ± 0.17	36.89 ± 13.12	15.62 ± 0.98	7.27 ± 2.31	41.74	137.87
								50.37 ± 47.64
Mansa	Flour	9	11.67 ± 1.12	44.80 ± 6.35	16.13 ± 2.37	7.99 ± 3.72	47.94	146.27
								69.86 ± 93.87
Samfya	Flour	8	12.37 ± 1.39	43.41 ± 13.85	14.54 ± 1.20	8.41 ± 3.21	48.19	144.83
								56.70 ± 35.78
Serenje	Flour	11	12.45 ± 0.97	38.86 ± 11.48	13.34 ± 1.26	7.12 ± 0.54	43.32	140.13
								31.32 ± 26.25

All values represent means of two replications ± Standard Deviation. Different superscript letters within the column indicate significant differences at $p \leq 0.05$, while those without any superscript indicate no significant difference at $p > 0.05$. L*= Lightness (e”100); a*= (-) red/green (+); b*= (-) blue/Yellow (+); ΔE = Difference in color change from the standard white background.

in moisture content, color parameters, and hydrogen cyanide (HCN) content among the various locations of cassava products. Post-hoc Tukey HSD tests (utilizing the R package 'multcomp') were performed to compare means, assuming normality of data distribution. In instances where normality was violated, data were transformed using log or square root transformations to address distribution concerns and ensure the validity of statistical analyses. If normality was not achieved, the non-parametric KruskalWallis test from the R packages 'rcompanion' and 'FSA' was employed, allowing for robust testing of significant differences in the respective variables.

Significant differences in means of response variables were considered at $p \leq 0.05$. The Betareg test (package: 'betareg') was employed to identify significant differences in moisture content among locations or between cassava products. A Chi-square test (package: 'chisq.test') was used to assess the significant difference in moisture content among locations. For further analysis, a post-hoc test (package: 'emmeans') was utilized to identify significant differences in means of moisture content among the various locations of cassava products. Additionally,
Pearson's correlation analysis (R function: 'co') was conducted to examine the relationship between moisture content and the whiteness of the cassava products.

RESULTS

Moisture content, color, and hydrogen cyanide content in dried cassava products

Table 1 presents the results of moisture content (MC), color, and hydrogen cyanide (HCN) in 102 dried cassava products obtained from households, processors, open markets, and supermarkets across seven districts. In order to ensure consumption safety, the CODEX Alimentarius Commission (FAO/WHO, 2020) mandates that edible dried cassava flour and chips must maintain a maximum HCN level of 10 mg kg^{-1} and a moisture content not exceeding 13%.

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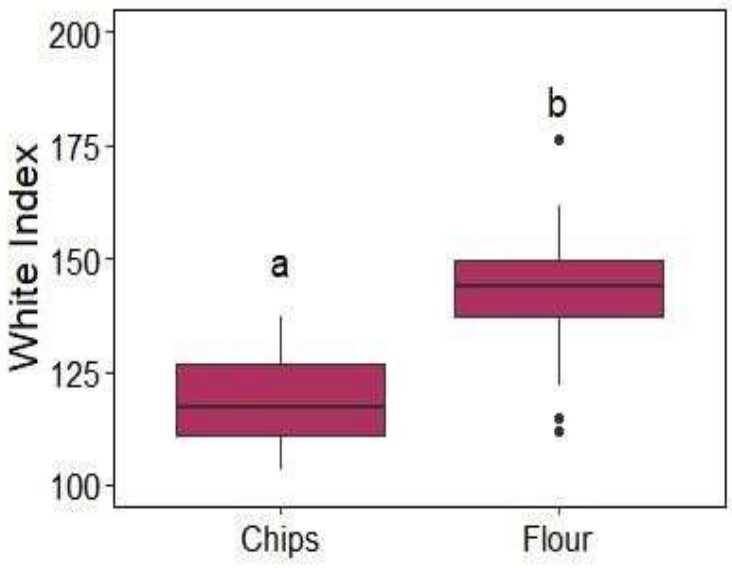

Figure 1. White index analysis of cassava products (chips and flour) from samples collected across seven study sites in Zambia. Lowercase letters denote significant differences in the white index between cassava products ($p \leq 0.05$, N = 102). White index, quantifies the degree of whiteness or brightness of the sample's color compared to a standard reference, typically white.

range of 13% (FAO/WHO, 2020; EAS 739:2010).

