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Removal of Fumonisins from Spoiled Pap Using Nano-Carbon Particles of Bryophyllum pinnatum Leaf: An Innovative Mycotoxin Detoxification Strategy

***Okpabi, T.S., & Ogbonda, K.H**
Biology Department, Ignatius Ajuru University of Education, Rumuolumeni Port Harcourt, Rivers State Nigeria.

***Corresponding author email:** okpabis@gmail.com

Abstract
The fumonisins are mycotoxins produced by the fungus Fusarium verticilliodes in cereals and their products such as pap produced from corn. Various methods have been employed for the removal of these toxins from pap. These methods, however, have been find to be ineffective. In this study, therefore, nano-carbon particles of the leaf of Bryophyllum pinnatum have been used for the removal of these toxins from spoiled pap, where is an innovative over previous methods. Using thermal pyrolysis method, the Bryophyllum pinnatum leaves nano-particles were prepared, the proximate composition of the pap was determined, lateral flow assay device was used to test for the fumonisins. The fumonisins were quantified and characterized. The results showed that pap is primarily a high-moisture (75.2%) and carbohydrate-rich (18.9%) food with low protein (1.3%), fat (0.6%), fiber (0.3%), and mineral content (0.7%), making it an easily digestible but nutritionally inadequate food. Fumonisin analysis indicated a progressive increase in FB1, FB2, and FB3 levels, with the highest concentrations recorded at 48 hours (6.20 ng/ml, 7.40 ng/ml, and 6.96 ng/ml, respectively), highlighting the rapid and significant accumulation of mycotoxins in stored pap. However, treatment with Aloe vera-derived nanocarbon particles resulted in the complete elimination of fumonisins, demonstrating their strong detoxification potential. It was concluded that nano-particles was effective in the detoxification of fumonisins. The study recommends fortifying pap with protein and micronutrient sources to enhance its nutritional value, implementing early detection and control strategies for fumonisin contamination, and further exploring the application of nanocarbon technology for mycotoxin detoxification in fermented foods

Keywords: Removal, Fumonisins, Spoiled Pap, Nano-carbon particles, Bryophyllum pinnatum Leaves

Introduction

Food contamination by mycotoxins poses a significant public health risk, particularly in regions where food preservation and storage conditions are suboptimal. Among these toxic compounds, fumonisins primarily produced by *Fusarium* species are of great concern due to their high prevalence in maize-based products, including pap (a fermented maize porridge widely consumed in Africa). These toxins have been linked to severe health complications, such as esophageal cancer, neural tube defects, and immunosuppression. Given the limitations of conventional detoxification methods, there is an urgent need for innovative, cost-effective, and environmentally sustainable strategies for fumonisin removal. Recent advances in nanotechnology have provided new opportunities for mycotoxin detoxification, particularly through the use of plant-derived nano-carbon particles (NCPs). *Bryophyllum pinnatum*, commonly known as the “miracle plant” or “life plant,” is a medicinal plant renowned for its bioactive compounds and adsorptive properties. The transformation of *B. pinnatum* leaves into nano-carbon particles offers a promising approach to fumonisin removal, leveraging their high surface area, functional groups, and enhanced binding affinity

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to toxic compounds. Unlike chemical and physical detoxification methods, which may compromise the nutritional quality and sensory properties of food, nano-carbon technology provides a non-destructive and biocompatible alternative.

Wang et al. (2013) aimed to develop a rapid detection method for fumonisin B1 and zearalenone in food. The study employed a lateral flow dual immunoassay for simultaneous quantification in corn and wheat. The findings indicated that this method successfully detected fumonisins at trace levels, suggesting its potential application in food safety monitoring. Similarly, Li et al. (2017) focused on developing a high-specificity monoclonal antibody for fumonisin B1 detection. The study used immunoassay techniques and demonstrated that monoclonal antibodies enhanced specificity and sensitivity in fumonisin detection, improving food safety protocols. Ren et al. (2017) developed a disposable aptasensing device for label-free detection of fumonisin B1. The study integrated a polydimethylsiloxane (PDMS) film-based microcell with a screen-printed carbon electrode. The results showed that the aptasensor effectively detected fumonisin B1 at low concentrations, indicating its potential for real-time food contamination monitoring. In another study, Wang et al. (2014) designed a quantitative fluorescence-based immunochromatographic assay for detecting fumonisin B1 in maize. The study provided high sensitivity and specificity, demonstrating that fluorescence-based approaches could be valuable for mycotoxin screening.

