



Research article

Assessment of some quality parameters and chemometric-assisted FTIR spectral analysis of commercial powdered ginger products on the Ghanaian market



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ABSTRACT

Background: *Zingiber officinale* Roscoe (ginger) rhizome is a global spice with marked pharmacological activities and industrial applications. The demand for the powdered spice soared in the wake of the COVID-19 global pandemic. The present study sought to assess powdered ginger products on the Ghanaian market for some quality parameters and compare their chemical composition via chemometric analysis of their FT-IR data.

Methods: A survey was conducted in three major markets in Ghana to determine the commercially available powdered ginger products. These products were purchased and assessed for microbial load, heavy metals contents and ash values using official methods. Also, principal component and hierarchical cluster analysis, as multivariate algorithms, were applied to their FT-IR spectral fingerprints, using *Z. officinale*, *Z. zerumbet* and some dried ginger rhizomes from Nigeria as reference samples.

Results: Seven products were found in the survey: three local and four foreign. The local products failed to meet regulatory label requirements. The microbial load, heavy metals and ash values of all commercial samples were generally within specifications except for the aerobic bacterial counts of some local samples. Pharmacopoeial identity test and the chemometric analysis revealed all the products to contain *Z. officinale*. The reference ginger sample from Nigeria also demonstrated some level of similarity with *Z. officinale*. The variations in physical attributes and slight difference in chemical composition of the different products was presumed to be due to chemical changes arising from different processing methods and possible adulteration with other flours.

Conclusion: The sampled ginger products on the market originate from *Z. officinale* and have quality attributes that make them suitable for food and medicinal applications. The observed deviations, however, suggest an urgent need for standardized processing methods to ensure consistency in quality indices, as well as regular quality checks by regulatory bodies.

1. Introduction

Food borne diseases result from the consumption of contaminated food. It is a global phenomenon that continues to be a threat to human health as it is associated with high mortality and morbidity (Jahan 2012;

Todd, 2020). They are caused by bacteria, viruses, or parasitic contaminants of food products. Some food products may also be contaminated with toxic metals, pesticide residues and other harmful additives or adulterants (Torgerson et al., 2014). It is on record that 1 in 10 people in the world fall sick from contaminated food, with 420,000 fatalities

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yearly. Children under five years are most vulnerable to food contamination, with 125, 000 deaths every year (World Health Organization, 2020).

This situation is worst in Africa where an estimated 92 million people fall sick from consuming contaminated foods each year with 137, 000 fatalities (Bisholo et al., 2018). A great percentage of this occurs in Sub-Saharan Africa where a high food safety burden increasingly co-exist with food scarcity and malnutrition (Fraval et al., 2019). Loss of productivity due to foodborne diseases is estimated at US\$ 95.2 billion per year with an annual treatment cost of US\$ 15 billion in the region. On this continent, majority of street foods are prepared with traditionally made local spices (Bakobie et al., 2017) including ginger, chilli and cloves. Some of these spices may harbor contaminants due to the unhygienic conditions under which they are harvested, dried, processed and stored (Marras and AgBendeche, 2016; Bakobie et al., 2017). For example, Addo (2005), reported the presence of microbial contaminants in ginger spices sold on the Ghanaian market. Elsewhere, aflatoxins were found in nutmeg, ginger, red pepper, and mustard seasonings (Vrabcheva, 2000), highlighting the need to perform regular quality checks on these food ingredients.

A food ingredient of interest is the rhizomes of *Zingiber officinale* Roscoe, the most widely used ginger specie of the family Zingiberaceae. *Z. officinale* is known in Ghana as the white variety whereas *Z. zerumbet* is known as the yellow variety (Juliani et al., 2007). The rhizomes are either used in the fresh form or dried ground powder (Sanwal et al., 2010). For a very long time, the fresh ginger rhizomes have occupied a special niche on the Ghanaian market; being easy to access, and affordable. In recent times, however, there has been increased patronage of the powdered form due to its convenience in handling and wider scope of use in food applications compared to the fresh rhizomes. Urbanisation also appear to contribute to its growing popularity as they are seen to be easy to handle. Their uses are reported in products like ginger beer and juice, ginger prickles, chocolates, and other confectioneries (Santos Braga, 2019). In addition to the culinary purposes, it is also patronized for its medicinal properties.

