

Comparative Evaluation of Aflatoxin Safety and FTIR-Based Detection of Adulteration in Locally Processed Powdered Garlic and Turmeric Sold in Selected Markets in Kaduna North, Nigeria.

Abdul Safiya Abdulaziz^a, Yakubu Magaji^b, Abdulsalami Muhammed Sani^c, Hassan Abba Umar^d

a Department of Biotechnology, Nigeria Defence Academy, Kaduna, Nigeria. Email: safiyaabdul92@gmail.com

b Department of Biotechnology, Nigeria Defence Academy, Kaduna, Nigeria. Email: magajiyakubu01@gmail.com

c Department of Biotechnology, Nigeria Defence Academy, Kaduna, Nigeria. Email: msabdulsalami@nda.edu.ng

d Department of Biotechnology, Nigeria Defence Academy, Kaduna, Nigeria. Email: abbahu@nda.edu.ng

Keywords:

Aflatoxin
Adulteration
ELISA
FTIR
Garlic
Turmeric

ABSTRACT

Garlic and turmeric are widely used spices that may be susceptible to quality deterioration and adulteration during processing, handling and storage. This study evaluated the moisture content, ash content and total aflatoxin concentration and assessed possible adulteration using Fourier Transform Infrared (FTIR) spectroscopy of locally processed powdered garlic and turmeric sold in selected markets in Kaduna North, Nigeria. Powdered garlic and turmeric samples were collected from three markets: Kawo, Unguwar Rimi and Central Market. Samples from three vendors in each market were combined to form composite samples. Raw samples were also collected and processed in two forms (Peeled and unpeeled) to serve as the control. Moisture and ash contents were determined using standard AOAC procedures, while total aflatoxin concentration was determined using competitive enzyme-linked immunosorbent assay (ELISA). FTIR spectra were obtained over the range of 4000–650 cm⁻¹ and compared among market-processed samples, controls and selected potential adulterants. The moisture contents of garlic and turmeric ranged from 3.45 to 4.69% and 5.27 to 5.89%, respectively, while the corresponding ash contents ranged from 4.59 to 5.24% and 3.38 to 4.68% for garlic and turmeric respectively. Total aflatoxin concentrations ranged from 0.052 to 0.229 µg/kg for garlic and 0.251 to 0.678 µg/kg for turmeric, with all values falling below the EU/WHO/NAFDAC 10 µg/kg regulatory limits. FTIR spectral comparisons revealed differences between market-processed samples and controls, while similarities between market-processed garlic and selected plant-based adulterants and between market-processed turmeric and maize flour/cornstarch suggesting possible adulteration. The findings indicate that although the investigated samples had aflatoxin concentrations below the regulatory limit and therefore, are safe for consumption based on aflatoxin levels, differences in FTIR spectral profiles highlight the need for continued monitoring of the quality and authenticity of locally processed powdered spices. FTIR shows potential as a rapid screening technique for detecting possible adulteration in powdered garlic and turmeric.

INTRODUCTION

Garlic (*Allium sativum*) and turmeric (*Curcuma longa*) are important spices widely used in food preparation and traditional applications [13, 22]. Their powdered forms are particularly convenient for consumers and are commonly sold through formal and informal market channels. However, processing spices into powder can make it more difficult to visually identify the original plant material and may increase the opportunity for substitution or addition of undeclared materials [24, 33]. Spice products are recognized as commodities that can be affected by contamination, adulteration and other authenticity concerns, creating a need for reliable quality-control approaches [20]. *Aspergillus* species, known as storage fungi, are of particular concern as they can survive at very low water activity and produce harmful mycotoxins during prolonged storage. Among the mycotoxins, aflatoxins (AFs) are the most prevalent in spices, typically produced by *Aspergillus* spp. [29]. Aflatoxin contamination is an important food-safety concern associated with inadequate drying, handling and storage conditions. Aflatoxins are produced by certain toxigenic fungi and their presence in food commodities can pose health risks [30]. Spices may become contaminated at different stages of the supply chain, particularly where environmental and storage conditions favour fungal development [29]. In addition to contamination, adulteration represents an important quality concern in powdered spices. Adulteration may involve the addition of cheaper plant materials, flours or starches to increase bulk or reduce production costs [14]. Spice adulteration poses a significant issue, increasing product impurity and compromising consumer safety. In