Chen et al. (2015) utilized an impedimetric aptamer-based approach to determine fumonisin B1 levels in food samples. The study showed that this electrochemical detection technique offered high sensitivity and selectivity, making it suitable for rapid food quality assessments. Li et al. (2015) developed a fluorescence polarization immunoassay for simultaneously detecting fumonisins B1 and B2 in maize. The findings highlighted that this method enabled efficient and accurate screening, reducing the risk of mycotoxin contamination in food products. Kaltner et al. (2017) validated a cost-effective high-performance liquid chromatography with fluorescence detection (HPLC-FLD) method for routine analysis of fumonisins B1 and B2 in corn and corn-based products. The study indicated that the method was both reliable and efficient for large-scale food safety testing. Barna-Vetró et al. (2000) designed an enzyme-linked immunosorbent assay (ELISA) for fumonisin B1 determination in cereals. The findings confirmed that ELISA techniques provided a rapid and cost-effective means of mycotoxin analysis.

Nguyen et al. (2018) explored surface-enhanced Raman scattering (SERS) quantification for monitoring fumonisin contamination in food. The study demonstrated that SERS offered high sensitivity and real-time monitoring capabilities. Similarly, Shorie et al. (2018) developed a plasmonic DNA hotspot system using tungsten disulfide nanosheets and gold nanoparticles for ultrasensitive detection of mycotoxins. The research found that this approach significantly enhanced detection accuracy, making it a promising technique for mycotoxin monitoring. Arslanoglu et al. (2011) investigated the use of nanotag-complexed antibodies for protein localization in food safety applications. The study revealed that this technique improved specificity and detection limits for fumonisins in contaminated samples. Wu et al. (2018) developed a bimodal (SERS and colorimetric) aptasensor for detecting *Pseudomonas aeruginosa* contamination, which could be adapted for fumonisin detection. The research suggested that this dual-mode detection system enhanced the accuracy and reliability of food safety assessments.

Chen et al. (2017) designed a fluorescence-based method for detecting copper ions in food samples. Although the primary focus was heavy metal contamination, the findings implied that similar fluorescence techniques could be adapted for fumonisin removal studies. Ling et al. (2015) developed ELISA and colloidal gold immunoassays for detecting tetrodotoxin, another food toxin. The study demonstrated that immunoassay techniques could be highly effective for fumonisin detection and removal strategies. Bian et al. (2016) employed single-molecule fluorescence correlation spectroscopy to detect fumonisin in food products. The findings indicated that this technique provided ultra-sensitive detection capabilities, making it a valuable tool for food safety applications. Wu and Cui (2018) designed a fluorometric assay utilizing platinum-coated gold nanorods and upconversion nanoparticles for detecting bacterial toxins. The study suggested that similar nanosensor techniques could be applied to fumonisin detection and detoxification.

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Huang et al. (2019) aimed to develop a magnetic nanoparticle-based immunoassay for fumonisin B1 detection in contaminated food. The study utilized functionalized iron oxide nanoparticles to enhance the specificity of mycotoxin detection. The results demonstrated that this method provided rapid and highly selective detection, making it a promising tool for food safety monitoring. Zhang et al. (2020) investigated the efficacy of graphene oxide-based nanocomposites for adsorbing fumonisins from maize. The study employed batch adsorption experiments to assess the removal efficiency. The findings revealed that graphene oxide significantly reduced fumonisin concentrations, highlighting its potential as an effective detoxification agent. Liu et al. (2021) focused on enzymatic degradation of fumonisins using laccase-functionalized nanoparticles. The study demonstrated that enzyme-nanoparticle conjugates effectively degraded fumonisin B1, reducing its toxicity in food samples. The results suggested that enzymatic treatment could be an efficient and eco-friendly approach to mycotoxin detoxification. Gong et al. (2022) explored the use of molecularly imprinted polymers (MIPs) for fumonisin removal in stored grains. The study applied MIP-coated adsorbents to contaminated samples and observed a significant reduction in fumonisin levels. The findings confirmed that MIPs could selectively bind and remove mycotoxins, improving food safety.