Color parameters in dried processed cassava products

The color parameter results in terms of CIE L* a* b* for 102 dried cassava chips and flour samples collected from the study sites were analyzed, and the results are shown in Table 1. According to EAS 739:2010 and EAS 740:2010, the color of dried cassava chips and flour should be white, creamy, or yellow.

No noticeable variation ($p > 0.05$) was observed in the lightness (L*) of cassava chips and flour across all research locations. The average lightness values for chips ranged from 9.25 in Lusaka to 22.49 in Mansa, while the average values for flour ranged from 36.86 in Lusaka to 45.04 in Kaoma (Table 1).

Similarly, there was no significant difference ($p > 0.05$) in the color intensity (a*) of cassava chips and flour across all study sites. The mean color intensity values for chips ranged from 0.31 in Kasama to 7.93 in Samfya, while the mean values for flour ranged from 12.59 in Kabompo to 16.13 in Mansa (Table 1).

The b* values of cassava chips and flour were similar across all study sites ($p > 0.05$), with cassava chips having mean values ranging from 8.78 to 11.96 and cassava flour having mean values ranging from 6.51 to 8.41 (Table 1).

The total color difference (ΔE*) between cassava chips from all study sites and white paper used as a standard was high, with mean values ranging from 14.05 to 27.28 for Serenje and Kabompo, respectively. On the other hand, cassava flour had mean values ranging from 41.74 to 49.09 in Lusaka and Kaoma, respectively (Table 1).

The white index of cassava chips and flour ranged from 112.05 to 126.86 and 137.87 to 146.36, respectively (Table 1), with significant variation ($p \leq 0.05$) observed between the two products (Figure 1).

Correlation analysis of the moisture content (MC) and whiteness in dried processed cassava products

The correlation between moisture content and whiteness in cassava chips and flour was examined, and the findings are illustrated in Figure 2. For cassava chips, the correlation between moisture content and whiteness was non-significant ($p = 0.83$) yet positive, showing a correlation coefficient of 0.041. Similarly, no significant ($p = 0.05$) positive correlation (correlation coefficient = 0.15) was observed between moisture content and whiteness in cassava flour.

Hydrogen cyanide (HCN) content in dried processed cassava products

The HCN content of cassava chips ranged from 31.64 to 101.25 mg kg^{-1} with Samfya and Kaoma displaying the respective extremes. Similarly, the HCN content for cassava flour spanned from 31.32 to 121.93 mg kg^{-1}, with Serenje and Kasama recording the highest and lowest values, respectively (Table 1).

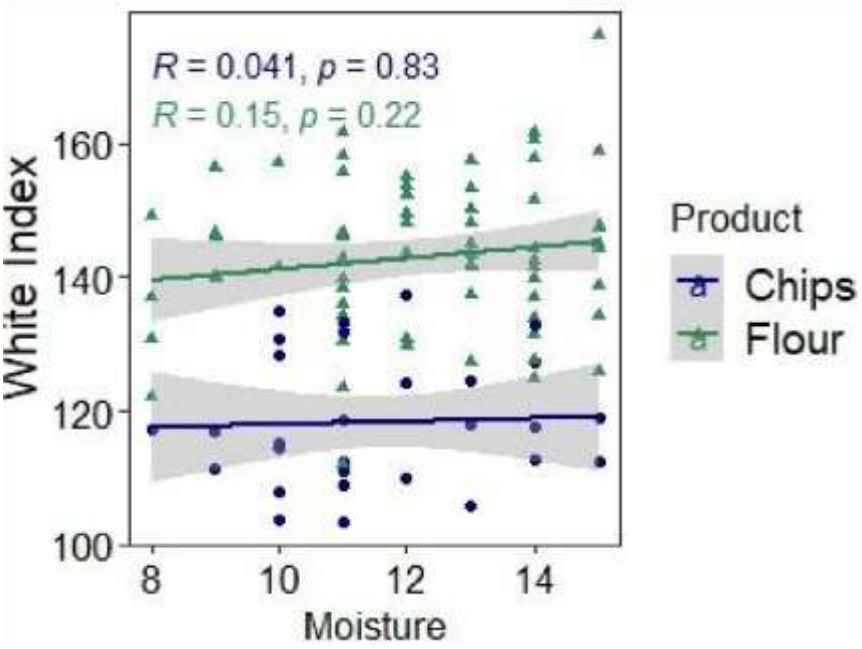

Figure 2. Relationship between white index and moisture in cassava products (chips and flour). Correlation coefficients (r) and statistical p-values are given for each cassava product. White index, quantifies the degree of whiteness or brightness of the sample's color compared to a standard reference, typically white.