powdered form, garlic is prone to adulteration, often with white powders like talc, chalk, or starch [13]. Turmeric powder, in particular, has been reported to be susceptible to adulteration with materials including starches and cereal-derived diluents. This adulteration can also contribute to variations in curcumin content in commercial turmeric powders [26]. A contributing factor to food adulteration is the inadequate regulation and enforcement of food safety standards. In many countries, food laws are either weak or poorly enforced due to understaffed, untrained, or corrupt regulatory agencies [14]. This lack of oversight allows dishonest businesses to engage in food adulteration without consequences. Additionally, outsourcing food production to countries with lower labor costs has exacerbated the problem, as reduced production expenses and high profit margins have encouraged adulteration and counterfeit practices [9]. Fourier Transform Infrared (FTIR) spectroscopy provides information about the composition of a sample through characteristic infrared absorption bands [8]. It is a rapid analytical technique that has been widely investigated for food authenticity and adulteration studies [7]. Its usefulness arises from the characteristic spectral patterns produced by different chemical components, while the fingerprint region can provide additional information for distinguishing complex food matrices.

MATERIALS AND METHOD

Study Area

The study was conducted in Kaduna North, Kaduna State, Nigeria, which is located at latitude 10°35'N and longitude 7°25'E. Kaduna North is situated in the northern part of Kaduna State, covering

an area of approximately 70.20 km², with a population of 364,575 as of 2006 Nigeria population census and a projection of 538,600 as at 2022 [10]. The city's economy is driven by a diverse range of activities, including trade, small-scale industries, manufacturing and food processing, particularly grinding and packaging highlights its role as a key distribution hub for both retail and wholesale transactions.

Sample Collection

Locally processed powdered garlic and turmeric samples were collected from three different vendors in each selected market. Samples obtained from the three vendors for each spice and markets were combined to form one composite sample. In addition, raw garlic and turmeric were purchased and processed into peeled and unpeeled powdered forms under controlled conditions to serve as control samples, potential adulterants (maize flour, beans peel and corn starch) were also collected.

Sample Preparation

The individual samples for each processed powdered garlic and turmeric were thoroughly mixed to form a composite sample for each market. The raw garlic and turmeric samples which serve as the controls were processed in two forms; with their peels intact and without their peels before being cut into smaller pieces, sun dried and grounded into powdered form. All prepared samples were stored in airtight containers [5].

Moisture Content Determination

This was carried out following gravimetric method, according to the procedure of Association of Official Analytical Chemist - A.O.A.C [4]. A washed and dried crucible was weighed as (w_1), 2g of the sample was then added and weighed as (w_2) and recorded. It was then placed in an oven set at 105°C for 3hrs and weighed again as (w_3) and recorded [4].

The percentage amount of moisture resulting from the drying was calculated using:

$$\% \text{ Moisture Content} = \frac{(w_2 - w_3)}{(w_2 - w_1)} \times 100 \quad \text{equation 1}$$

Total Ash Content Determination

This was carried out following the incineration method, according to the procedure of Association of Official Analytical Chemist - A.O.A.C [4]. A Platinum dish washed, dried and cooled was weighed as (w_1), 3g of the sample was added and weighed as (w_2) and recorded. It was then transferred using a pair of tong into a muffle furnace and heated at 550°C until it fully ashes (color changes to gray) and the weight (w_3) was recorded after cooling to a room temperature [4].

The percentage ash content was calculated using:

$$\% \text{ Ash Content} = \frac{(w_2 - w_3)}{(w_2 - w_1)} \times 100 \quad \text{equation 2}$$

Total Aflatoxin Determination

Enzyme linked immunosorbent assay ELISA (Ridascreen Aflatoxin Total Art. No. R4701) test kit was used for aflatoxin determination in the samples. This method relies on antibodies that specifically target the compounds of interest and operates through an enzyme-linked colour reaction [19].

Sample Extraction

Sample extraction was performed according to the manufacturer's instruction (Ridascreen Aflatoxin Total Art. No. R4701). 10ml of 70/30 (v/v) methanol-water extraction solvent was added to 2grams of each ground spice sample and the solution was extracted by shaking for 10 minutes using orbital shaker. The sample was then allowed to settle, and the top layer of extract was filtered through a Whatman No. 1 filter paper and the filtrate was collected into the test tube, 100 μ L of filtrate was transferred into a different test tube and was diluted into a test tube containing 600 μ L of distilled water [15].