Wang et al. (2018) developed a colorimetric aptasensor for rapid fumonisin B1 detection in corn products. The study employed gold nanoparticles and aptamer-conjugated sensors to enable visual detection of contamination. The results indicated that this approach provided a simple, cost-effective, and highly sensitive detection method. Chen et al. (2020) investigated the ability of activated carbon derived from *Moringa oleifera* to adsorb fumonisins from aqueous solutions. The study applied batch adsorption techniques and observed a significant reduction in toxin levels. The findings suggested that plant-derived activated carbon could serve as an affordable and sustainable alternative for fumonisin removal. Xie et al. (2019) examined the impact of UV and ozone treatment on fumonisin degradation in stored maize. The study found that exposure to UV-ozone significantly reduced fumonisin B1 and B2 levels without compromising the nutritional quality of the grains. The results highlighted the potential of non-thermal decontamination techniques in food safety applications. Okeke et al. (2021) explored the role of biosorbents derived from *Bryophyllum pinnatum* in fumonisin detoxification. The study utilized nano-carbon particles extracted from the leaves and assessed their adsorption efficiency. The findings revealed that *Bryophyllum pinnatum*-based nano-carbon effectively removed fumonisins from pap, demonstrating its potential as a natural detoxification strategy. Alshannaq et al. (2022) investigated the use of biopolymer-based nanocarriers for fumonisin detoxification in dairy products. The study designed a chitosan-based nano-adsorbent and tested its ability to bind fumonisins in contaminated milk. The results showed that the biopolymer effectively reduced fumonisin concentrations while preserving the sensory qualities of the dairy products. Yang et al. (2023) applied a combination of cold plasma and nanotechnology to degrade fumonisins in food products. The study demonstrated that plasma-assisted nanomaterials significantly enhanced the breakdown of fumonisins, reducing their toxicity. The findings indicated that this approach could be integrated into food processing industries to improve safety standards.

Aim and Objectives

The aim of this research is to investigate the removal of fumonisins from spoiled pap using nano-carbon particles of *Bryophyllum pinnatum* Leaves. The objectives were to;

i. determine the proximate composition of pap;
ii. quantify and characterize the fumonisins produced on the soured pap;
iii. detoxify the fumonisins using the nano-carbon particles of *Bryophyllum pinnatum* Leaves.

Materials and Method

Determination of Moisture Content

A clean, dry Petri dish labeled A was put in an oven at 800°C for about 30 minutes, then cooled in a desiccator, and weighed. Five grams of the newly cooked African salad were put to the petri dish, measured, and labeled as B. The petri dish and its contents were put in an oven set to 700°C. After five hours, the petri dish containing the sample was removed and promptly transferred to a desiccator for cooling. The petri dish was returned to the oven and set to 1050°C for a further 5 hours, following which it was removed and placed in desiccators to cool. The procedure was repeated and measured until a stable weight C was achieved.

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The % moisture content was determined as follows;

$$\% \text{ moisture content} = \frac{B-C}{B-A} \times 100$$

Where A = weight of empty petri-dish, B = weight of petri-dish + sample, C = weight of petridish + sample after drying.

Determination of Ash Content

A vacant crucible was first heated in a muffle furnace for one minute and then cooled in a desiccator with silica gel. Five grams of the material were precisely measured into the prepared dish. The mass of the porcelain dish and the specimens was recorded. Subsequently, the dish was heated using a Bunsen burner inside a fume closet until smoke ceased, and then transported to a muffle furnace at 550-570°C for about 18-24 hours to incinerate all organic material. Subsequent to ashing, the crucible was extracted from the furnace and positioned in a desiccator to equilibrate at ambient temperature before being weighed. The percentage ash content of the sample was calculated thus;

$$\% \text{ Ash} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

$$= \frac{W3-W1}{W2-W1} \times 100$$

Where; W_1 = weight of empty crucible, W_2 = weight of crucible + sample before ashing

W_3 = weight of crucible + sample after ashing

Determination of Crude Fiber

Two grams of the defatted material were measured into a conical flask, and 200 mL of 1.25% boiling sulfuric acid was added within one minute. The flask's contents were filtered using a Buchner funnel equipped with a moistened 12.5 cm filter paper. The material was returned to the original flask with 200 mL of 1.25% NaOH and cooked for 30 minutes. All insoluble substances were transferred to the crucible and processed until the sample was devoid of acid. The specimen was reheated in a muffle furnace at 550°C. The crucible was then cooled in a desiccator and reweighed.

$$\% \text{ Crude fiber} = \frac{W2-W1}{W} \times 100$$

Where; W = weight of sample, W_1 = weight of crucible + sample (after washing, boiling and drying)

W_2 = weight of crucible + sample of ash (after ashing).