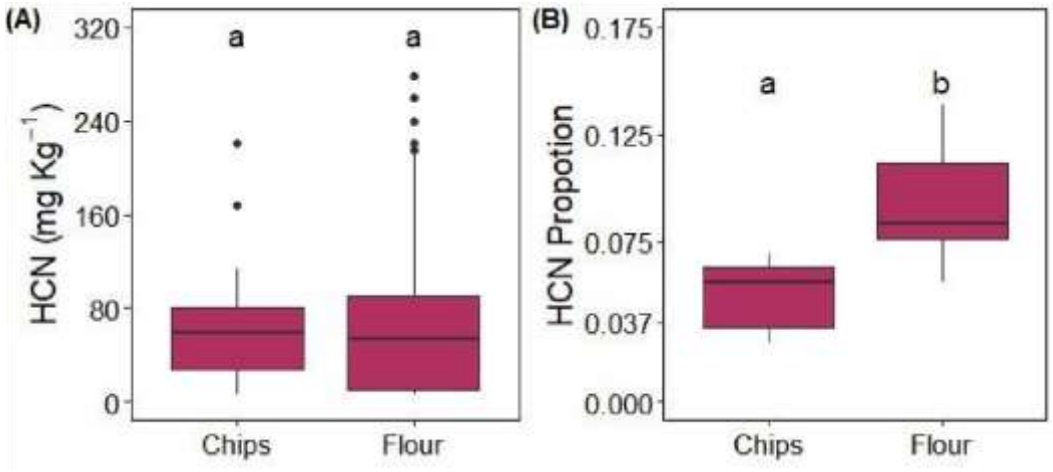

Figure 3. HCN concentration (A) and presence (B) in cassava products (chips and flour) from samples across Zambia's seven study sites. Lowercase letters denote significant differences in HCN concentration between cassava products ($p \leq 0.05$, n = 72). Measurement was done in duplicate.

While the differences in HCN concentration between cassava products were not deemed significant ($Chi^2 = 0.08$, $p = 0.776$) (Figure 3A), the concentrations exceeded the maximum acceptable recommended limit of 10 mg kg^{-1}

(FAO/WHO, 2020). Moreover, a notable distinction in the proportion of HCN was observed between cassava chips and cassava flour ($Chi^2 = 7.02$, $p = 0.008$), with the content being higher in flour than in chips (Figure 3B).

DISCUSSION

Moisture content (MC) in dried processed cassava products

The observed moisture content range in this study aligns with the recommended moisture range of below 13% for cassava chips. These findings are consistent with the report by Gacheru et al. (2015), indicating low moisture content in cassava chips and normal results in cassava flour. Chisenga et al. (2019) also noted low moisture content in cassava varieties in the northern part of Zambia, ranging from 10.43 to 11.76%. In contrast, higher moisture content than the recommended range in cassava chips and flour has been reported by Uchechukwu-Agua (2015) in South Africa, Oladunmoye et al. (2014) in Lagos, and Alamu et al. (2019) in major markets of Zambia. Moisture content testing is a standard procedure in food analysis because the water content in food significantly influences preservation and the chemical, physical, and microbiological changes during storage (Passos et al., 2013). Proper drying techniques play a crucial role in preserving cassava products due to their perishable nature. The extent of drying and relative humidity during sun-drying can impact the moisture content of cassava products (Apea-Bah et al., 2011), prompting processors and traders to ensure proper drying practices to prevent losses. Lower moisture content in cassava products indicates microbial stability and may reduce staling in baked food products (Ogiehor and Ikenebomeh, 2006).