Ginger has a characteristic pungent taste and odour attributable to its non-volatile compounds and essential oils (Juliani et al., 2007). The phenolic compounds in ginger, such as the shogaols, gingerols and paradols, are reportedly responsible for its numerous pharmacological activities. These include chemotherapy-induced nausea and vomiting (Walstab et al., 2013), mitigation of upper respiratory tract disorders (Townsend et al., 2013) and anti-inflammatory actions (Zhang et al., 2016; Oladele et al., 2020). The anti-inflammatory actions of ginger are linked to its inhibition of protein kinase B and activation of nuclear factor kappa light chain-enhancer of activated B cells (NF- κ B), a decline in proinflammatory cytokines and enhancement in anti-inflammatory cytokines (Mao et al., 2019).

In the wake of the COVID-19 global pandemic, the demand for the spice soared (Hamulka et al., 2020). With no remedy for the disease in sight, the orientation of the masses was skewed towards natural remedies with known anti-viral and anti-inflammatory effects. Widespread pharmacological reports suggest the use of ginger in home remedies for prophylaxis and management of lung inflammation related to the SARS-CoV-2 viral infection (Haridas et al., 2021). The phytochemicals in ginger rhizomes have been found to exert antiviral properties by interacting at the site of the COVID-19 spike protein and human angiotensin converting enzyme-2 (ACE-2) receptor in the alveoli of the lungs and respiratory epithelium (Haridas et al., 2021).

As a result of the above-mentioned benefits, there has been a proliferation of different brands of powdered ginger products on the market. The growing popularity of the product also brings up issues related to quality. Reports show that ginger could be mixed with similar-looking herbs or adulterated on purpose (Abdo et al., 2021). Also, several factors have been identified to contribute to differences in the quality of powdered ginger products and these include harvesting methods, and postharvest activities such as drying and storage (Abdo et al., 2021). For

example, it has been shown that extended harvest, over drying and long storage periods could lead to low oleoresin content per unit volume of ginger powder (Geta and Kifle, 2011). There are also concerns about the unhygienic conditions under which ginger, and spices generally are handled during harvesting and postharvest stages (Marras and AgBendeche, 2016; Bakobie et al., 2017). For instance, the crude traditional means of processing ginger reportedly led to contamination with molds and aflatoxins, among other impurities (Geta and Kifle, 2011). Regarding heavy metal contamination, some studies have also demonstrated their presence in the rhizomes (Nkansah and Amoako, 2010). They reported that ginger rhizomes sampled in the Kumasi Metropolis contained lead contents above the permissible levels.

In view of this, it has become particularly needful to put in measures to control the quality of the spice on the Ghanaian market. The studies carried out so far have either concentrated on spice-mixes (where ginger together with other spices have been mixed for culinary purposes) (Bakobie et al., 2017) or on the fresh rhizomes (Nkansah and Amoako, 2010; Addo, 2005). Considering that the rhizomes are processed into the powdered products, which are widely patronized, the current investigation aimed at assessing some quality parameters of these powdered ginger products on the market. The yellow ginger variety, *Zingiber zerumbet*, does not exhibit the characteristic pungency and other attributes for which the most widely used species, *Zingiber officinale* is noted for. *Z. zerumbet* is cultivated as an ornamental in some jurisdictions and used to adulterate *Z. officinale*. Therefore, the study sought to explore the use of Fourier transform infra-red (FT-IR) spectral fingerprinting to elucidate the chemical diversity in the products, viz, the two main species in Ghana. The present research also assessed if the products satisfied pharmacopoeial and regulatory requirements as well as possible microbial and heavy metal contaminants.

2. Materials and methods

2.1. Sampling of ginger products

Seven different brands of ginger powder were identified in a market survey within the Kumasi Metropolis of Ghana. Four samples (from two batches) of each product were purchased from different markets in Kumasi. Powdered ginger products, containing other ingredients as stated on the label, were excluded from the study.

Fresh ginger rhizomes, *Z. officinale* (ZO) and *Z. zerumbet* (L.) Smith (ZZ) (representing the two species in Ghana) were also collected from the Kumasi Central Market in the month of October and authenticated by Mr Clifford Asare of the Herbarium section of the Department of Pharmacognosy, Faculty of Pharmacy and Pharmaceutical Sciences, KNUST, to serve as reference samples. The fresh rhizomes were washed thoroughly under running water, cut into thin sections and sundried for 24hrs. Longitudinally diced and dried ginger samples obtained from Nigeria, served as a third reference sample (STN). The dried reference samples were milled into powder and stored in paper envelopes until further use.

2.2. Label and physical properties analyses

The label of the seven brands of ginger products were listed and analysed based on the regulatory specifications (Food and drugs authority Ghana, 2013). Physical examination was conducted on the products according to standard methods (Kilcast, 1996, World Health Organization, 1998). Parameters assessed included taste, odour, colour and texture. The total ash and acid insoluble ash values were also determined according to official methods (World Health Organization, 1998).