Determination of Crude Protein

One gram of the material was measured and placed into a Kjeldahl flask. A small quantity of antibumping granules, 4g of digesting catalyst, and 20mL of concentrated sulfuric acid were introduced at a 40°C angle using a retort stand on an electrothermal heater. The flask was gradually heated to induce foaming, which then diminished, before the temperature was raised to around 250°C. The digestion occurred within 2-6 hours, resulting in the full digestion of the whole sample. The digest was allowed to cool to ambient temperature and then diluted to 100 mL with distilled water.

A 20 mL aliquot of the digest was put into a round-bottom flask for distillation. The flask was linked to a Liebig condenser by a mono-arm steel head (adapter). The Liebig condenser was linked to a receiving flask via a receiver adapter. Ten milliliters of 2% boric acid and two drops of double indicator were put into the distillation flask. Thirty milliliters of 40% sodium hydroxide was administered into the distillation flask via a cork using a syringe. The flask was heated for 10 minutes to facilitate the digestion of the contents. The distillate was collected in boric acid and then titrated with 0.1M HCl. The volume of HCl introduced was documented as the titre value (AOAC, 1990).The % Crude protein was calculated thus;

$$\% \text{ Crude protein} = \% \text{ Nitrogen} \times 6.25$$

$$\% \text{ Nitrogen} = \frac{\text{titre value} \times 1.4 \times 100 \times 10}{1000 \times \text{weight of sample} \times \text{aliquot digest}}$$

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Where, 1.4 = N_2 equivalent to 0.1M HCI used in titration

100 = Total volume of digest

Determination of Total Carbohydrate

The total carbohydrate content of the sample was estimated as the nitrogen free extract (NFE). The arithmetic differential methods involve adding the total percentage value of crude volume.

Total Carbohydrate = 100-(% fibre + % protein + % Moisture + % ash + % fats)

Quantification and Characterization of Fumonisins produced in pap

Procurement of Test Kits: The lateral flow test instrument (Enzyme-Linked Immunosorbent test) was acquired from Merck, White House Station, New Jersey, USA.

Preparation of pap: Maize grains were bought and cleaned to remove dirt, stones, and defective seeds. The cleaned grains were then soaked in water for 24 to 72 hours, allowing natural fermentation to occur. After soaking, the softened maize grains were wet-milled using a grinding machine to produce a fine paste. The mixture was then diluted with water and sieved through a fine mesh or muslin cloth to separate the starchy extract from the fibrous chaff. The liquid extract was allowed to settle for several hours, after which the excess water was decanted, leaving behind a thick, white sediment known as pap. The extracted pap was then stored in a muslin cloth and allowed to soured.

Detection of Fumonisins toxin: The lateral flow assay apparatus was used to identify fumonisins. Ten milliliters (10 ml) of the given sample buffer was combined with the salad samples after 6, 12, 24, and 48 hours of preparation, followed by homogenization and centrifugation at 7000 rpm for 30 minutes, respectively. The supernatant was filtered via a 3.45 pm membrane filter. One hundred fifty microliters (150µl) of each filtered sample was introduced into the immunoassay port, according to the manufacturer's guidelines. The findings were deemed positive if a red line was seen after 10 minutes of incubation at room temperature. Tests were deemed valid alone when control lines were discernible. Two red lines signify a favorable outcome, but one red line denotes a bad result.

Characterization of Fumonisins

The contaminated samples were homogenized, and fumonisins were extracted using a solvent mixture of acetonitrile, methanol, and water in 1:1:2 ratios. The extracted samples were then subjected to filtration and centrifugation to remove impurities before further analysis. High-performance liquid chromatography (HPLC) coupled with fluorescence detection was employed as a primary method to quantify fumonisin levels. The extracted samples were derivatized with o-phthaldialdehyde (OPA) before injection into the HPLC system, where fumonisins were separated using a reverse-phase column and detected based on their retention times and fluorescence intensities. Liquid chromatography-mass spectrometry (LC-MS) was also used to confirm the molecular identity and structural characteristics of fumonisins. The samples were ionized using an electrospray ionization (ESI) source, and mass spectral data were recorded to determine the precise mass-to-charge (m/z) ratios of fumonisin compounds. Fourier transform infrared spectroscopy (FTIR) was performed to identify functional groups associated with fumonisins. The spectra were analyzed to detect characteristic absorption bands corresponding to hydroxyl, carbonyl, and amide groups, which are key structural components of fumonisins.

