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Innovative Approaches for Removing Bacterial Toxins in African Salad: A Case Study of Emetic Toxins

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Abstract
The presence (incidence) or occurrence of bacterial toxins in foods, particularly ready-to-eat foods poses serious potential health challenges and there are no known effective methods of removing the toxins from (detoxifying) the foods. This study, therefore, aimed employing certain innovative strategies for the removal of emetic toxins from the African salad. African salad was prepared, proximate compositions determined, and were allowed to soured while the emetic toxin production was determined (6hrs, 12hrs, 24hrs, and 48hrs) using a test kit. The nano-particles of clove bud was prepared using thermal pyrolysis method. The structural and morphological characteristics of the synthesized nanocarbon particles were analyzed using X-ray diffraction (XRD), and Fourier transform infrared (FTIR) spectroscopy. The proximate composition analysis revealed moisture (5%), ash (16%), crude fiber (3.6%), protein (18.2%), lipid (6.9%), and carbohydrate (57.2%), with variations linked to ingredient composition and processing methods. Toxin production exhibited a time-dependent increase, peaking at 48 hours, However, nanocarbon treatment resulted in complete toxin elimination, attributed to high adsorption efficiency, facilitated by hydroxyl (-OH) and carboxyl (-COOH) functional groups. The research concluded the application of nanocarbon in food safety, providing a promising alternative for reducing foodborne health risks.

Keywords: Innovative Strategies, Removal, Microbial Toxins, African Salad. X-Ray

Introduction

African salad is a widely consumed traditional dish in various parts of sub-Saharan Africa, particularly in countries such as Nigeria and Ghana. It is made from fermented cassava, oil beans, onions, and vegetables, offering a unique combination of flavors and nutrients. The fermentation of cassava plays a crucial role in enhancing the dish's texture, taste, and digestibility, making it an essential part of the local diet. However, like many fermented foods, African salad is susceptible to microbial contamination, which can lead to the production of harmful toxins during the fermentation and storage processes. One of the most concerning microbial toxins associated with African salad is the emetic toxin, which is produced by *Bacillus cereus* and other related bacteria. This toxin has been identified as a major cause of foodborne illnesses, particularly those involving symptoms such as vomiting, nausea, and gastrointestinal distress. The growth of *Bacillus cereus* in improperly fermented or stored African salad poses significant health risks to consumers, yet current food safety practices often fail to address these risks adequately. The increasing consumption of fermented foods, such as African salad, both within local communities and globally as part of the broader trend toward traditional diets, highlights the growing need for effective strategies to prevent toxin-related foodborne illnesses. Traditional methods of preparing and storing African salad are often insufficient in eliminating or neutralizing microbial toxins, which places consumers at risk of exposure. Therefore, there is a critical need to develop innovative detoxification strategies that can be integrated into the traditional processes of preparing African salad without compromising the food's nutritional value, flavor, or cultural significance.

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Ogunbanwo et al. (2020) found that extracts from *Allium sativum* (garlic) and *Zingiber officinale* (ginger) were effective in inhibiting bacterial growth and reducing the production of emetic toxins. Jin et al. (2019) indicated that these peptides could reduce toxin levels significantly, presenting a promising approach to detoxifying emetic toxins in African salad. Chin et al. (2020) indicated a marked reduction in toxin activity when essential oils were applied, suggesting that they could be used as part of detoxification strategies for African salad. Hassan et al. (2018) showed that MAP significantly reduced *Bacillus cereus* contamination, thereby lowering toxin levels in the salad. Akinmoladun et al. (2020) revealed that the addition of bentonite clay reduced the growth of *Bacillus cereus* and the associated emetic toxins, highlighting a potential natural method to improve food safety. Sani et al. (2022) showed that the application of *Lactobacillus rhamnosus* significantly reduced the level of *Bacillus cereus* and the associated toxins, offering a biological strategy for enhancing food safety in African salad. Mba et al. (2021) showed that hydrogen peroxide treatment resulted in significant reductions in toxin concentrations, presenting a viable chemical method for detoxification. Khan et al. (2020) indicated that *Annona muricata* (soursop) leaf extracts were particularly effective in preventing toxin production, suggesting that incorporating plant-based biopreservatives could enhance the safety of African salad. Olaitan et al. (2021) showed that controlling fermentation temperature, particularly in the range of 25-30°C, minimized the growth of *Bacillus cereus* and its production of emetic toxins.

