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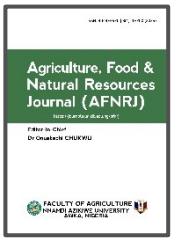

Original Article

Geo-spatial variation of nutritional and phytochemical content of Okra in major agro-commercial zones in Ilorin, Nigeria

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ABSTRACT

This study evaluated the proximate and phytochemical composition of Abelmoschus esculentus samples from three major markets in Ilorin: Oja-Oba, Mandate, and Ganmo to assess nutritional quality, bioactive potential, and spatial variability. Samples were analyzed for moisture, total dry matter, ash, crude protein, fat, crude fibre, and carbohydrates using standard analytical methods, while phytochemical profiling quantified alkaloids, saponins, flavonoids, tannins, phenolics, terpenoids, glycosides, steroids, and cardiac glycosides. Moisture content ranged from 66.71 ± 3.22% to 68.60 ± 2.15%, total dry matter from 31.54 ± 0.85% to 33.30 ± 2.35%, ash from 3.85% to 4.05%, and crude protein from 11.91 ± 1.80% to 12.51 ± 1.34%, indicating consistent nutritional contributions across markets. Fat and crude fibre were low (2.09–2.64% and 1.40–1.92%, respectively), while carbohydrates were slightly higher in Mandate samples (12.79 ± 0.66%). Phytochemicals were abundant, with alkaloids (16.52–20.07 mg/100 g) and saponins (15.53–19.27 mg/100 g) dominant, flavonoids (6.02–7.32 mg/100 g) and tannins (1.78–3.49 mg/100 g) moderate, and phenolics stable across markets (3.17–3.21 mg/100 g). Terpenoids, glycosides, steroids, and cardiac glycosides occurred at low but comparable levels. Limited spatial variability suggests compositional stability and reinforces the nutritional adequacy and functional potential of okra. These findings support targeted sourcing based on market origin for dietary and functional applications and provide a reference for future studies linking phytochemical profiles with agronomic and soil factors.

KEYWORDS: *Bioactive compound, Functional food, Indigenous vegetable, Nutraceutical potential, Variation.*

INTRODUCTION

The intricate connection between diet, nutrition, and health has been long established, but recent decades have witnessed a surge in scientific and policy-level attention toward improving dietary quality as a means of combating the global rise in non-communicable diseases (NCDs) such as diabetes, cardiovascular disorders, and obesity. Poor nutrition now ranks among the leading causes of morbidity and mortality worldwide (Wang *et al.,* 2019). In low- and middle-income countries like Nigeria, where food insecurity and nutritional deficiencies coexist with rising NCDs, the consumption of locally available, culturally acceptable, and nutrient-rich plant foods is both a dietary necessity and a public health imperative (Akinola *et al.*, 2020).

Among indigenous vegetables widely consumed across sub-Saharan Africa, *Abelmoschus esculentus* (okra) holds significant nutritional, medicinal, and economic value. Belonging to the Malvaceae family, okra is extensively cultivated across tropical and subtropical climates. Nigeria, one of the top producers and consumers globally, integrates okra deeply into traditional cuisine, where its mucilaginous pods are favored for their thickening properties in soups and stews (Dantas *et al.,* 2021). Beyond its culinary value, okra is increasingly recognized as a functional food due to its dense

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nutritional composition; rich in dietary fiber, vitamins C and A, folate, essential minerals, and bioactive compounds such as flavonoids, tannins, alkaloids, and saponins (Elkhalifa *et al*., 2021; Guebebia *et al*., 2023). These constituents have been associated with diverse health benefits, including antioxidant, anti-inflammatory, antihyperglycemic, and antimicrobial activities (Romdhane *et al*., 2020).

In Nigeria, particularly in urban centers like Ilorin, okra varieties such as Clemson Spineless and Dwarf Long Green are prevalent in local markets. However, nutritional and phytochemical profiles can vary significantly due to factors like agroecological conditions, soil type, harvest maturity, and post-harvest handling (Ilodibia *et al.*, 2017; Petropoulos *et al.*, 2018). Despite its widespread consumption, localized data on the nutritional and phytochemical composition of market-sourced okra in Ilorin remain scarce. This gap not only limits scientific understanding but also perpetuates misconceptions that may lead to its underutilization, especially among youth and urban populations. This study was therefore designed to assess and compare the proximate composition and phytochemical profiles of *A. esculentus* obtained from three major market sources in Ilorin, Kwara State.