2.3. Pharmacopoeial identity test for *Z. officinale*

The identity test was done according to official methods (United States Pharmacopoeia, 2006). Briefly, 50 mg of the alcohol soluble

extractives of the ginger products and reference powders, prepared by the USP method, were reconstituted in 25 mL of water, and then extracted twice with 15 mL portions of diethyl ether. The combined ether extracts were evaporated to dryness and the residue dissolved in 5 mL of sulphuric acid (7.5 mL in 10 mL distilled water). Five mg of vanillin (Sigma-Aldrich, USA, CAS 121335) was then added to the solution, allowed to stand for 15 min and then an equal volume of water added. *Z. officinale* presence in the samples was confirmed by the formation of an azure blue coloured solution.

2.4. Microbial load analysis

MacConkey agar, Nutrient agar, Potato dextrose agar, Salmonella, Shigella and *Pseudomonas* Cetrimide agar (Oxoid Ltd, UK), were obtained from the Pharmaceutical Microbiology section of the Department of Pharmaceutics, KNUST, Ghana. The equipment used included general laboratory glassware, oven (Gallenkamp), electronic balance (Mettler Toledo), laboratory incubator (Gallenkamp) and Stuart colony counter (SC6, England). Media viabilities were tested for, using the organisms *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 4853), *Salmonella typhi* (clinical strain) and *Aspergillus niger* (ATCC 11414).

2.4.1. Microbial load determination

The microbial load of the powdered ginger products was determined using the pour plate method described in the British Pharmacopoeia (British Pharmacopoeia, 2018). Evaluation of total viable bacterial and coliform count was done using nutrient and MacConkey agar, dried potato dextrose agar for yeast and molds, Cetrimide Nutrient agar for *Pseudomonas spp.* and Bismuth sulphite for *Salmonella spp.* One gram of the ginger powder was suspended in 9 mL sterile water under aseptic conditions. Ten-fold serial dilutions of the stock solution was made by taking 1 mL of the stock solution into 9 mL of distilled water to achieve concentrations up to 10^{-6} . Preparation of all dehydrated media was done using the manufacturer's specifications. Twenty milliliters (20 mL) of the stabilized molten agar (45 °C for 15 min) were seeded with 0.1 mL of the diluted test solutions in duplicate plates and incubated at 37 °C for up to 48 h for bacterial load, and at 25 °C for five days to assess the fungal load. Counting was done using the Stuart colony counter (model SC6) and the microbial load enumerated, at the end of the incubation period, as the number of colony forming units per gram (CFU/g). The CFU/g, which is a product of the average number of colonies and the dilution factor, was compared with reference values from the British Pharmacopoeia (British Pharmacopoeia, 2018).

2.5. Heavy metal analysis

2.5.1. Determination of Cadmium (Cd), Copper (Cu), Arsenic (As) and Zinc (Zn) by atomic absorption spectroscopy

The method outlined by Turek et al. (2019) was followed with slight modifications. One (1 g) of sample was weighed into Kjeldahl digestion

tube. One part of nitric acid and three parts of hydrochloric acid were added to the sample. The mixture was then digested at a temperature of 450 °C until completion, indicated by a clear solution. This took about 60 min after which the mixture was decanted into a 100 mL volumetric flask, and the solution made up to the 100 mL mark. The absorbance of this solution (of unknown concentration) was then read using Buck Scientific model 210 VGP atomic absorption spectrophotometer for the various metals at specified wavelengths; Zn at 213.9 nm, Cu at 324.8 nm, As at 193.7 nm and Cd at 228.9 nm. A calibration curve was plotted for each of the elements analyzed from the stock standards (Buck Scientific) and used to estimate the metal content.

2.5.2. Mercury analysis

An automatic mercury analyzer (Lumex RA 915M, St Petersburg, Russia) equipped with a pyrolysis unit (Lumex 92) for heating solid samples was used for the determination of the mercury content. The absorption of the 254 nm resonance radiation by mercury atoms using Zeeman correction for background absorption (Sholupov et al., 2004) formed the operational principle of the analyser. A known mass (approximately 0.3 g) of the dry powdered ginger samples were placed in the sample cell of the Pyro-915 + operating at a heating temperature of 450 °C and airflow of 1 L/min (Rweyemamu et al., 2020). The run time for signal peaking was <1 min. The developed peaks were then integrated against a reference calibration (Cat: 500292: Lumex, St Petersburg, Russia) to obtain the concentrations. The detection limit based on the signal/noise ratio of 3 was 0.0005 mg/kg. Four determinations were made per product.