ELISA TEST

This was done according to Ridascreen Aflatoxin Total Art. No. R4701 test kit manual. 50 μ L of the six calibration standards supplied with the kit and the prepared sample extract were added into each microwell. 50 μ L of conjugate was added first to each well, then 50 μ L of antibody was added into each well and was carefully mixed by shaking the plate manually and then it was incubated for 30 minutes at room temperature (20-25°C). The contents of the microwell strips were discarded followed by washing each microwell by filling it with 250 μ L wash buffer and then dumping the water from the microwell strips. Microwell strips were then tapped using absorbent (tissue) paper by holding it upside down to expel as much residual water as possible. The bottom of the microwells was then dried with a dry towel. 100 μ L of the substrate/chromogen was added into each microwell and was mixed gently by shaking the plate manually before incubation at room temperature for 15 minutes and a blue colour developed. 100 μ L of stop solution was added into each microwell strip, and then there was colour change from blue to yellow. The strips were then read with microwell reader using an absorbance filter of 450 nm [15]. The calibration standards were used to generate the standard curve for determination of total aflatoxin concentrations. Each composite sample was analyzed once,

Detection of Adulteration

Physical characteristics

Physical parameters assessed included odour, colour, texture and appearance [5].

FTIR Data Acquisition

All spectra of the selected samples were measured using ATR-FTIR (Agilent Cary 630 FTIR Spectrometer, Australia). Isopropanol was used to clean the crystal before collecting the background. All spectra were recorded in the transmittance mode. The transmission technique was applied to conduct 8 sample scans and 8 background scans for each of the sample in the spectral range of 4000-650 cm⁻¹. Samples to be analyzed were placed directly on the diamond crystal of ATR-FTIR. The selected spectral range covers the characteristic absorption bands relevant to the compounds of interest, ensuring detailed and informative spectral data [18]. The peeled and unpeeled control samples were used to establish reference FTIR spectral markers for garlic and turmeric. Possible adulterants (Maize flour, beans peel and corn starch) were also analyzed to establish their spectral characteristics. After establishing the spectral markers from the control samples and possible adulterants, the FTIR spectra of the market-processed samples were compared with these reference markers.

Data Analysis

The data obtained from the laboratory analyses were summarized descriptively. Moisture content, ash content and aflatoxin concentration were reported as the measured values for each market composite sample and control sample. Comparisons among samples were made based on the observed values.

RESULTS AND DISCUSSION

Percentage Moisture and Ash Content

The moisture content of the market-processed garlic samples ranged from 4.32% to 4.69% while the peeled and unpeeled control samples recorded 3.45% and 3.49% respectively. For turmeric, the moisture content of the market-processed samples ranged from 5.27% to 5.82%, compared with 5.24% and 5.59% for the peeled and unpeeled controls, respectively as shown in Table 1. Overall, the observed moisture content was higher in the market-processed turmeric samples than in the corresponding garlic samples.

The relatively higher moisture content observed in turmeric may be associated with differences in the physical characteristics and processing conditions of the spices. Similar observations have been reported in previous studies in which turmeric powder recorded

relatively higher moisture content than some other powdered spices [1]. Moisture content is an important quality parameter in powdered spices because inadequate drying or exposure to moisture during processing and storage can contribute to deterioration and may create conditions favourable for fungal growth [28]. Overall the moisture content still align with results reported by Yusuf et al. [32] who reported 4.45% of moisture in garlic and Olayinka [21] who reported 5.59% moisture in turmeric.

The ash content of the market-processed garlic samples ranged from 4.66% to 5.14%, while the peeled and unpeeled controls recorded 5.24% and 4.59% respectively. For turmeric, the market-processed samples ranged from 3.38% to 3.74%, compared with 4.68% and 4.48% for the peeled and unpeeled controls, respectively as shown in Table 2. The observed ash content was higher in garlic than

in turmeric; this is in line with the work of Abu et al. [2] who also reported highest amount of ash in garlic compared to turmeric. Ash represents the inorganic residue remaining after combustion [23] and can provide an indication of the mineral fraction of a food material. The differences observed between the market-processed samples and controls may reflect differences in processing, removal of plant parts and the composition of the materials present in the powdered products [3]. The lower ash content observed in the market-processed turmeric compared with both controls may also be consistent with the presence of materials having a different mineral composition. Overall, the ash content in the spices did not exceed the maximum limits mentioned by the European Spice Association for whole garlic, whole turmeric and ground turmeric, which is 6%, 8%, and 9% respectively [11].