Color parameters in dried processed cassava products

The findings of the present study are consistent with color parameter values reported by Gacheru et al. (2015) in a study conducted in Nairobi. Their study indicated an increase in ΔE and b* for traditionally processed cassava flour and further processing led to increased whiteness with a significant decrease in ΔE and b*. The white index results obtained in this study align with the color parameter values presented in a publication by Hongbété et al. (2009). In another study conducted in South Africa, Omolola et al. (2017) reported whiteness values in the range of 82.88 to 89.42 for cassava products. The observed variations in whiteness may be attributed to different drying temperatures and times. Higher temperatures and prolonged cooking periods can increase the a* (redness) and b* (yellowish) values of chips, reducing their whiteness. This suggests that higher L* values and lower a* and b* values may contribute to higher white index values. Color is a critical quality parameter that appeals to consumers and is often used as an indicator of quality. When selecting cassava flour for industrial applications, high values of lightness (L*) and low values for chroma are considered ideal color quality parameters (Sankhon et al., 2014). However, slight changes in yellowness and greenness can impact whiteness. The color of cassava products is influenced by factors such as variety, maturity stage, and processing techniques (McClements et al., 2017; RodriguezSandoval et al., 2017). Cassava products prepared from unpeeled or improperly peeled roots can develop a grey color during wet storage and a purple color during drying, which diminishes quality and value (Jyothi et al., 2007). To produce flour with increased lightness (L*) and whiteness, controlled sorting, peeling, enhanced washing with potable water, thorough grating, and high-pressure dewatering are required.

Consumers often associate color with safety and quality, frequently preferring white products despite the possibility of higher residual hydrogen cyanide (HCN) levels. The color of flour and chips can be influenced by natural pigments from peels (McClements et al., 2017), and the product's whiteness diminishes with the age of the processed cassava (Jyothi et al., 2007).

Hydrogen cyanide (HCN) content in dried processed cassava products

The potential for high levels of hydrogen cyanide (HCN) in cassava products can result from inadequate processing of cassava roots or excessive levels of total cyanide in the raw cassava roots (Cardoso et al., 2005; Gacheru et al., 2015).

The findings of this study, indicating HCN levels exceeding the recommended acceptable limit of 10 mg kg^{-1}, align with the results of Oghenechavwuko et al. (2013) in a study conducted in Nigeria. Burns et al. (2011) also reported elevated HCN in cassava chips, with an overall mean of 91 mg kg^{-1} HCN and up to 262 mg kg^{1} HCN, despite these chips typically undergoing further processing from raw cassava roots into dry chips and flour. According to Cardoso et al. (2005), the cyanide content of chips and flour produced after sun drying in eastern, central, and southern Africa is higher during low rainfall seasons, possibly due to the dilution factor of cyanide brought by rainwater. Additionally, root cyanide levels increase during periods of low rainfall due to water stress on the cassava plant (Bokanga et al., 1994; Cardoso et al., 2005). In a study conducted in Australia, Vandegeer et al. (2013) reported that the impact of drought on the distribution of cyanide concentration (CNs) within the cassava plant that had experienced a 28-day drought was 4-fold greater than in tubers from well-watered plants. This effect of drought could explain the high cyanide levels observed in the present study, as the cassava samples were collected during the dry and cold seasons with minimal moisture in the air and soil in Zambia between June 2021 and July 2021. According to the Zambia Meteorological Department's report for 2020/2021 (ZMD report), Zambia received an average rainfall between 1000 and 1500 mm, an annual average minimum temperature of 10°C, and an average maximum temperature of 29°C in cassava agro-ecological areas. High levels of cyanide in cassava products have been linked to acute intoxication and the occurrence of Konzo in communities (Ernesto et al., 2002). The consumption of cyanide-containing products presents a health hazard, especially for individuals unaware of the necessity to detoxify cassava. The impact of cyanide on human health varies based on body size, health condition, the quantity of cyanide ingested, and the duration of exposure. The acute lethal dose of hydrogen cyanide for humans ranges from 0.5 to 3.5 mg kg^{-1} of body weight (Halstrøm and Møller, 1945).

In response to potential public health risks linked to cassava consumption, the Food and Agriculture Organization (FAO) has developed effective processing methods to mitigate cyanide levels in cassava. These methods offer significant reductions and, in some instances, complete elimination of cyanide content based on the applied processing techniques (FOA, 2004). Typically, these techniques encompass a series of steps such as peeling, slicing, fermentation, boiling, drying, pounding or milling, and sieving. Notably, fermentation methods like loop fermentation have shown promise in reducing or eradicating HCN in cassava products (Egwim Evans et al., 2013; Bulkan, 2019). Nambisan and Sundaresan (1985) reported a significant 50% decrease in cyanide levels in cassava roots following the boiling process, highlighting the effectiveness of boiling in reducing cyanide content. Additionally, Quinn et al. (2022) found that cooking grated cassava products led to a substantial reduction in cyanide levels. The content dropped significantly from 12.9 to 1.3 mg kg^{-1}, bringing it below the safe limit of 10 mg kg^{-1} in all cassava products. Among Zambian cassava traders, the most prevalent traditional processing methods include peeling, soaking, washing, slicing/mashing, grinding, and drying (SHEMP, 2004). Collectively, these steps aid in the reduction of cyanide levels and ensure safer cassava consumption.