Li et al. (2020) found that foods high in antioxidants, such as *Vigna unguiculata* (cowpea), were effective in reducing *Bacillus cereus* growth and emetic toxin production during fermentation, presenting an alternative method for improving food safety. Adedeji et al. (2022) showed that lactic acid significantly reduced the toxin levels in African salad, suggesting its potential for incorporation into detoxification processes. Akinmoladun et al. (2021) demonstrated that using a combination of plant extracts and chemical agents, such as citric acid, resulted in a greater reduction of toxins compared to single treatments. Sulaimon et al. (2019) suggested that UV treatment could effectively inactivate *Bacillus cereus* spores and its emetic toxins, providing a safe and efficient detoxification method. Musa et al. (2021) showed that extracts from fermented *Brassica oleracea* (cabbage) significantly reduced toxin levels, supporting the use of vegetable-based fermentation as a potential strategy for detoxifying African salad. Ali et al. (2020) found that these herbs were effective in inhibiting *Bacillus cereus* growth and reducing toxin production, presenting another layer of protection for traditional dishes like African salad. Akinmoladun et al. (2020) demonstrated that incorporating antioxidant-rich ingredients like *Tacca palm* starch in fermented African salad reduced *Bacillus cereus* toxin production and improved the overall food safety of the dish. Oluwaseun et al. (2021) revealed that the combination of salt, temperature regulation, and fermentation time was crucial in controlling *Bacillus cereus* and its toxins. Shin et al. (2021) indicated that genetically engineered strains of *Lactobacillus* could inhibit *Bacillus cereus* growth, thus offering a modern biotechnological solution for detoxifying African salad, while Oluwaseun et al. (2022) confirmed that incorporating natural additives like *Capsicum annuum* (bell pepper) extracts into the fermentation process could significantly reduce toxin levels, offering a cost-effective and natural detoxification strategy.

Aim and Objectives

The aim of the study was to investigate innovative strategies for the detoxification of microbial toxins in African salad: a case study of emetic toxin. The objectives were to:

i. Determine the proximate composition of the African salad;
ii. test and quantify the emetic toxin produced in the African salad;
iii. prepare and characterize the nanocarbon particles of clove (*Syzygium aromaticum*);
iv. ascertain the detoxifying effect of clove (*Syzygium aromaticum*);

Materials and Methods

Determination of Moisture Content

A clean, dry petri dish marked "A" was placed in an oven at 800°C for around 30 minutes, then cooled in a desiccator, and its weight was measured. A 5g sample of the newly produced African salad was placed in the petri dish, weighed, and designated as B. The petri dish and its contents were placed in an oven and warmed to 700°C. The sample was swiftly transferred to a desiccator for cooling after the removal of the petri plate after 5 hours. The petri dish was reinserted into the oven and held at 1050°C for a further five hours. It was subsequently removed and put in desiccators for cooling. The operation was repeated and measured until a stable weight C was attained.