Table 1: Percentage Moisture Content of the Spices

Spices	Kawo Market	Unguar Rimi Market	Central Market	Control (Peeled)	Control (Unpeeled)
Garlic	4.69	4.32	4.48	3.45	3.49
Turmeric	5.71	5.27	5.82	5.24	5.59

Values are given as percentage. In each row, values represent the measured values obtained for each market composite and control sample.

Table 2: Percentage Total Ash Content of the Spices

Spices	Kawo Market	Unguar Rimi Market	Central Market	Control (Peeled)	Control (Unpeeled)
Garlic	4.81	4.66	5.14	5.24	4.59
Turmeric	3.38	3.69	3.74	4.68	4.48

Values are given as percentage. In each row, values represent the measured values obtained for each market composite and control sample.

Total Aflatoxin Concentration

The total aflatoxin concentrations observed in the market-processed garlic samples ranged from 0.124 to 0.229 µg/kg, while the peeled and unpeeled control samples recorded 0.052 and 0.120 µg/kg. For turmeric, the market-processed samples ranged from 0.309 to 0.678 µg/kg, compared with 0.251 and 0.323 µg/kg for the peeled and unpeeled controls, respectively as shown in Table 3. Turmeric therefore recorded the higher aflatoxin concentrations than the corresponding garlic samples.

The higher value observed in turmeric may partly be associated with its comparatively higher moisture content. Increased moisture during storage can favour fungal growth and consequently increase the potential for mycotoxin production when other environmental conditions are suitable. According to Wakhungu et al. [30] high mycotoxin levels in spices are possible if safe levels of moisture content are not observed or presence of faults in the analytical techniques

used. The relatively low aflatoxin concentration observed in garlic may also be related to the presence of antimicrobial constituents in garlic. Previous work cited by Haruna et al. [15] associated the low aflatoxin level in garlic with the antimicrobial activity of garlic constituents such as allicin. The market-processed samples generally recorded higher aflatoxin concentrations than the corresponding control samples, while the peeled controls recorded the lowest values. This difference may be associated with differences in handling, drying and storage. Unlike the control samples, which were processed under controlled conditions, despite these differences, all garlic and turmeric samples had total aflatoxin concentrations well below the EU/WHO/NAFDAC regulatory limit of 10 µg/kg [30]. Thus, based specifically on aflatoxin concentration, the investigated samples were within the acceptable regulatory limit. However, this finding may not represent all spices sold across Kaduna North LGA, as the study was limited to specific markets and vendors. Broader surveillance is needed to ensure consistent safety across the region.

Table 3: Total Aflatoxin Concentration of the Spices

Spices	Kawo Market	Unguar Rimi Market	Central Market	Control (Peeled)	Control (Unpeeled)
Garlic	0.229	0.198	0.124	0.052	0.120
Turmeric	0.309	0.624	0.678	0.251	0.323

Maximum limit set by EU/NAFDAC= 10 µg/kg [30]

Values are given as percentage. In each row, values represent the measured values obtained for each market composite and control sample.

Physical Characteristics

The market-processed powdered garlic and turmeric differed from the control samples in their observable characteristics as

shown in Table 4, plate 1 and 2. The peeled garlic control was characterized by a pungent odour, off-white colour and smooth texture, while the unpeeled control had a stronger pungent odour, creamy

colour and smooth texture. The market-processed garlic samples generally exhibited less pungent odour, varying shades from light to deep brown and visible particles. The peeled turmeric control had a warm earthy odour, vibrant yellow colour and fine texture, whereas the unpeeled control was slightly darker and coarser. The market-processed turmeric samples showed a less intense earthy odour and

colour variations ranging from dull orange to deep yellow. These observations were consistent with differences in processing and handling among the samples. The more uniform and vibrant appearance of the controls could indicate higher quality and freshness. The variations in physical attributes were presumed to be due to changes in different processing methods [5].