Future studies will delve deeper into the analysis of HCN in raw cassava samples, exploring variations in HCN content among different cassava varieties, and investigating the impact of diverse processing and pretreatment techniques in reducing HCN levels. These studies aim to provide valuable insights into the safety of cassava consumption and to help develop effective strategies for mitigating the health risks associated with HCN. By examining these crucial factors, a better understanding of the elements influencing HCN content in cassava can be gained, leading to improvements in food safety, nutritional value, and public health associated with this important staple crop.

Conclusion

The findings of this study highlight significant levels of HCN in processed cassava chips and flour, which are available to consumers in Zambia. This poses potential health risks for humans and animals consuming these

products, as acute poisoning can lead to permanent upper motor neuron damage and other clinical implications. Despite the good quality of cassava products in terms of moisture content and color, they are deemed unsafe for consumption due to their high cyanide concentration (CNs). To mitigate these risks, cassava processors at both household and commercial levels must adopt appropriate processing techniques to reduce residual HCN levels in processed cassava products to acceptable levels in accordance with standards. Authorities should evaluate cassava processing techniques to ensure that residual cyanide levels in cassava products are reduced to acceptable levels as standards require. This would help protect consumers' health and prevent potential health hazards associated with the consumption of cassava products. Overall, these measures are crucial for improving the safety and quality of cassava products in Zambia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Abass A (2008). Recent developments in cassava processing, utilization and marketing in East and Southern Africa and lessons learned. In FAO Expert Consultation Meeting held at the Natural Resources Institute, University of Greenwich, United Kingdom. https://biblio.iita.org/documents/S08UnpAbassRecentNothomNodev.

pdf-ba886f0feda344b30dec53e87769eb61.pdf

Alamu EO, Ntawuruhunga P, Chibwe T, Mukuka I, Chiona M (2019). Evaluation of cassava processing and utilization at household level in Zambia. Food Security 11(1):141-150.

Association of Official Analytical Chemist (AOAC) (2019). Official method of analysis 15 Edn Washington D C.

Association of Official Analytical Chemists (AOAC) (2012). Official methods of analysis 18th edn. Arlington, VA, USA, 925.10.

Apea-Bah FB, Oduro I, Ellis WO, Safo-Kantanka O (2011). Factor analyzis and age at harvest effect on the quality of flour from four cassava varieties. World Journal of Dairy and Food Sciences 6(1):43-54.

Baskin SI, Petrikovics I, Kurche JS, Nicholson JD, Logue BA, Maliner BJ, Rockwood GA (2004). Insights on cyanide toxicity and methods of treatment. Pharmacological Perspectives of Toxic Chemicals and Their Antidotes pp. 105-146.

Bokanga M, Ekanayake IJ, Dixon AG, Porto MC (1994). Genotypeenvironment interactions for cyanogenic potential in cassava. Acta Horticulturae 375:131-139.

Bulkan J (2019). The place of bitter cassava in the social organization and belief systems of two indigenous peoples of Guyana. Culture, Agriculture, Food and Environment 41(2):117-128.

Burns AE, Bradbury JH, Cavagnaro TR, Gleadow RM (2011). Total cyanide content of cassava food products in Australia. Journal of Food Composition and Analysis 25(1):79-82.

Cardoso AP, Mirione E, Ernesto M, Massaza F, Cliff J, Haque MR, Bradbury JH (2005). Processing of cassava roots to remove cyanogens. Journal of Food Composition and Analysis 18(5):451-460

Cassava Cyanide Diseases Network (CCDN) (2008). (Online).

Available: http://online.anu.edu.au/BoZo/CCDN/ (25 July.

Chisenga SM, Workneh TS, Bultosa G, Laing M (2019). Proximate composition, cyanide contents, and particle size distribution of cassava flour from cassava varieties in Zambia. AIMS Agriculture and Food pp. 869-891.