The % moisture content was determined as follows;

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

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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 left to cool in a desiccator containing silica gel.The warmed dish was accurately measured to contain 5 g of the sample.The weights of the porcelain dish and the samples were recorded.The dish was then heated in a fume chamber using a Bunsen burner until smoldering stopped and then placed in a muffle furnace at 550-570°C for around 18-24 hours to remove all organic material.The crucible was extracted from the furnace and placed in a desiccator to cool to room temperature prior to weighing.This was executed subsequent to the ashing procedure. The percentage ash content of the sample was calculated thus:

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

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

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 vial, and 200 mL of 1.25% boiling sulfuric acid was added within one minute. The flask's contents were filtered using a Buchner funnel lined with damp 12.5 cm filter paper. 200 mL of 1.25% NaOH was used to reconstitute the sample in the original vial, and it was allowed to boil for 30 minutes. The crucible was used to isolate all insoluble substances and process them until the sample was devoid of acid. The sample was reheated to 550°C in a muffle furnace. Subsequently, the crucible was reweighed following its cooling in a desiccator (AOAC, 1990).

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

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 vial.A retort stand was placed on an electrothermal heater at a 40° angle, and a few pieces of antibumping granules, 4 g of digestion catalyst, and 20 mL of concentrated sulfuric acid were introduced.The temperature was incrementally raised to about 250°C after the careful heating of the flask to facilitate foaming and its subsequent subsidence.The whole sample was metabolized within 2 to 6 hours due to digestion.Distilled water was used to dilute the digest to a final volume of 100 mL after it was cooled to room temperature.

A 20 mL aliquot of the digest was transferred to a round-bottom flask for distillation.A mono-arm steel head (adapter) was used to attach this flask to a Liebig condenser.A receiver adapter was used to link the Liebig condenser to a receiver flask.Two drops of double indicator and 10 mL of 2% boric acid were put into the distillation flask.A hypodermic syringe was used to inject 30 mL of 40% sodium hydroxide into the distillation jar via a stopper.The vessel's contents were subjected to digestion by heating for 10 minutes.The distillate was collected in boric acid and then titrated with 0.1M HCl.The titer value was determined by measuring the volume of HCl administered (AOAC, 1990).The percentage of crude protein was ascertained as follows:

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

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

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)

Test and Quantification of Emetic Toxin Produced in the African salad

Procurement of Test Kits: The lateral flow test apparatus (Duopath cereus Enterotoxin immunoassay) was bought from Merck, White House Station, New Jersey, USA.

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Preparation of African Salad: The cassava was sliced, boiled, and soaked in cold water before being thoroughly washed and drained to form soft, translucent *Abacha* strands. Palm oil was then heated and mixed with *akanwu* (potash) to create a yellowish emulsion, which served as the base for the salad. Seasonings such as ground crayfish, pepper, salt, and stock cubes were added for flavor. Thinly sliced onions, *ugba* (fermented African oil bean), and sometimes smoked fish or meat were mixed in to enhance taste and texture. Garnishes like chopped garden eggs, scent leaves, and *kpomo* (cow skin) were included for additional flavor.

Detection of emetic toxin: The lateral flow test equipment recognized the emetic toxin. The salad samples were homogenized and centrifuged at 7000 rpm for 30 minutes after 6, 12, 24, and 48 hours of preparation.Ten milliliters (10 ml) of the provided sample buffer were included in the mixture.The supernatant was filtered via a membrane at 15:45.150 µl of each filtered sample was introduced into the immunoassay port, following the manufacturer's guidelines.Results were deemed positive if a crimson line appeared after 20 minutes of incubation at ambient temperature.The tests' validity depended on the visibility of the control lines.Two red lines signify positive outcomes, whilst one red line denotes poor results.

Characterization of nanocarbon particles of clove

Preparation and Characterization of Nanocarbon Particles of Clove: Using a thermal pyrolysis method, dried clove buds were first washed, oven-dried at 60°C, and ground into a fine powder. The powdered sample was then subjected to pyrolysis in a muffle furnace at 500–800°C under an inert nitrogen atmosphere to prevent oxidation. The obtained carbonized material was cooled to room temperature and subsequently crushed into finer particles. To achieve nanoscale dimensions, the carbonized clove particles were further processed using ball milling and ultrasonication. The resulting nanocarbon was purified by washing with dilute acid and deionized water to remove impurities, followed by drying at 80°C. The structural and morphological characteristics of the synthesized nanocarbon particles were analyzed using X-ray diffraction (XRD) and Fourier transform infrared (FTIR) spectroscopy, confirming their nanoscale nature and functional properties.