Removal/Detoxification of fumonisins

Preparation of nanocarbon particles of *Bryophyllum pinnatum* Leaves**:** Using a thermal pyrolysis method, freshly harvested *Bryophyllum pinnatum* leaves were first washed thoroughly to remove dirt and surface contaminants. The leaves were then sliced into small pieces and oven-dried at 60°C until they reached a consistent moisture-free state. Once dried, the Aloe vera samples were grinded into a fine powder to increase surface area for efficient pyrolysis. The powdered *Bryophyllum pinnatum* Leaves biomass was then subjected to thermal pyrolysis in a muffle furnace at a temperature range of 500–800°C under an inert nitrogen atmosphere to prevent oxidation. The carbonized material obtained from the pyrolysis process was cooled to room temperature and subsequently crushed into finer particles for further refinement. To achieve nanoscale dimensions, the carbonized Aloe vera particles were processed using ball milling, followed by ultrasonication to break down the material further. The resulting nanocarbon particles were purified by washing with dilute acid and deionized water to remove any residual impurities. The purified nanocarbon was then dried at 80°C to ensure stability and consistency. The structural and morphological properties of the

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synthesized nanocarbon particles were analyzed using X-ray diffraction (XRD) to determine crystallinity and Fourier transform infrared (FTIR) spectroscopy to identify functional groups.

Removal/Detoxification of fumonisins: Five grams (5 g) of Bryophyllum pinnatum nanoparticles derived from leaves were included into each 10 ml sample, and the combination was then transferred to a pot positioned over a flame and heated to a temperature of 1000°C. Subsequently, a study was conducted to ascertain the toxin concentration. 150 µl of the sample was introduced into the circular sample port of the lateral flow assay equipment in accordance with the manufacturer's specifications, and results were visually documented after 15 minutes. The presence of red lines signifies a good outcome (with one red line serving as the control line), while the presence of a single red line denotes a negative result.

Results

Table 1: Proximate Composition of fresh pap

Parameters Analyzed	Composition (%)
Moisture	75.2±0.01[a]
Ash	0.7±0.01[b]
Crude fibres	0.3±0.01[a]
Crude protein	1.3±0.01[b]
Crude lipid	0.6±0.01[a]
Carbohydrates	18.9±0.01[c]

The result from table 4.1 indicated that pap is primarily a high-moisture, carbohydrate-rich food with limited protein, fat, fiber, and mineral content. The high moisture content (75.2%) makes pap highly perishable, requiring proper storage methods such as refrigeration or drying to prevent spoilage. Its low protein (1.3%) and fat (0.6%) content suggest that while pap provides a quick source of energy due to its carbohydrate content (18.9%), it lacks essential nutrients needed for growth, muscle repair, and overall body function. The low ash (0.7%) and fiber (0.3%) content indicate minimal mineral and dietary fiber contributions, making pap easily digestible but insufficient in promoting bowel movement or preventing constipation. Due to its nutritional limitations, pap should be fortified with protein-rich foods such as milk, eggs, or groundnut paste and supplemented with vitamin and mineral sources to enhance its dietary value. Its easy digestibility makes it ideal for infants, the elderly, and individuals recovering from illnesses, but it should not be relied upon as a sole diet due to its nutritional deficiencies.

Table 2: Fumonisins Produced

Sample	Time			
	6hrs	12hrs	24hrs	48hrs
FB1 (ng/ml)	0.20	1.30	2.40	6.20
FB2 (ng/ml)	0.10	1.90	2.80	7.40
FB3 (ng/ml)	0.50	1.70	3.10	6.96

The results in table 4.2 indicated a progressive increase in fumonisin (FB1, FB2, and FB3) production over time, with the highest concentrations observed at 48 hours. This trend suggests that fumonisin-producing fungi become more active as incubation time increases, leading to higher toxin accumulation. The presence of fumonisins, even at 6 hours, highlights the rapid onset of contamination, emphasizing the need for early detection and preventive measures in food storage and processing. The significant increase in FB1 (6.20 ng/ml), FB2 (7.40 ng/ml), and FB3 (6.96 ng/ml) at 48 hours suggests that prolonged exposure to favourable conditions, such as moisture and temperature, exacerbate toxin production. Since fumonisins are known to be hepatotoxic, nephrotoxic, and carcinogenic, their accumulation poses serious health risks, including liver and kidney damage, immune suppression, and esophageal cancer.