Chukwu O, Abdullahi H (2015). Effects of moisture content and storage period on proximate composition, microbial counts and total carotenoids of cassava flour. International Journal of Innovative Science, Engineering and Technology 2(11):753-763.

EAS (2010). Dried cassava chips; dried cassava chips specification. Arusha: East African Community.

Egwim Evans AM, Abubakar Y, Mainuna B (2013). Nigerian indigenous fermented foods: processes and prospects. Mycotoxin and Food Safety in Developing Countries 153:153-180.

Ernesto M, Cardoso AP, Nicala D, Mirione E, Massaza F, Cliff J, Haque MR, Bradbury JH (2002). Persistent Konzo and cyanide toxicity from cassava in Northern Mozambique. Acta Tropica 82(3):357-362.

FAO/WHO (2020). Joint FAO/WHO Food Standards Programme. Codex Alimentarius Commission XII. Supplement 4, FAO, Rome,

Italy;

FAOSTAT (2017). Faostat: Food and Agriculture Data. Rome: FAOSTAT (Accessed Jan 04, 2017).

Gacheru PK, Abong GO, Okoth MW, Lamuka PO, Shibairo SI, Katama CM (2015). Cyanogenic Content, Aflatoxin Level and Quality of Dried Cassava Chips and Flour Sold in Nairobi and Coastal Regions of Kenya. Current Research in Nutrition and Food Science pp. 197-206

Halstrøm F, Møller KO (1945). The content of cyanide in human organs from cases of poisoning with cyanide taken by mouth. With a contribution to the toxicology of cyanides. Acta Pharmacalogica et Toxicologica 1(1):18-28.

Hongbété F, Mestres C, Akissoé NH, Coffi Nago M (2009). Effect of processing conditions on cyanide content and colour of cassava flours from West Africa.

Howlett WP, Brubaker GR, Mlingi N, Rosling H (1990). Konzo, an epidemic upper motor neuron disease studied in Tanzania. Brain 113(1):223-235.

Joint FAO/WHO Expert Committee on Food Additives, JECFA (2010).

Codex Alimentarius Commission XII, Supplement 4, FAO, Rome,

Italy.

Jyothi AN, Kiran KS, Wilson B, Moorthy SN, Nambisan B (2007). Wet storage of cassava starch: Use of sodium metabisulphite and acetic acid and the effect on starch properties. Starch-Stärke 59:141-148.

Lantum H (1998). Spastic paraparesis - Konzo. In the Garoua Boulai Health District. East Province – Cameroon: a hidden endemic disease. Monograph. Cameroun; Yaounde 85.

Marziaz ML, Frazier K, Guidry PB, Ruiz RA, Petrikovics I, Haines DC (2013). Comparison of brain mitochondrial cytochrome oxidase activity with cyanide LD (500) yields insight into the efficacy of prophylactics. Journal Applied Toxicology 33(1):50-55.

Mburu FW, Swaleh S, Njue W (2013). Potential toxic levels of cyanide in cassava (Manihot Esculenta Crantz) grown in Kenya. African Journal of Food Science 6 (16):1-40.

McClements DJ, Chung C, Wu BC (2017). Structural design approaches for creating fat droplet and starch granule mimetics.

Food and Function 8(2):498-510.

Morrison WR, Laignelet B (1983). An improved colorimetric procedure for determining apparent and total amylose in cereal and other starches. Journal of Cereal Science 1(1):9-20.

Nambisan B, Sundaresan S (1985). Effect of processing on the cyanoglucoside content of cassava. Journal of the Science of Food and Agriculture 36(11):1197-1203.

Nweke F, Spencer DS, Lynam JK (2002). The Cassava Transformation*:*

Africa's Best-Kept Secret. East Lansing.

Oghenechavwuko UE, Saka GO, Adekunbi TK, Taiwo AC (2013). Effect of processing on the physico-chemical properties and yield of gari from dried chips. Journal of Food Processing and Technology 4(8):1-6.

Ogiehor IS, Ikenebomeh MJ 2006). the effect of different packaging materials. Journal of Biotechnology pp. 741-745.

https://academicjournals.org/article/article1379946821_Ogiehor%20a nd%20Ikenebomeh.pdf

Oladunmoye OO, Aworh OC, Maziya-Dixon B, Erukainure OL, Elemo GN (2014). Chemical and functional properties of cassava starch, durum wheat semolina flour, and their blends. Food Science and Nutrition 2(2)*:*132-138.