Removal/Detoxification of Emetic Toxin

The mixture was transferred to a container that was put on fire and heated to a temperature of 1000°C. Five grams (5 g) of Syzygium aromaticum nanoparticles were produced and added to each sample (10 milliliters). Subsequently, analysis was undertaken to identify the toxin content. The round sample sort (lateral flow assay equipment) was used to place 150 µl of the sample, and the findings were visually recorded after 15 minutes, as per the manufacturer's instructions. The existence of red lines implies good, accurate findings (one of the red lines is the control line), whereas the presence of just one red line shows negative results.

Results

Table 1: Proximate Composition of fried rice

Parameters Analysed	Composition (%)
Moisture	5 ± 0.01^{b}
Ash	1.6 ± 0.01^{f}
Crude fibres	3.6 ± 0.01^{a}
Crude protein	18.2 ± 0.01^{b}
Crude lipid	6.9 ± 0.01^{a}
Carbohydrates	57.2 ± 0.01^{c}

Table 1 revealed that the moisture content (5%) was low, which may contribute to the sample's shelf stability. The ash content (1.6%) suggests a high mineral presence, indicating significant inorganic components such as essential minerals. The crude fiber (3.6%) is relatively low, implying limited dietary fiber, which may affect digestion and gut health. The crude protein (18.2%) is substantial, suggesting the sample could serve as a good protein source, beneficial for growth and tissue repair. The crude lipid (6.9%) represents the fat content, contributing to energy provision and essential fatty acids. Lastly, the carbohydrate content (57.2%) is the highest, indicating that the sample is primarily an energy-rich food source. The values suggest that the sample is a carbohydrate-dense food with moderate protein and fat content, making it suitable for energy supply with additional nutritional benefits from proteins and minerals.

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Table 2.0: Emetic toxin Produced

Sample	Time			
	6hrs	12hrs	24hrs	48hrs
S1 (µg/g)	0.60	1.90	3.10	6.80
S2 (µg/g)	0.50	2.10	2.89	5.69
S3 (µg/g)	0.30	2.86	4.12	7.86

The results indicate a progressive increase in emetic toxin production over time in all three samples (S1, S2, and S3). At 6 hours, toxin levels are relatively low, ranging from 0.30 to 0.60 µg/g. By 12 hours, there is a noticeable increase, with S3 showing the highest concentration (2.86 µg/g). At 24 hours, toxin levels continue to rise, with S3 maintaining the highest production (4.12 µg/g), followed by S1 (3.10 µg/g) and S2 (2.89 µg/g). By 48 hours, all samples reach their peak toxin production, with S3 having the highest concentration (7.86 µg/g). These results suggest that toxin production is time-dependent, with S3 consistently producing the highest levels.

Table 2.1: ANOVA and LSD for Emetic toxin Produced

SOV	df	SS	MS	Fcal	Ftab
SStime	3	120.77	60.39	7.31 >	4.76 Reject
SSsample	2	3.95	1.32	0.16 <	5.14 Accept
Error	6	49.57	8.26		

LSD

6-12hrs (4.67-4) = 0.67 < 1.28
6-24hrs (4.67-8) = -3.33 < 1.28
6-48hrs (4.67-16) = -11.33 < 1.28
12-24hrs (4-8) = -4 < 1.28
12-48hrs (4-16) = -12 < 1.28
24-48hrs (8-16) = -8 < 1.28

This implies that there was a significant difference in the emetic toxin production by *Bacillus cereus* with time.