2.6. Fourier transform infra-red (FT-IR) analysis

The procedure described by Wulandari et al. (2016) was adopted with some modifications. Prior to analysis, the samples were equilibrated at room temperature (25–30 °C) and pulverised with mortar and pestle to obtain samples of uniform particle size (to allow for reproducible acquisition of spectra). No further sample preparation was needed. All spectra were collected in absorbance mode in the mid-infrared region (4000–400 cm^{-1}) in a single reflection configuration, using a Bruker ALPHA Attenuated Total Reflectance Fourier Transform Infra-Red (ATR-FTIR) Spectrometer (Bruker Optik GmbH, Ettlingen, Germany). The spectra were collected at a resolution of 4 cm^{-1} and an average of 24 scans was obtained for each sample spectrum. The ATR plate of the spectrometer was cleaned with methanol until visually clean and dried. Cleaning was confirmed with a background scan after which 1 g sample was then placed on the ATR plate for spectral measurements.

2.7. Statistical analysis

Multivariate analysis of the spectral data was performed using SpectraGryph software (version 1.2.15, Germany) (Menges, 2020) and Minitab 18.1 (version 18.1, Minitab, Inc., USA, 2017) (Thomas et al., 2017). The raw spectral data were preprocessed using baseline correction, peak

Table 1. Label analysis of ginger samples.

Product code	Label available	Manufacturer's information	Country of origin	Batch number	Best before dates	Net weight	FDA Number
A	√	√	USA	√	√	√	√
B	√	√	GH	X	√	X	√
C	√	√	IND	√	√	√	√
D	√	X	GH	X	X	X	X
E	√	√	SA	√	√	√	√
F	√	√	NG	√	√	√	√
G	X	X	GH	X	X	X	X

√ = Yes, available; X = No, not available; GH = Ghana; NG = Nigeria; IND = India; SA = South Africa. FDA; Food and Drugs Authority, Ghana.

Table 2. Physical features and pharmacopoeial identity test for the ginger products.

Product code	Colour	Taste	Odour	Texture	Pharmacopoeial test for ZO
A	Dark brown	Burning	Aromatic/choking	Smooth	Detected
B	Dark brown	Burning	Aromatic/choking	Very smooth	Detected
C	Dark brown	Bland burning	Aromatic/choking	Smooth	Detected
D	Light brown	Bland	Aromatic	Smooth	Detected
E	Dark brown	Bland burning	Aromatic/choking	Smooth	Detected
F	Brown	Sharp burning	Aromatic/choking	Smooth	Detected
G	Light brown	Burning	Aromatic	Smooth	Detected
STN	Brown	Burning	Aromatic/choking	Smooth	Detected
ZO	Light brown	Burning	Aromatic/choking	Smooth	Detected
ZZ	Yellowish brown	Bland	Aromatic	Smooth	Not detected

STN = reference ginger from Nigeria; ZO = *Z. officinale* and ZZ = *Z. zerumbet* (reference samples from Ghana).

normalisation, standard normal variate (SNV) method and second derivative Savitzky–Golay transformation tools (Mishra et al., 2021). Pattern recognition models including principal component analysis (PCA) and hierarchical cluster analysis (HCA) were then used to analyse the processed data, and classify the ginger samples (Rohman et al., 2014).

Ordinary one way analysis of variance (ANOVA) followed by Dunnett's multiple comparison test was used to compare the ash values and heavy metal content of the powdered ginger samples to the pharmacopoeial and WHO reference values respectively. Graphpad prism (version 8 for windows, San Diego, USA) was used for computing the means and standard deviations as well as the analysis of variance. Data was presented as mean \pm SD. P values less than 0.05 were considered statistically significant.

3. Results

3.1. Survey

A survey of powdered ginger products on the Ghanaian market revealed seven brands available in all the major cities of Ghana. These were given codes and their label information examined and documented (Table 1). Three of the products were produced in Ghana (42.8%) and the other four imported from the United States of America, India, Nigeria, and South Africa. All three local products (i.e B, D and G) did not have batch numbers and net weights. Two did not have the manufacturer's information and expiry/best before dates. One local product did not have any label at all. In a sharp contrast, the foreign products had all the specifications required for a good label.

3.2. Physical characteristics

The sampled ginger products (A, B, C, D, E, F and G), and the reference samples ZO, ZZ and STN, all had characteristic aromatic and pungent odours. They had a burning taste, with some sharper than others and the texture ranged from smooth to very smooth. The reference sample ZZ

however, did not exhibit these physical characters typical of *Zingiber officinale*. This was confirmed by the failure of ZZ to form the azure blue colour in the identity test (Table 2). There was no foreign matter present or visible fungal or bacteria growth, evidenced by black or white patches or clumps in the ginger products (Table 2).