MATERIALS AND METHOD

Study Area and Sample Collection

This study was conducted in Ilorin, the capital of Kwara State, Nigeria, located between latitudes 8.50°N and 8.52°N and longitudes 4.55°E and 4.58°E. Ilorin is a metropolitan city with diverse socioeconomic activities and a culturally embedded consumption of okra (*Abelmoschus esculentus*), a staple in local diets. Fresh okra samples were collected from three major markets: Oja-Oba Market, Mandate Market, and Ganmo Market. These sites were strategically chosen for their high volume of daily agricultural produce transactions, thus providing a representative sampling of okra consumed by residents. The selected okra pods were manually harvested, inspected visually for freshness, uniformity, and absence of physical or pathological damage, and then packaged in sterile, labeled zip-lock bags to avoid cross-contamination. Samples were immediately transported to the laboratory at ambient temperature for processing and storage.

Oja Oba Market, also known as the Central Market, is a bustling commercial hub in Ilorin, Kwara State, Nigeria, (Lat: 8.4833°N, and Long: 45833°N), where a wide variety of goods are sold, including fresh produce, vegetables, grains, spices, textiles, household items, and electronics. The market is usually crowded, with traders and customers haggling over prices, creating a lively atmosphere that showcases the rich cultural heritage and economic vitality of Ilorin.

Sample Preparation

The collected okra pods were washed thoroughly under running tap water and rinsed with distilled water. The stalks were trimmed using a sterile stainless-steel knife, and the edible portions were longitudinally sliced into uniform pieces. Samples were then oven-dried at 70 °C for 24 hours to constant weight, as described by Lawal *et al*. (2011). The dried samples were ground into fine powder using a sterile mortar and pestle, packed into airtight, sterile polyethylene bottles, and stored in a desiccator until further analysis.



Plate 1: Study Area 1: Oja-Oba market, Ilorin



Plate 2: Study Area 2; Mandate Market, Ilorin

Ganmo Market, located in Ilorin, Kwara State, Nigeria, (Lat:8.5167°N and Long: 4.5667°N), is a bustling marketplace that offers a wide range of goods and services, including fresh produce, food items, textiles, household essentials, electronics, beauty products, and traditional medicine.



Plate 3: Study Area 3; Ganmon Market

Laboratory Analysis

Proximate Composition

Proximate composition (moisture, ash, crude protein, fat, fiber, carbohydrate, and caloric value) was determined following the standard procedures of the Association of Official Analytical Chemists (Feldsine *et al.*, 2002)

Moisture Content

Approximately 5.0 g of each sample was weighed into pre-weighed aluminum dishes and dried in an oven initially at 80 °C for 2 hours, followed by 100 °C for 3 hours. The samples were repeatedly dried and weighed until a constant weight was obtained. Moisture content was calculated as:

$$\text{Moisture (\%)} = \frac{W2-W3}{W2-W1} \times 100 \quad (1)$$

Where: W_1 = weight of empty crucible, W_2 = weight of crucible + fresh sample, W_3 = weight of crucible + dried sample.

Ash Content

Twenty grams (20 g) of each sample were placed into pre-weighed platinum crucibles, incinerated in a muffle furnace at 550 °C for 3 hours, cooled in a desiccator, and reweighed. Ash content was calculated as:

$$\text{Ash (\%)} = \frac{\text{Weight of ash}}{\text{Weight of original sample}} \times 100 \quad (2)$$

Lipid (Fat) Content

Fat content was estimated using Soxhlet extraction with petroleum ether as solvent. Fifteen grams (15 g) of each sample were extracted for 6 hours, the solvent removed using a rotary evaporator, and the residue (lipid) was dried and weighed. Fat percentage was calculated by:

$$\text{Fat (\%)} = \frac{\text{Weight of extracted lipids}}{\text{Weight of dry sample}} \times 100 \quad (3)$$

Crude Protein Content

Protein content was determined using the Kjeldahl method, with digestion, distillation, and titration steps involving sulfuric acid, sodium hydroxide, and boric acid. Protein was calculated using:

$$\text{Crude Protein (\%)} = \frac{(Vs-Vb)\times 0.01401\times N\times 6.25}{\text{Sample weight}} \times 100 \quad (4)$$

Where: Vs = volume of acid for sample titration, Vb = volume for blank, N = normality of HCl.