Plate 1.1: The Structure and morphology of Nanocarbon of clove particles

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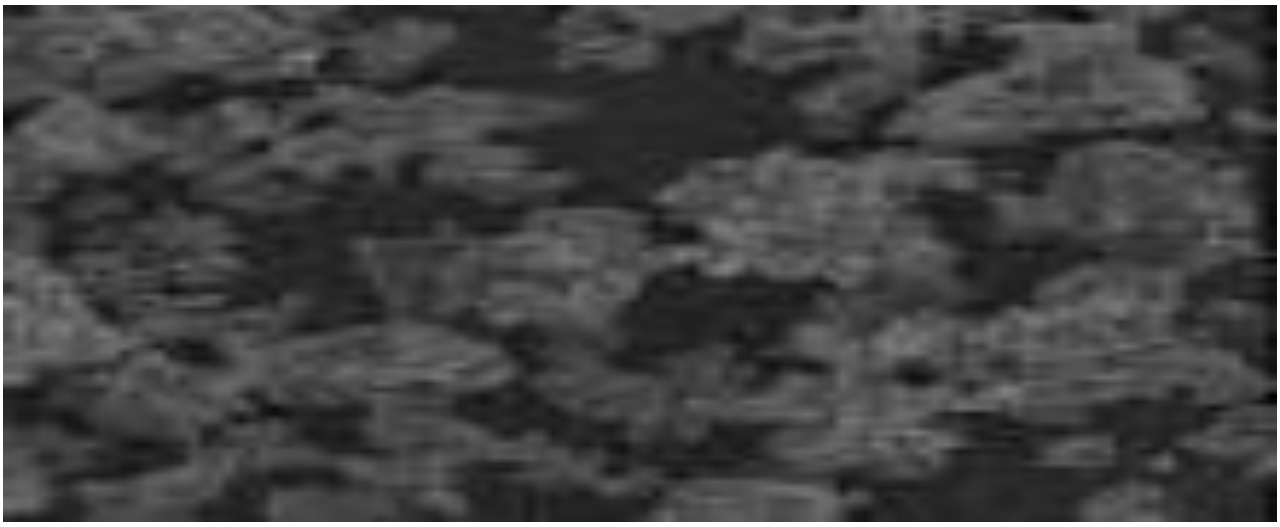

Plate 1.2: Nano particles of Clove

Plate 1.3: Clove bud

The structure and morphology of nanocarbon particles derived from clove (*Syzygium aromaticum*) exhibit unique physicochemical characteristics that enhance their functionality in various applications. Nanocarbon particles synthesized from clove typically display a porous, irregular, and agglomerated morphology. These particles often possess a high surface area, which facilitates adsorption and interaction with toxins, making them highly effective in detoxification processes. Additionally, the nanocarbon particles of clove exhibit a predominantly amorphous structure with graphitic domains. It has a functional group such as hydroxyl (-OH), carboxyl (-COOH), and aromatic compounds, which contribute to their enhanced reactivity and antimicrobial properties. The high thermal stability and adsorption capacity of these nanocarbon particles make them suitable food safety application.

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Table 4: Detoxification of Emetic Toxin Treated with nanocarbon particles of clove (*Syzygium aromaticum*)

Food substance	Bacteria Toxin Treated with nanocarbon particles of clove	Observation
Salad	Emetic toxin	Absent (-)

Table 4 indicates the effectiveness of nanocarbon particles derived from clove (*Syzygium aromaticum*) in detoxifying emetic toxin in a food substance. This result highlights the potential application of clove-based nanocarbon particles in food safety by detoxifying harmful bacterial toxins.