3.3. Microbial load of samples

All the powdered ginger samples did not contain *Escherichia coli*, *Salmonella species* or any enterobacteria. Two test samples did not contain yeast or molds whereas the fungal load of the remaining samples were within allowable limits. Five ginger samples recorded higher aerobic counts than recommended (Table 3).

3.4. Heavy metal analysis

All powdered ginger samples contained levels of heavy metals which were significantly lower ($P < 0.0001$) than the maximum permissible limit (MPL) set by the WHO. However, the reference sample ZZ had Zn levels higher than the maximum allowable limit but not significantly different from it ($P = 0.7648$) (Table 4).

3.5. Ash values

The total ash value (Table 5) for all the products were significantly ($P < 0.05$) lower than the pharmacopoeial maximum limit for *Z. officinale* (United States Pharmacopoeia, 2006) except samples B and F (with P values 0.9505 and 0.0659 respectively). Similarly, the acid-insoluble ash values were also significantly lower than the pharmacopoeial reference value of 2%^{w/w} except for B, D, E, STN and ZO ($P > 0.05$) (Table 5).

3.6. FT-IR spectral features of samples

The FTIR spectra (Figure 1) of the ginger samples appeared similar across the IR range considered (400 - 4000 cm^{-1}) when visually inspected. The spectra were characterised by the presence of broad

Table 3. Microbial load of powdered ginger products.

Samples	Total aerobic count	Total yeast or molds	<i>S. aureus</i> MSA; 37 °C; 48h	<i>E. coli</i> (MaC; 37 °C; 48h)	<i>Salmonella spp</i> (BSA; 37 °C; 48h)
Specifications (BP)	$\leq 1.0 \times 10^5$ cfu/mL	$\leq 1.0 \times 10^3$ cfu/mL	Absent (in 1 mL)	Absent (in 1 mL)	Absent (in 1 mL)
A	2.0×10^1	0	None detected	None detected	None detected
B	3.9×10^6	1.0×10^2	None detected	None detected	None detected
C	2.5×10^6	0	None detected	None detected	None detected
D	1.4×10^5	1.7×10^2	None detected	None detected	None detected
E	1.6×10^3	1.0×10^2	None detected	None detected	None detected
F	4.6×10^5	1.9×10^2	None detected	None detected	None detected
G	2.5×10^5	1.2×10^2	None detected	None detected	None detected

Values are means of two determinations (n = 2).

Table 4. Levels of heavy metals in powdered ginger samples.

Samples	Heavy metal content mg/kg				
	Cu	****Zn	****As	****Cd	****Hg
A	6.80 ± 0.42	26.66 ± 2.80	0.0022 ± 0.001	0.0065 ± 0.004	0.002 ± 0.002
B	8.30 ± 0.22	13.71 ± 4.20	0.0023 ± 0.002	0.0054 ± 0.001	0.004 ± 0.002
C	5.80 ± 0.84	21.97 ± 2.52	0.0025 ± 0.001	0.0045 ± 0.002	0.042 ± 0.007
D	7.30 ± 0.24	17.73 ± 4.45	0.0031 ± 0.002	0.0052 ± 0.001	0.005 ± 0.001
E	9.30 ± 1.42	17.10 ± 2.64	0.0021 ± 0.000	0.0054 ± 0.002	0.16 ± 0.010
F	10.40 ± 1.80	25.27 ± 6.24	0.0027 ± 0.000	0.0045 ± 0.003	0.003 ± 0.001
G	11.20 ± 1.20	28.61 ± 4.40	0.0032 ± 0.001	0.0063 ± 0.002	0.002 ± 0.007
ZO	4.40 ± 1.60	32.28 ± 6.64	0.0022 ± 0.002	0.0051 ± 0.001	0.002 ± 0.001
ZZ	8.20 ± 1.05	53.86 ± 5.26	0.0026 ± 0.002	0.0045 ± 0.001	0.003 ± 0.002
STN	6.30 ± 2.20	28.10 ± 3.48	0.0023 ± 0.000	0.0036 ± 0.002	0.004 ± 0.002
*MPL mg/kg	NS	50	5	0.3	0.5

MPL = maximum permissible limit ([*World Health Organization, 2007](#); [Dghaim et al., 2015](#)); Values are means of four replicates (n = 4); NS = standard not set, ZO = *Z. officinale* and ZZ = *Z. zerumbet* (reference samples from Ghana), STN = reference ginger from Nigeria. Values were compared to the maximum permissible limit set by WHO using one way ANOVA followed by Dunnett's multiple comparison test. *P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001 were considered statistically significant.

stretching vibration of the O–H bond between 3200 – 3400 cm⁻¹. Another characteristic band, depicting the presence of aromatic skeletal stretching typical of lignans ([Zhao et al., 2015](#)), was shown at 1512 cm⁻¹. All other functional bands were also documented ([Table 6](#)).