Crude Fiber

Twenty grams (20 g) of defatted samples were boiled in 1.25% H_2SO_4, filtered, washed, and then boiled in 1.25% NaOH. The residue was dried, weighed, incinerated at 600 °C, and reweighed. Crude fiber was computed as:

$$\text{Crude Fiber (\%)} = \frac{(C2-C3)}{\text{sample weight}} \times 100 \quad (5)$$

Where: C_2 = weight of crucible + dried residue, C_3 = wei ght after ashing.

Carbohydrate Content

Calculated by difference:

$$\text{Carbohydrate (\%)} = 100-(\text{Protein}+\text{Moisture}+\text{Ash}+\text{Fiber}+\text{Fat}) \quad (6)$$

$$\text{Caloric Value (kJ/100 g): Energy} = (\text{Protein}\times 16.7) + (\text{Fat}\times 37.7) + (\text{Carbohydrate}\times 16.7) \quad (7)$$

Phytochemical Analysis

Qualitative Screening

Standard phytochemical tests were conducted for the presence of alkaloids, tannins, flavonoids, saponins, phenols, glycosides, terpenoids, and anthocyanins following protocols by Ben *et al.* (2013), Lawal *et al*. (2019) and Solanki *et al*. (2019). Key indicators such as color change, precipitate formation, or frothing were used to infer compound presence in aqueous or methanolic extracts.

Quantitative Phytochemical Estimation

Quantification of selected bioactive compounds in the okra samples was carried out using standard spectrophotometric and gravimetric techniques. Total phenolic content (TPC) was determined using the Folin–Ciocalteu reagent, with results expressed as milligrams of gallic acid equivalents (GAE) per 100 grams of dry extract, following the method described by Molole *et al.* (2022). Total flavonoid content was assessed using the aluminum chloride colorimetric assay, with rutin serving as the standard, and values expressed as milligrams of rutin equivalents (RE) per gram of extract, as outlined by Chandra *et al*. (2014).

Alkaloid content was quantified based on the acid-alcohol extraction method followed by precipitation with ammonium hydroxide, and the results were expressed as a percentage of dry weight in accordance with Senguttuvan *et al*. (2014). Saponin content was estimated through aqueous ethanol extraction and subsequent partitioning with n-butanol, with values reported as percentage dry weight, following the protocol of Chen *et al*. (2025). Tannin content was measured using the Folin–Ciocalteu method with gallic acid as the standard, and the concentrations were expressed as milligrams of GAE per gram of extract, as described by Makkar and Harinder (2003). Cardiac glycosides were evaluated using acid hydrolysis followed by chloroform extraction, with the dried and weighed residue representing the glycoside content, as detailed by Pellati *et al.* (2009). Similarly, Steroid content was analyzed through ethanol extraction followed by reaction with acetic anhydride and sulfuric acid,

producing a color change measured spectrophotometrically, in accordance with the method of Iqbal *et al.* (2015). Terpenoid content was assessed using petroleum ether extraction, followed by evaporation and gravimetric quantification of the residue, following the protocol described by Rustiani *et al.* (2021). All measurements were conducted in triplicates to ensure accuracy and reproducibility. All analyses were conducted in triplicate to ensure statistical reliability, and results were presented as means ± standard deviation.

RESULTS AND DISCUSSION

Geo-Spatial Proximate Composition of *Abelmoschus esculentus* in Major Ago-Commercial Zones

The proximate analysis of *Abelmoschus esculentus* (okra) samples collected from three major commercial hubs in Ilorin revealed site-dependent variations in essential nutritional parameters (Table 1). Moisture content was highest in samples from Ganmo (68.60 ± 2.15%), followed closely by Oja-Oba (67.53 ± 3.16%) and Mandate (66.71 ± 3.22%). This is consistent with previous findings by Adetuyi *et al.* (2008), which reported moisture levels of 65–80% in fresh okra pods. Moisture levels in fruits and vegetables directly impact storage life and microbial susceptibility; hence, the higher moisture in Ganmo-sourced samples may predispose them to faster spoilage, although it contributes positively to dietary hydration.

Conversely, dry matter values reflected an inverse trend, with Mandate exhibiting the highest percentage (33.30 ± 2.35%), followed by Oja-Oba (32.47 ± 2.00%) and Ganmo (31.54 ± 0.85%). This indicates that okra from Mandate is more nutrient-dense, as higher dry matter is associated with greater accumulation of solids, including macronutrients and phytochemicals (Gemede *et al.,* 2015). The protein content ranged from 11.91 ± 1.80% in Mandate to 12.51 ± 1.34% in Ganmo. This is comparable to 11–13% previously reported by Akintoye *et al*. (2011) and confirms the nutritional significance of okra as a moderate source of plant-based protein, especially in regions where animal protein is limited. The marginally higher protein level in Ganmo samples could reflect microclimatic or varietal effects enhancing nitrogen assimilation. Fat content across the samples was low (2.09-2.64%), characteristic of most vegetables and consistent with the report by (Odoh *et al.,* 2018). However, the highest value recorded in Mandate may reflect soil fertility or cultivar-specific lipid synthesis pathways. These lipids are important for the absorption of fat-soluble vitamins and contribute to satiety.