Oluwole OS, Onabolu AO, Cotgreave IA, Rosling H, Persson A, Link H (2013). Incidence of endemic ataxic polyneuropathy and its relation to exposure to cyanide in a Nigerian community. Journal of Neurology, Neurosurgery and Psychiatry 74:1417-1422.

Omolola AO, Jideani AI, Kapila PF (2017). Quality properties of fruits as affected by drying operation. Critical Reviews in Food Science and Nutrition *57*(1):95-108.

Osuret J, Musinguzi G, Mukama T, Halage AA, Natigo AK, Ssempebwa JC, Wang J (2015). Aflatoxin contamination of selected staple foods sold for human consumption in Kampala markets, Uganda. Journal of Biological Sciences 16(1-2):44-48.

Passos ME, Moreira CF, Pacheco MT, Takase I, Lopes ML, ValenteMesquita VL (2013). Proximate and mineral composition of industrialized biscuits. Food Science and Technology 33:323-331.

Quinn AA, Myrans H, Gleadow RM (2022). Cyanide content of cassava food products available in Australia. Foods 11(10):1384.

Rodriguez-Sandoval E, Prasca-Sierra I, Hernandez V (2017). Effect of modified cassava starch as a fat replacer on the texture and quality characteristics of muffins. Journal of Food Measurement and Characterization pp. 1630-1639.

Sankhon A, Amadou I, Yao WR, Wang H, Qian H, Sangare M (2014). Comparison of physicochemical and functional properties of flour and starch extract in different methods from Africa locust bean (*Parkia biglobosa*) seeds. African Journal of Traditional, Complementary and Alternative Medicines 11(2):264-272.

Shittu TA, Dixon A, Awonorin SO, Sanni LO, Maziya-Dixon B (2008). Bread from composite cassava–wheat flour. In: effect of cassava genotype and nitrogen fertilizer on bread quality. Food Research International 41:569-578.

Siddiqi OK, Kapina M, Kumar R, Moraes AN, Kabwe P, Mazaba ML, Hachaambwa L, Ng'uni NM, Chikoti PC, Morel-Espinosa M, Jarrett JM (2020); Konzo outbreak in the Western Province of Zambia. Neurology Journal 94(14):e1495-501.

Smallholder Enterprise and Marketing Program (SMEMP) (2003).

Cassava a Market research study report Zambia. pp. 102-120.

Taiwo KA (2006). Utilization potentials of cassava in Nigeria: the domestic and industrial products. Food Reviews International 22:2942.

Team R Core (2021). R: A language and environment for statistical computing. Published online 2020. Supplemental Information References S, 1:371-378.

Tylleskar T (1994, March). The association between cassava and the paralytic disease konzo. In International Workshop on Cassava Safety 375:331-340.

Tylleskär T, Legue FD, Peterson S, Kpizingui E, Stecker P (1992). Konzo in the Central African Republic. Neurology 44(5):959-959.

Uchechukwu-Agua AD (2015). Effect of Packaging and Storage Condition on Functional Properties and Quality Attributes of Cassava Flour (CVS. 'TME 419' and 'UMUCASS 36'). MSc thesis, Department of Food Science, Stellenbosch University, Stellenbosch, South Africa. Vandegeer R, Miller RE, Bain M, Gleadow RM, Cavagnaro TR (2013). Drought adversely affects yield and nutritional quality of cassava (*Manihot esculenta* Cranz.). Functional Plant Biology 40:195-200.

World Health Organization (WHO) (1996). Konzo: a distinct type of upper motor neuron disease. Weekly Epidemiological Record pp. 225-232.

Yusuf AS, Omoghie ES, Adeleye AS, Akhideno LO, Akemien NN, Osazuwa DK (2022). Constraints in the utilization of cassava processing techniques amongst agro-forestry farmers in Edo State, Nigeria. Journal of Research in Forestry, Wildlife and Environment, 14(1):65-71.

Zambia Metrological Department (ZMD) (2020/2021). Weather focus rainfall pattern report (2021).

Zhu F, Sakulnak R, Wang S (2016). Effect of black tea on antioxidant, textural, and sensory properties of Chinese steamed bread. Food Chemistry 194:1217-1223.