3.7. Pattern recognition analysis of FT-IR spectral data

Notwithstanding the similarities in the FT-IR spectra ([Figure 1](#)), pattern recognition analysis, involving principal component analysis (PCA) and hierarchical cluster analysis (HCA) were carried out to identify the inherent features common and different among the samples (including the reference samples) ([Christou et al., 2018](#)). [Figure 2](#) shows regions in the spectral data with some levels of similarity after pre-processing. In the PCA, a correlation matrix was adopted to calculate the eigenvalues of the samples ([Jolliffe and Cadima, 2016](#)). Two principal components, principal component 1 (PC-1) and principal component 2 (PC-2) were selected from the eigen analysis, as they were shown to explain 90.0% of the variability in the data: PC-1 explained about 86.1% of the variability in all the samples whereas PC-2 explained about

3.8% of the variations observed in samples A, F and B. The score plots from the PCA depicts the presence of clusters based on their eigen scores as shown in [Figure 3A](#). The variability as explained by PC-1 was further attributed to the inherent spectral differences within the IR ranges around 1000–1080 cm⁻¹ (for C–O bond stretch) and 1500–1520 cm⁻¹ (for aromatic stretch) in all the samples ([Figure 3B](#)). On the other hand, PC-2, explained the variability due to inherent spectral differences within the range, 399–420 cm⁻¹ in the samples mentioned.

HCA was carried out using Ward's Linkage method with a squared Euclidean distance measure to calculate the similarities of the samples ([Murtagh and Legendre, 2014](#)). There were 3 clusters observed ([Figure 3C](#)); the first cluster from the left comprised samples G, E, ZO, F, B, D, C and A at a similarity of 67.78%, the second cluster consisted of STN and the third cluster had ZZ. The first and second could also be considered as one cluster at a similarity of 66.03%. Effectively, these samples shared similar spectral features and the features were significantly different from that of ZZ. The clusters were consistent with the outcomes of the PCA, further demonstrating the inherent similarities and differences among the samples.

4. Discussion

4.1. Quality of ginger samples

Good quality ginger assures high potency and efficacy of its intended medicinal and culinary use. These benefits are largely attributed to the gingerols and shaogoals which also gives the characteristic pungent aroma present in *Z. officinale* ([Lin et al., 2014](#); [Sharifi-Rad et al., 2017](#)). All seven powdered ginger products (designated A-G), documented in the market survey, positively aligned with the Pharmacopoeial identity test for *Z. officinale* ([Table 2](#)). Thus, the present study has shown the commercial ginger products to contain *Z. officinale*, irrespective of other ingredients that may be present. This is particularly important for the local sample 'G', as it does not have any label to indicate the ingredients present. However, in comparison with the yellow variety (ZZ), also found in Ghana, the latter did not respond positively to the test and did not register the pungent aromatic odour and burning taste characteristic of *Z. officinale* ([Mahomoodally et al., 2021](#)).

All three local products (B, D, G) did not comply with the label specification outlined by the regulator ([Food and drugs authority Ghana, 2013](#)); two of these did not have manufacturer's information, batch numbers and expiry dates, with one completely without a label ([Table 1](#)). The present research depicts local manufacturers of ginger powder in Ghana to be non-adherent to labelling requirements as stipulated by

Table 5. Ash values of ginger samples.

Product code	Mean ± SD Total ash (% ^W / _W)	Acid insoluble ash (% ^W / _W)
A	***3.32 ± 0.74	**0.41 ± 0.07
B	7.36 ± 0.51	2.96 ± 0.20
C	*5.34 ± 0.61	*0.81 ± 0.09
D	**4.14 ± 0.06	1.43 ± 0.01
E	**4.72 ± 0.85	1.07 ± 0.04
F	5.78 ± 0.31	*0.86 ± 0.04
G	***2.21 ± 0.04	**0.60 ± 0.09
STN	*5.35 ± 0.71	1.27 ± 0.30
ZO	*5.26 ± 1.70	1.14 ± 1.00
ZZ	***3.60 ± 0.62	**0.34 ± 0.06
Reference values (w/w) (United States Pharmacopoeia, 2006)	Not more than 8.0%	Not more than 2.0%

ZO = *Z. officinale* and ZZ = *Z. zerumbet* (reference samples from Ghana), STN = reference ginger samples from Nigeria. Values are means of two determinations (n = 2), SD = standard deviation. Values were compared to the pharmacopoeial ash values for ginger using one way ANOVA followed by Dunnett's multiple comparison test. *P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001 were considered statistically significant.