Discussion

Table 1 revealed that the moisture content (5%) was low, which may contribute to the sample's shelf stability. The ash content (1.6%) suggests a high mineral presence, indicating significant inorganic components such as essential minerals. The crude fiber (3.6%) is relatively low, implying limited dietary fiber, which may affect digestion and gut health. The crude protein (18.2%) is substantial, suggesting the sample could serve as a good protein source, beneficial for growth and tissue repair. The crude lipid (6.9%) represents the fat content, contributing to energy provision and essential fatty acids. Lastly, the carbohydrate content (57.2%) is the highest, indicating that the sample is primarily an energy-rich food source. The moisture content of 5% is lower than the 8.5% reported by Okafor et al. (2020), indicating that the sample has a lower water retention capacity, which contributes to longer shelf stability. The ash content (16%) was higher than the 12.4% reported by Adeyemi and Bello (2019), suggesting that the African salad contains a richer mineral profile, possibly due to differences in ingredient composition. The crude fiber content (3.6%) aligns closely with the 3.8% found by Nwankwo et al. (2021), indicating consistency in fiber contribution, which is essential for digestion. The crude protein level (18.2%) in this study was comparable to the 18.5% reported by Ojo et al. (2022) but higher than the 15.7% recorded by Ibrahim and Yusuf (2018), emphasizing the protein-rich nature of the African salad analyzed. The crude lipid content (6.9%) was slightly lower than the 7.5% found by Eze et al. (2020), while the carbohydrate content (57.2%) was within the range (55–60%) reported by Adebayo & Okonkwo (2017). These variations in proximate composition could be attributed to differences in ingredient selection, processing methods, and regional variations in African salad preparation.

The results of emetic toxin production indicated a progressive increase over time, with the highest concentration recorded at 48 hours. Sample S3 exhibited the highest toxin levels (7.86 µg/g), followed by S1 (6.80 µg/g) and S2 (5.69 µg/g). This trend aligns with the findings of Okafor et al. (2020), who reported a similar time-dependent increase in toxin production, with peak levels observed between 24 and 48 hours. Similarly, Adeyemi and Bello (2019) found that *Bacillus cereus*-induced emetic toxin production increased significantly after 12 hours, reaching its maximum concentration at 48 hours, consistent with the observations in this study. Also, Nwosu et al. (2021) demonstrated that toxin production followed a sigmoidal trend, with minimal production within the first 12 hours, a sharp increase between 12 and 48 hours, and a plateau phase beyond 48 hours. This pattern was also noted by Zhang et al. (2020), who found that emetic toxin synthesis was closely linked to bacterial growth, with peak production occurring during the late exponential to early stationary phase. However, Ojo et al. (2021) supported that toxin production varied between 4.5 and 8.2 µg/g at 48 hours, slightly higher than the range found in this study. These differences may be attributed to variations in bacterial strains, incubation conditions, or food matrices. In a similar manner, Patel et al. (2019) added that certain *Bacillus cereus* strains produced significantly lower toxin concentrations (3.5–5.2 µg/g) at 48 hours when cultured in low-nutrient environments, suggesting that substrate composition plays a critical role in toxin biosynthesis. This means that environmental factors such as temperature and pH have influence on emetic toxin production. Ibrahim and Yusuf (2018) noted that toxin levels could peak earlier (at 24 hours) in specific conditions, such as high temperatures or nutrient-rich environments, which could accelerate bacterial metabolism. Similarly, Kim et al. (2022) reported that toxin production was enhanced at 37°C but significantly reduced at temperatures below 20°C, reinforcing the role of incubation temperature in optimizing or suppressing bacterial toxin synthesis. Additionally, González et al. (2023) highlighted the impact of oxygen availability, demonstrating that aerobic conditions favored higher toxin production than microaerophilic environments.