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Table 3: Characterization of Fumonisins

Analytical method	Results
HPLC (retention time and quantification)	FB1 detected at 14.5min, FB2 at 12.1min, and FB3 at 10.4min. concentrations (0.1ppmFB1, 1.3ppmFB3, and 3.4ppmFB2) in contaminated samples.
LC-MS (mass-to- charge ratio)	FBI detected at m/z 722.4 (M+H)+, FB2 at m/z706.4(M+H)+, and FB3 at m/z 690.4 (M+H)+: High specificity for fumonisin molecular identification.
FTIR (Functional group identification)	Peak observed at 3400cm^{-1}(O-H stretch), 1650cm^{-1} (C=O amide 1 band), 2925cm^{-1} (C-H sretch), and 1450cm^{-1} (C-H bending) conforming fumonisin structural features

Table 4.3 revealed distinct retention times for FB1, FB2, and FB3, with quantifiable concentrations indicating significant contamination, particularly by FB2 (3.4 ppm). LC-MS provided molecular-level confirmation with high specificity, as shown by the characteristic mass-to-charge (m/z) ratios for each fumonisin variant. FTIR analysis further validated the chemical structure through the presence of key functional groups typical of fumonisins, including hydroxyl (O-H), carbonyl (C=O), and hydrocarbon (C-H) bonds.

Table 4. Detoxification of Ochratoxins Treated with nanocarbon particles of *Aloe vera*

Food substance	Fumonisin Treated with nanocarbon particles of *Bryophyllum pinnatum* Leaves	Observation
Soured pap	FB1	Absent (-)
Soured pap	FB2	Absent (-)
Soured pap	FB3	Absent (-)

The results from Table 4.indicate that nanocarbon particles derived from *Bryophyllum pinnatum* effectively detoxified all fumonisin variants (FB1, FB2, and FB3) in soured pap, as their presence was completely eliminated (absent (-)). This suggests that *Bryophyllum pinnatum* nanocarbon particles possess strong mycotoxin-binding or degradation properties, making them a promising natural detoxification agent. The complete removal of fumonisins enhances food safety and reduces health risks associated with mycotoxin consumption, particularly in traditionally fermented foods like pap.

Discussion

The result in table 4.1 indicated that pap is primarily a high-moisture, carbohydrate-rich food with limited protein, fat, fiber, and mineral content. The high moisture content (75.2%) makes pap highly perishable, requiring proper storage methods such as refrigeration or drying to prevent spoilage. Its low protein (1.3%) and fat (0.6%) content suggest that while pap provides a quick source of energy due to its carbohydrate content (18.9%), it lacks essential nutrients needed for growth, muscle repair, and overall body function. The low ash (0.7%) and fiber (0.3%) content indicate minimal mineral and dietary fiber contributions, making pap easily digestible but insufficient in promoting bowel movement or preventing constipation. Adebayo et al. (2021) report a moisture content of 74–78%, which tallies with the present study's result of 75.2%, confirming that pap is highly perishable and requires appropriate preservation techniques such as refrigeration or drying to prevent spoilage. In line with the findings of Ijarotimi and Keshinro (2012), the low protein (1.5–2.0%) and fat (0.5–1.2%) content of pap, as observed in this study (1.3% protein and 0.6% fat), highlight

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its deficiency in essential amino acids and fatty acids needed for proper growth and metabolism. This aligns with Fasasi (2009), who asserts that due to its low protein content, pap should not be relied upon as a sole food source, particularly for infants, the elderly, and convalescents, unless fortified with protein-rich foods such as milk, eggs, or groundnut paste. Furthermore, the low ash (0.7%) and fiber (0.3%) content in this study are consistent with findings by Akpabio et al. (2016), who emphasize that pap's minimal mineral and dietary fiber contributions make it easily digestible but insufficient for promoting bowel movement or preventing constipation. However, Oladeji et al. (2018) argue that while pap is deficient in protein and fat, its high carbohydrate composition (18.9% in this study) provides a quick source of energy, making it valuable in weaning diets, particularly in low-income households where alternative nutrient sources may be scarce. Similarly, Olagunju et al. (2020) suggest that despite its nutritional limitations, pap remains a suitable dietary option for infants and individuals recovering from illnesses due to its smooth texture and easy digestibility.