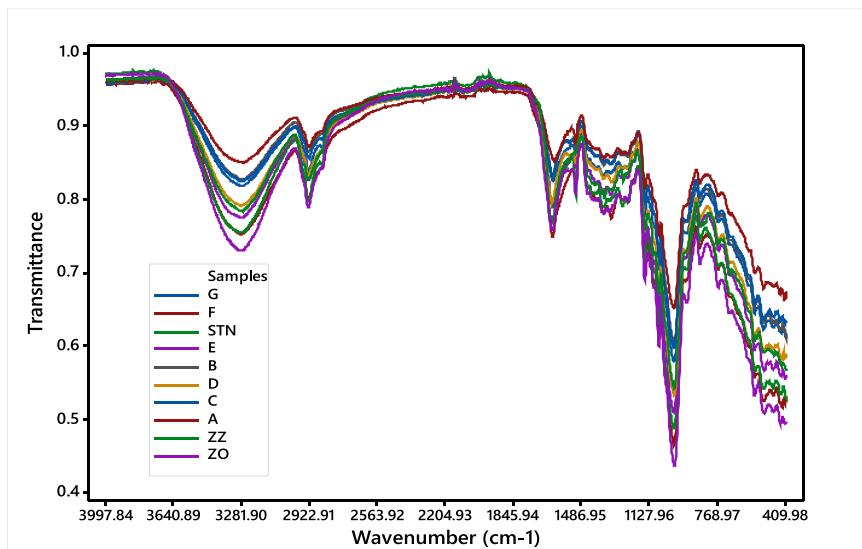


Figure 1. Stacked FT-IR spectra of the powdered ginger samples analysed.

Table 6. Main functional group bands identified in the FT-IR spectra of the ginger samples.

Sr No	Wavenumber (cm ⁻¹)	Functional group assignment	Comments
1	3200–3400	OH stretch	Hydroxyl and phenolic groups in gingerols, shogaols, zingerone and paradols, among others.
2	2930	Methylene C–H asymmetric stretch	Backbone of several secondary metabolites
3	1900–2200	Aromatic combination and overtone bands	-
4	1640	C=C stretching	Terpenes like zingiberene, camphene, β-elemene, limonene present.
5	1512	Aromatic skeletal stretch; C–H In-plane deforming and stretching	Aromatic skeletal stretching of lignin
6	1230–1380	C–N stretching	Zingerines
7	997	C=C bending	Terpenes like zingiberene, camphene, β-elemene, limonene present.

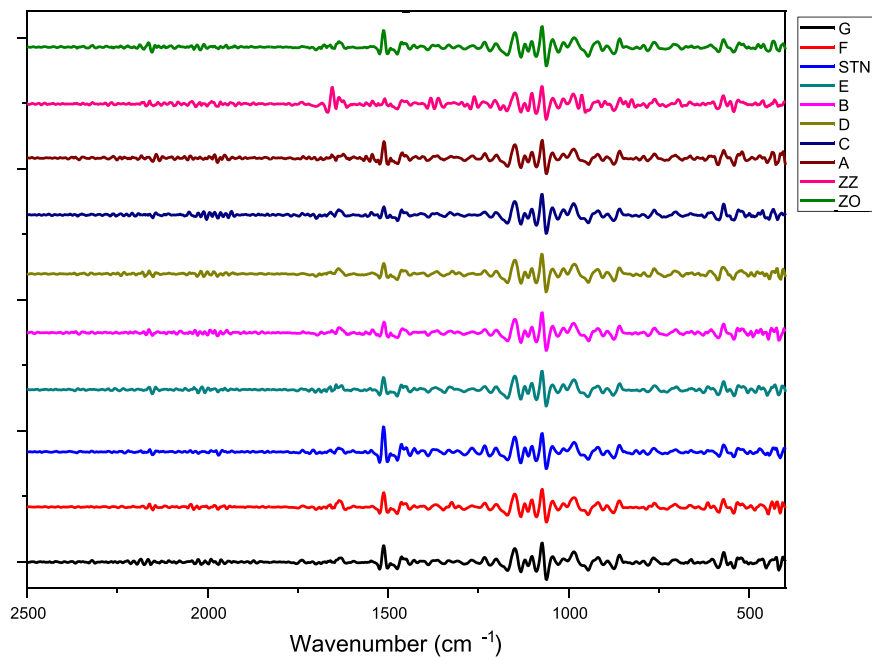


Figure 2. FT-IR spectra of powdered ginger samples after pre-processing.