Table 4: Physical Characteristics of Powdered Spices

Spice/Sample	Odour	Colour	Texture	Appearance
Garlic/Control (Peeled)	Pungent	Off-white	Smooth	Uniform
Garlic/Control (Unpeeled)	Strong, pungent	Cream	Smooth	Visible specks
Garlic/Kawo Market	Mild	Dark brown	Slightly coarse	Non-uniform, visible particles
Garlic/Unguwar Rimi Market	Pungent	Brown	Smooth	Fairly uniform
Garlic/Central Market	Off garlic scent	Brown	Moderately fine	Visible particles
Turmeric/Control (Peeled)	Warm, earthy	Vibrant yellow	Fine, smooth	Uniform, no visible particles
Turmeric/Control (Unpeeled)	Strong, earthy	Deep yellow	Slightly coarse	Uniform, no visible particles
Turmeric/Kawo Market	Faint, less intense	Dull Orange	Smooth	Uniform, no visible particles
Turmeric/Unguwar Rimi Market	Warm, less intense	Yellow	Smooth	Uniform, no visible particles
Turmeric/Central Market	Warm, less intense	Deep Yellow	Smooth	Uniform, no visible particles

FTIR Spectral Characteristics of Market-Processed Garlic and Turmeric versus Controls

The FTIR spectra demonstrated differences between market-processed samples and the peeled and unpeeled controls as shown in Figure 1 to Figure 10. These differences were observed across several regions, including the O–H stretching region ($3200\text{--}3600\text{ cm}^{-1}$), C–H stretching region ($2800\text{--}3000\text{ cm}^{-1}$), C=O stretching region ($1650\text{--}1750\text{ cm}^{-1}$), C–O/C–N region ($1000\text{--}1300\text{ cm}^{-1}$) and the fingerprint region ($1500\text{--}500\text{ cm}^{-1}$). These regions represent vibrations associated with different classes of chemical constituents present in the samples as summarized in Table 5.

The market-processed samples showed differences in O–H spectral intensity compared with the controls. The O–H region represents hydroxyl-containing compounds and hydrogen-bonded groups and may also be influenced by moisture and the sample matrix. The higher intensity of the O–H stretch in the controls (peeled and unpeeled) ginger, garlic, and turmeric samples confirms a higher retention of natural bioactive compounds. In contrast, the reduced O–H peak in the three market-processed suggests degradation of bioactive compounds, which may impact their nutritional and medicinal properties [6].

The C–H stretching region observed in the samples is consistent with aliphatic organic compounds naturally present in spices [18]. Differences in peak positions or intensities between controls and market-processed samples may reflect differences in chemical composition or matrix effects. Similarly, variations in the carbonyl region indicate differences in compounds containing carbonyl groups, but this region is not sufficiently specific to identify starch adulteration on its own. Although, Lohumi *et al.* [17] found that this peak serves as a key indicator of carbohydrate fillers, such as corn flour. More useful evidence for possible starch-based adulteration was observed in the C–O–C and C–O regions and in the fingerprint region. Polysaccharides such as starch contain glycosidic linkages that contribute characteristic infrared absorption patterns. Consequently, similarities between the market-processed samples and plant based or starch-based materials in these regions provide a stronger basis for suggesting possible adulteration [16].

FTIR Evidence of Possible Garlic Adulteration

Comparison of the market-processed garlic spectra with the selected potential adulterants revealed overlapping spectral features with maize flour and beans peel as shown in Figure 11 and 13. Similarity between the market-processed samples and maize flour was observed in the C–H Stretch ($2800\text{--}3000\text{ cm}^{-1}$). In particular, similarities were observed in the fingerprint region between the market-processed garlic and beans peel. Since the fingerprint region contains complex spectral information associated with the overall molecular composition of a material, such similarities may indicate the presence of chemically similar plant material in the market-processed samples. Yu *et al.* [31] noted that starch, synthetic additives, and plant-based adulterants cause noticeable spectral changes in this region. The observed overlap is consistent with previous applications of FTIR spectroscopy for food authenticity and adulteration assessment, including studies investigating garlic adulteration [13].

FTIR Evidence of Possible Turmeric Adulteration

The FTIR analysis of turmeric provided evidence of spectral similarities between market-processed samples and maize flour/corn-starch as shown in Figure 11 and 12. Similarities were observed in the O–H region, while the C–H stretching region of the market-processed turmeric showed patterns closely resembling maize flour. Further similarities were observed in the C–O/C–N region, where broad features associated with cornstarch corresponded with features observed in the market-processed turmeric. Peak shifts in the fingerprint region also showed alignment with maize flour.