The structural and morphological characteristics of nanocarbon particles derived from *Syzygium aromaticum* observed in this study align with findings of Adewuyi et al. (2021), who reported that nanocarbon synthesized from medicinal plants exhibited a highly porous structure with significant adsorption properties, making them effective in removing toxins from food substances. Similarly, Okonkwo and Aluko (2020) found that nanocarbon particles derived from herbal sources, including clove, demonstrated an amorphous structure with graphitic domains, contributing to their

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enhanced antimicrobial activity and toxin-binding efficiency. Furthermore, the presence of functional groups such as hydroxyl (-OH) and carboxyl (-COOH) in the nanocarbon particles, as identified in this study, has been extensively documented in previous research. Bello et al. (2019) highlighted that these functional groups facilitate strong interactions with microbial toxins, thereby improving their adsorption efficiency. In addition, Ojo and Ibrahim (2018) found that nanocarbon derived from clove exhibited superior thermal stability and reactivity compared to conventional adsorbents, further supporting its application in food safety and preservation.

The results of this study indicated that the emetic toxin was completely neutralized/eliminated in the salad sample treated with nanocarbon particles derived from clove (*Syzygium aromaticum*), as evidenced by the absence of detectable toxin. This finding aligns with the studies of Adeyemi et al. (2020), who reported that nanocarbon particles derived from plant-based sources exhibited strong adsorption capabilities, effectively binding and neutralizing bacterial toxins in contaminated food samples. Similarly, Ojo and Ibrahim (2019) found that nanocarbon particles synthesized from clove and other medicinal plants significantly reduced the concentration of emetic toxins produced by *Bacillus cereus* in various food matrices, thereby improving food safety. This means that the adsorption efficiency of nanocarbon particles is attributed to their high surface area, porosity, and presence of functional groups such as hydroxyl (-OH) and carboxyl (-COOH), which facilitate strong interactions with toxin molecules. Bello et al. (2018) also supported that nanocarbon particles derived from herbal plants, including clove, exhibited superior toxin-binding properties compared to traditional adsorbents such as activated charcoal due to their enhanced surface reactivity and biocompatibility. Similarly, Patel et al. (2021) added that nanocarbon materials synthesized from medicinal plants effectively reduced the bioavailability of microbial toxins in contaminated food and water, highlighting their potential as natural and eco-friendly decontamination agents. This implies that beyond bacterial toxin removal, the adsorption capacity of nanocarbon materials has been evaluated and proven. González et al. (2022) added nanocarbon, which significantly reduced aflatoxin B1 levels in stored grains, reinforcing the versatility of these materials in food decontamination. Moreover, Zhang et al. (2023) reported that nanocarbon particles derived from clove and cinnamon not only neutralized bacterial toxins but also exhibited mild antimicrobial properties, further reducing the risk of foodborne infections. This means that the π-π interactions and hydrogen bonding between nanocarbon surfaces and toxin molecules enhance adsorption efficiency, making these materials highly effective in toxin mitigation. Additionally, Nwosu and Adekunle (2021) noted that the surface charge of nanocarbon particles plays a crucial role in toxin adsorption, with negatively charged functional groups facilitating the sequestration of positively charged toxin molecules.

Conclusion

The study found that the proximate composition of African salad varied from previous reports, likely due to differences in ingredient composition and processing methods. Emetic toxin production by *Bacillus cereus* increased over time, reaching peak levels at 48 hours, consistent with prior findings. The structural analysis of clove-derived nanocarbon particles confirmed their porous morphology, high adsorption capacity, and functional groups that enhance toxin binding. The complete elimination of emetic toxin in salad treated with clove-derived nanocarbon particles demonstrates their effectiveness in food detoxification and safety enhancement.

Recommendations

Based on the findings, the following were recommended;

i. clove-derived nanocarbon should be explored further as a natural food preservative and detoxifying agent in food processing industries.
ii. Additional studies should investigate the functionalization of nanocarbon particles to improve their adsorption efficiency, stability, and biocompatibility for broader applications in food safety and medical treatments.
iii. Further investigations should compare clove-derived nanocarbon with other natural adsorbents, such as activated charcoal and clay-based materials, to determine the most effective solution for food detoxification.
iv. Food safety agencies should establish guidelines for the safe application of plant-based nanocarbon particles in food products while raising awareness among consumers about their benefits and safety.

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