In the physicochemical analysis, the levels of heavy metals such as Hg, Cd and As were within the maximum permissible limit (MPL) outlined by the [World Health Organization, 2007](#). The reference sample ZZ had Zn levels more than the MPL of 50 mg/kg for herbal materials but this was found to be statistically insignificant ($P > 0.05$). Zn is an invaluable trace element for DNA and protein synthesis as well as proper functioning of the thyroid gland. Even though its toxicity is not widespread, it is believed that levels in excess of regulatory requirement may be associated with disruption of immune function and alteration of lipoprotein levels in the blood ([Fosmire, 1990](#)). The total ash and acid insoluble ash values of the products were within specifications for ginger as stipulated in the [United States Pharmacopoeia \(USP, 2006\)](#) except for one local product (B) which recorded a slightly higher value for the latter albeit not significantly different ($P > 0.05$) from the reference value. The low ash values indicates that the products have not been adulterated with inorganic variables such as silicates, carbonates, sulphates and nitrates ([Ajazuddin and Saraf, 2010](#)).

4.2. Chemometric analysis of ginger products

The outcome of the present study emphasises the benefits of chemometrics application in herbal medicine quality control. Due to the complexity of the phytochemical constituents of the ginger samples, PCA and HCA, as multivariate algorithms, were applied to the FT-IR spectral fingerprints and this demonstrated some similarities and differences in the phytochemistry of the samples. For example, as reported (Section 3.6), PC-1 was thought to account for spectral differences within the IR ranges around 1000–1080 cm^{-1} (for C–O bond stretch) and 1500–1520 cm^{-1} (for aromatic stretch) in all the samples. This may indicate that the samples differed in the constitution of phytochemicals with C–O bonds, such as methoxy groups in gingerols and shogaols, and o-glycosides of terpenoids. The differences related to the aromatic stretch in 1500–1520 cm^{-1} could also be a result of differences in lignan composition ([Zhao et al., 2015](#)).

In effect, as determined from the chemometric analysis, the phytochemical composition of the commercial ginger samples (that is, A-G) were similar. Their PCA scores and the clusters from HCA show that they were probably produced from a similar ginger source and that irrespective of the different manufacturing origins of the products ([Table 1](#)), their FT-IR spectral features were consistent. Also, their clustering with ZO, a reference *Z. officinale* from Ghana further proves that these products were likely produced from *Z. officinale* species. STN, a reference ginger sample from Nigeria also demonstrated some level of similarity ([Figure 3A](#)) with the commercial samples, and this may also indicate that STN is also a *Z. officinale* sample. The slight variation observed in the ZO laden products could be attributed to drying method, maturity of the rhizomes and geographical origins ([Abdo et al., 2021](#)). Consistent with this assertion was the observation that ZZ, a reference of *Z. zerumbet*, possessed spectral features significantly different from that of the above-mentioned samples. These results corroborate with the reflections of [Jiang et al. \(2006\)](#), for example, that limonene and 3-carene occurs exclusively in *Z. zerumbet* whereas citronellal is present only in *Z. officinale*. Similarly gingerols and their derivatives, shogaols and paradols have also not been reported in any *Zingiber* species except *Z. officinale* ([Jiang et al., 2006](#)). Thus, the variations in chemical composition of the two species could have accounted for the significant difference in the infra red spectral features observed in this study. FT-IR analysis with PCA and HCA has therefore demonstrated that *Z. officinale* is a common ingredient of the commercial ginger samples.

5. Conclusion

The powdered ginger products investigated in the current study generally comply with the specifications for heavy metals, ash content and microbial load (except for total aerobic count). However, locally manufactured products did not meet label regulatory requirements with

some also recording high aerobic bacterial counts and slight deviations from the physical attributes of the reference sample, *Z. officinale*. All test samples mainly contained the ginger species *Z. officinale* (white variety) and not *Z. zerumbet*, the yellow ginger variety. Although the findings on the physical characteristics cast some doubts on the authenticity of products, they can be largely considered as acceptable in terms of their intrinsic and extrinsic compositions and deemed suitable for consumption and use for medicinal purposes. We recommend that the food and drug regulatory agency enforce regulatory requirements for these powdered products, and pay equal attention to local products.

Declarations

Author contribution statement

Isaac Kingsley Amponsah, Abena Boakye, Emmanuel Orman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Francis Ackah Armah: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Lawrence Sheringham Borquaye: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Silas Adjei, Yaa Afrakoma Dwamena, Benjamin Kingsley Harley: Performed the experiments; Wrote the paper.

Kennedy Ameyaw Baah: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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