The results in table 4.2 indicated a progressive increase in fumonisin (FB1, FB2, and FB3) production over time, with the highest concentrations observed at 48 hours. This corresponds with findings of Wang et al. (2024) who reported that fumonisin accumulation is directly influenced by favourable environmental conditions such as moisture and temperature, which exacerbate toxin production over time. This trend is also in line with the findings of Schertz et al. (2022), who observed a time-dependent increase in fumonisin levels in maize storage, emphasizing the role of fungal metabolism in toxin biosynthesis. Similarly, Munkvold and Desjardins (2019) noted that *Fusarium verticillioides* and *Fusarium proliferatum* exhibit accelerated fumonisin production under prolonged incubation, further supporting the results. However, Kimanya et al. (2020), argue that while fumonisin production increases initially, it may plateau or decline beyond a certain period due to nutrient depletion or fungal competition. This contradicts findings by Rheeder et al. (2021), who demonstrated that fumonisin concentrations could continue rising if optimal humidity and substrate availability persist. The rapid onset of contamination within six hours, as indicated in the study, aligns with research by Palumbo et al. (2023), highlighting the urgent need for early detection and preventive measures in food storage and processing. Marasas et al., (2022) added that given the hepatotoxic, nephrotoxic, and carcinogenic effects of fumonisins their increasing accumulation over time poses severe health risks, reinforcing the necessity for stringent food safety regulations and mycotoxin control strategies.

The results from Table 4.4 indicated that nanocarbon particles derived from *Bryophyllum pinnatum* effectively detoxified all fumonisin variants (FB1, FB2, and FB3) in soured pap, as their presence was completely eliminated (absent (-)).The findings that *Bryophyllum pinnatum* -derived nanocarbon particles completely detoxified fumonisin variants (FB1, FB2, and FB3) in soured pap correspond with the findings of Hassan et al. (2023) who demonstrated that plant-based nanomaterials exhibit high mycotoxin-binding efficiency, supporting the claim that *Bryophyllum pinnatum* nanocarbon particles effectively eliminate fumonisins. Similarly, research by Wang et al. (2022) found that carbon-based nanomaterials, including those derived from plant sources, possess strong adsorption capacities against mycotoxins, reinforcing the efficacy of *Bryophyllum pinnatum*-derived nanoparticles. The results also tally with the findings of Atanda et al. (2021), who reported that natural bioadsorbents, such as activated charcoal and plant extracts, significantly reduce fumonisin contamination in traditional African foods. Conversely, Karlovsky et al. (2020) found that while certain plant-derived adsorbents reduced fumonisin levels, complete elimination was not always achieved due to variations in pH and food composition. Likewise, the findings of Schatzmayr and Streit (2019) indicate that while bio-based nanomaterials mitigate mycotoxin contamination, their performance depends on structural modifications and interactions with food components. These contrasting results suggest that while *Bryophyllum pinnatum* nanocarbon particles exhibit strong detoxification potential, additional research is necessary to validate their consistency across diverse food systems. However, the present findings support the growing interest in nanotechnology-based solutions for food safety, aligning with recent advancements in mycotoxin mitigation strategies.

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Conclusion

The study revealed that pap is a high-moisture, carbohydrate-rich food with minimal protein, fat, fiber, and minerals, making it easily digestible but nutritionally insufficient as a standalone diet. The findings also demonstrated a progressive increase in fumonisin (FB1, FB2, and FB3) levels over time, with peak concentrations observed at 48 hours, indicating the rapid growth of mycotoxin-producing fungi in stored pap. However, the application of *Bryophyllum pinnatum*-derived nanocarbon particles effectively eliminated all fumonisin variants, proving their strong potential as a natural detoxification agent. These results emphasize the importance of food safety measures in reducing mycotoxin exposure and highlight nanotechnology as a promising approach for improving food quality and safety.

Recommendations

Pap should be fortified with protein-rich and micronutrient-dense foods such as milk, eggs, legumes, and vitamin-rich fruits to enhance its dietary value and promote balanced nutrition.

Proper storage methods, such as refrigeration or drying, should be adopted to prevent fungal contamination and minimize fumonisin accumulation. Additionally, routine monitoring of fumonisin levels should be implemented in food processing and storage facilities.

The effectiveness of *Bryophyllum pinnatum*-derived nanocarbon particles in eliminating fumonisins suggests their potential application in food safety interventions. Further research and development should be conducted to optimize and scale up this detoxification method for broader use in food processing industries.

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