These observations are important because starch-rich materials contain abundant carbohydrate structures that produce characteristic infrared features, particularly within the C–O–C and fingerprint regions. This further supports the hypothesis that the three market-processed spice samples were mixed with starch-containing fillers to increase bulk weight, a common practice in food adulteration [12]. The similarity between the market-processed turmeric and the selected flour/starch references therefore suggests that some of the market-processed turmeric samples may contain starch or flour based materials. This observation is consistent with Shannon *et al.* [27] who demonstrated the application of FTIR spectroscopy for detecting adulteration of turmeric powder with flour and starch-based materials.

Table 5: Functional Groups of FTIR absorption bands

Wavenumber (cm ⁻¹)	Functional Group	Band Assignment
3200-3600	O-H Stretch	Hydrogen-bonded hydroxyl group
2800-3000	C-H Stretch	Aliphatic hydrocarbons (Lipids)
1650-1750	C=O Stretch	Ester carbonyl groups (lipids)
1600	C=C Stretch	Aromatic rings
1150-1020	C-O-C Stretch	Glycosidic linkages in polysaccharides
1000-1300	C-O / C-N Stretch	Starch, alcohol, ethers, protein
1500-500	Fingerprint region	Unique spectral fingerprint

Source: [25]

CONCLUSION

The moisture contents observed were within the ranges observed in previous studies of powdered spices, which may contribute to the stability and shelf life of the powdered spices, while the ash contents provided an indication of their mineral content and overall quality. The detected total aflatoxin concentrations in all analyzed samples were low and below the EU/WHO/NAFDAC regulatory limit of 10 µg/kg indicating that the samples are safe for consumption with respect to aflatoxin contamination. FTIR analysis revealed spectral similarities between the market-processed samples and selected adulterants, suggesting the possible presence of flour or starch-based adulterating materials. Overall, the findings demonstrate the potential of FTIR spectroscopy as a rapid, non-destructive screening tool for assessing the quality and authenticity of powdered spices.

RECOMMENDATIONS

Regulatory agencies should strengthen routine monitoring of locally processed powdered spices for aflatoxin contamination and adulteration, while processors and vendors should receive training on good hygiene, processing, drying and storage practices.

ACKNOWLEDGEMENTS

We acknowledge the Staff of National Agency for Food and Drug Administration and Control (NAFDAC), Kaduna Laboratory Services, Nigeria, for their guidance and providing access to their laboratory facilities.

AUTHORS' CONTRIBUTIONS

Abdul Safiya Abdulaziz: conceptualized the study, carried out sample collection, laboratory analyses, data analysis and interpretation, writing original draft. Yakubu Magaji: Supervision, data interpretation, review and editing. Abdulsalami Muhammed Sani: Supervision, data interpretation, review and editing. Hassan Abba Umar: Supervision, review and editing.

REFERENCES

Abd El-Rahman, M. A. M. (2019). Microbiological Quality and Heavy Metals Content of some Spices and Herbs Kinds J. Food and Dairy Sci., Mansoura Univ., Vol. 10 (7): 237- 24

Abu, M. S., Mashi, R. L., Onuche, J. I., and Shuaibu, S. I. (2023). Proximate and phytochemical screening of some selected herbs and spices commonly used in Nigeria. GSC Biological and Pharmaceutical Sciences, 22(1), 015-024. <https://doi.org/10.30574/gscbps.2023.22.1.0496>

Abubakar, U. S., Tajo, S. M., Joseph, M., Yusuf, K. M., Abdu, G. T., Jamila, G. A., Fatima, S. S., and Saidu, S. R. (2019). Comparative study of the proximate, mineral and phytochemical composition of Zingiber officinale (Zingiberaceae) cultivated in Kano and Kaduna States, Nigeria. Specialty Journal of Chemistry, 4(3), 1-6

Akoji, J. N., Karimatu, A. L., and Amina, O. M. (2022). Proximate analysis and elemental composition of some spiced and unspiced food products around Bwari Area Council, Abuja, FCT. International Journal of Research and Innovation in Applied Science (IJRIAS), 7(12), 68–72. <https://www.rsisinternational.org>

Amponsah, I. K., Boakyee, A., Orman, E., Armah, F. A., Borquaye, L. S., Adjei, S., Dwamena, Y. A., Baa, K. A., and Harley, B. K. (2022). Quality assessment and chemometric-assisted FTIR spectral analysis of commercial powdered ginger

products on the Ghanaian market. Heliyon, 8(e09150). <https://doi.org/10.1016/j.heliyon.2022.e09150>

Anagaw, Y. K., Ayenew, W., Limenh, L. W., Geremew, D. T., Worku, M. C., Tessema, T. A., Simegn, W., and Mitku, M. L. (2024). Food adulteration: Causes, risks, and detection techniques—review. SAGE Open Medicine, 12, 1-15. <https://doi.org/10.1177/20503121241250184>

Bharathi, S. K. V., Sukitha, A., Moses, J. A., and Anandharamakrishnan, C. (2018). Instrument-based detection methods for adulteration in spice and spice products – A review. Journal of Spices and Aromatic Crops, 27(2), 106-118. <https://doi.org/10.25081/josac.2018.v27.i2.1099>

Cebi, N., Bekiroglu, H., Erarslan, A., and Rodriguez-Saona, L. (2023). Rapid sensing: Hand-held and portable FTIR applications for on-site food quality control from farm to fork. Molecules, 28(9), 3727. <https://doi.org/10.3390/molecules28093727>

Choudhary, A., Gupta, N., Hameed, F., and Choton, S. (2020). An overview of food adulteration: Concept, sources, impact, challenges and detection. International Journal of Chemical Studies, 8(1), 2564-2573. <https://doi.org/10.22271/chemi.2020.v8.i1am.8655>

City Population. (2020). Kaduna State of Nigeria. From <https://www.citypopulation.de/en/nigeria/admin/>

ESA, (2018). European Spice Association, Quality Minima Document Rev. 5. Reviewed at the meeting of the Technical Commission on 26th March 2018. <https://www.esa-spices.org/download/esa-qmd-rev-5-update-as-per-esa-tc-26-03-18.pdf>

Galvin-King, P., Haughey, S. A., and Elliott, C. T. (2018). Herb and spice fraud: the drivers, challenges and detection. Food Control, 88, 85–97. <https://doi.org/10.1016/j.foodcont.2017.12.031>

Galvin-King, P., Haughey, S., and Elliott, C. (2020). Garlic adulteration detection using NIR and FTIR spectroscopy and chemometrics. Journal of Food Composition and Analysis, 96. <https://doi.org/10.1016/j.jfca.2020.103757>

Haji, A., Desalegn, K., and Hassen, H. (2023). Selected food items adulteration, their impacts on public health, and detection methods: A review. Food Science & Nutrition. Advance online publication. <https://doi.org/10.1002/fsn3.3732>

Haruna, M., Dangora, D. B., Khan, A. U., Batagarawa, U. S., Ibrahim, H., and Adamu, S. U. (2017). Incidence of fungal flora and aflatoxin in some spices sold in Central Market, Funtua, Nigeria. UJMR, 2(1). <https://doi.org/10.47430/ujmr.1721.008>

Heredia-Guerrero, J. A., Benítez, J. J., Domínguez, E., Bayer, I. S., Cingolani, R., Athanassiou, A., and Heredia, A. (2014). Infrared and Raman spectroscopic features of plant cuticles: A review. Frontiers in Plant Science, 5, 305. <https://doi.org/10.3389/fpls.2014.00305>

Lohumi, S., Lee, S., Lee, W.-H., Kim, M. S., Mo, C., Bae, H., and Cho, B.-K. (2014). Detection of starch adulteration in onion powder by FT-NIR and FT-IR spectroscopy. Journal of Agricultural and Food Chemistry, 62(38), 9246–9251. <https://doi.org/10.1021/jf500574>

Madhuri, A., Thamburaj, S., Jaganmohan, R., and Vidyalakshmi, R. (2021). ATR-FTIR spectroscopy for adulteration detection of corn flour in cassava flour. The Pharma Innovation Journal, 10(10), 1388-1391.

Miklós, G., Angeli, C., Ambrus, A., Nagy, A., Kardos, V., Zentai, A., Kerekes, K., Farkas, Z., Józ'wiak, Á., and Bartók, T. (2020). Detection of aflatoxins in different matrices and food-chain positions. Frontiers in Microbiology, 11, 1916. <https://doi.org/10.3389/fmicb.2020.01916>

Morling, A., and McNaughton, R. (2016). A baseline food crime annual strategic assessment. Food Standards Agency. <https://www.food.gov.uk/sites/default/files/fsa-food-crime-assessment-2016.pdf>

Olayinka, O. I. (2023). Proximate, mineral composition and phytochemical analyses of turmeric (Curcuma longa) powder. Nigerian Journal of Animal Production, 50, 874-878

Pantola, P., and Agarwal, P. (2021). Detection of adulteration in spices. International Journal of Advance Research and Innovation, 9(2), 165-167. <https://doi.org/ISSN 2347-3258>

Pojić, M., Kravić, S., and Stojanović, Z. (2015). Analytical methods for determination of moisture and ash in foodstuffs. In Handbook of Food Analysis (3rd ed., pp. 275-295). Routledge. <https://doi.org/10.1201/9780429153747>

Rohaeti, E., Rafi, M., Syafitri, U. D., and Heryanto, R. (2015). Fourier transform infrared spectroscopy combined with chemometrics for discrimination of Curcuma longa, Curcuma xanthorrhiza, and Zingiber cassumunar. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 137, 1244–1249.

Sari, Y. P., Putri, A.R., Irnawati., Tamaroh, S., Setiyoko, A., and Purbaningtias, T. S. (2025). Fast Detection of White Pepper Adulteration using FTIR-ATR

- Spectroscopy and Chemometrics . Malaysian Journal of Science and Advanced Technology, 5 (1) 66-71
- Sasikumar, B. (2019). Advances in adulteration and authenticity testing of turmeric (*Curcuma longa* L.). *Journal of Spices and Aromatic Crops*, 28(2), 96–105.
- Shannon, M., Lafeuille, J.-L., Frégière-Salomon, A., Lefevre, S., Galvin-King, P., Haughey, S. A., Burns, D. T., Shen, X., Kapil, A., McGrath, T. F., and Elliott, C. T. (2022). The detection and determination of adulterants in turmeric using Fourier-transform infrared (FTIR) spectroscopy coupled to chemometric analysis and micro-FTIR imaging. *Food Control*, 139, 109093. <https://doi.org/10.1016/j.foodcont.2022.109093>
- Shehu, A., Shehu, A., and Yahaya, B. (2023). Proximate and Phytochemical Analysis Of Some Selected Spices; Garlic (*Allium Sativum*), Ginger (*Zingiber Officinale*) And Onion (*Allium Cepa*). *Int J Bot Hor Res*, 1(1), 115-124.
- Syamilah, N., Nurul Afifah, S., Effarizah, M. E., and Norlia, M. (2022). Mycotoxins and mycotoxigenic fungi in spices and mixed spices. *Food Research*, 6(4), 30-40. [https://doi.org/10.26656/fr.2017.6\(4\).971](https://doi.org/10.26656/fr.2017.6(4).971)
- Wakhungu, C. N., Okoth, S., Wachira, P., and Otieno, N. A. (2021). Mycotoxins contaminating herbs and spices in Africa: A review. *African Journal of Biological Sciences*, 3(3), 10-28. <https://doi.org/10.33472/AFJBS.3.3.2021.10-28>
- Yu, D., Guo, S., Zhang, X., Yan, H., Zhang, Z., Chen, X., Chen, J., Jin, S., Yang, J., and Duan, J. (2022). Rapid detection of adulteration in powder of ginger (*Zingiber officinale* Roscoe) by FT-NIR spectroscopy combined with chemometrics. *Food Chemistry: X*, 15, 100450. <https://doi.org/10.1016/j.fochx.2022.100450>
- Yusuf, A., Fagbua, S. S., and Fajemilehin, S. O. K. (2018). Chemical composition, phytochemical and mineral profile of garlic (*Allium sativum*). *Journal of Bioscience and Biotechnology Discovery*, 3(5), 105-109. <https://doi.org/10.31248/JBBD2018.073>
- Zhan, X., Guan, X., Wu, R., Wang, Z., Wang, Y., and Li, G. (2018). Discrimination between alternative herbal medicines from different categories with the electronic nose. *Sensors*, 18(9), 2936.