Ash content, indicative of the total mineral composition, varied slightly among the samples (3.85-4.05%). Mandate samples again recorded the highest value, corroborating Elkhalifa *et al.* (2021), who emphasized the contribution of okra to dietary calcium, magnesium, potassium, and phosphorus. This highlights its relevance in mineral-deficient populations. Crude fibre ranged between 1.40 ± 0.10% (Ganmo) and 1.92 ± 0.75% (Mandate), and although modest, these levels contribute significantly to dietary fibre intake. Fibre is crucial for promoting gastrointestinal health and mitigating risks of cardiovascular diseases and type 2 diabetes (Alahmari, 2024).

Carbohydrate content was highest in Mandate (12.79 ± 0.66%), followed by Oja-Oba (12.44 ± 1.50%) and Ganmo (11.54 ± 0.27%), indicating differential metabolic energy contributions across sites. While okra is not a carbohydrate-dense crop, its moderate carbohydrate content complements other staples and supports dietary energy needs, especially when incorporated into soups and stews in traditional diets.

Table 1: Geo-Spatial Proximate Composition of *Abelmoschus esculentus* in Major Ago-Commercial Zones

Parameter	A (Oja-Oba) (%)	B (Mandate) (%)	C (Ganmo) (%)
Total Dry Matter	32.47 ± 2.00	33.30 ± 2.35	31.54 ± 0.85
Moisture Content	67.53 ± 3.16	66.71 ± 3.22	68.60 ± 2.15
Ash Content	3.86 ± 0.33	4.05 ± 0.87	3.85 ± 0.30
Crude Protein	12.46 ± 1.08	11.91 ± 1.80	12.51 ± 1.34
Fat and Oil	2.09 ± 0.31	2.64 ± 0.58	2.10 ± 0.25
Crude Fibre	1.63 ± 0.22	1.92 ± 0.75	1.40 ± 0.10
Carbohydrate	12.44 ± 1.50	12.79 ± 0.66	11.54 ± 0.27

Figure 1 presents Inter-Market Variability and Chemical Superiority of *Abelmoschus esculentus* samples collected from Oja-Oba (A), Mandate (B), and Ganmo (C) markets in Ilorin exhibited noticeable variations across all measured parameters. These differences may reflect market-level influences such as agronomic practices, soil nutrient availability, harvest maturity, and post-harvest handling conditions.

Total Dry Matter content ranged from 31.54 ± 0.85% in Ganmo to 33.30 ± 2.35% in Mandate. Mandate samples recorded significantly higher values ($p < 0.05$), indicating denser tissue biomass, possibly due to lower water retention or improved post-harvest dehydration. This observation is consistent with the findings of Adejumo and Olayiwola (2019), who reported that okra fruits from well-managed farms tend to exhibit higher dry matter content, enhancing shelf stability and market value. Moisture Content followed an inverse trend to dry matter, ranging from 66.70 ± 2.35% (Mandate) to 68.46 ± 0.85% (Ganmo). The higher moisture observed in Ganmo samples may be linked to early harvesting or insufficient post-harvest drying, which has implications for microbial stability and storage life. Similar trends were reported by Afolabi, Samuel, and Udo (2020) in moisture variation across okra cultivars from different agro-ecological zones in Southwest Nigeria.

Ash Content, which reflects total mineral composition, varied marginally among markets: 3.74 ± 0.39% (Oja-Oba), 3.58 ± 0.33% (Mandate), and 3.28 ± 0.24% (Ganmo). Although differences were not statistically significant ($p > 0.05$), Oja-Oba samples consistently showed higher mineral residue. These values align with those documented by Fasuyi & Nonyerem (2018), who reported ash contents ranging from 3.2% to 4.1% in Nigerian okra cultivars. Crude Protein content revealed a subtle but important difference among the markets. Mandate samples had the highest protein level (12.89 ± 0.91%), followed

by Oja-Oba (12.33 ± 1.00%) and Ganmo (12.05 ± 0.76%). These values are within the range reported by Olorunfemi *et al.* (2022), indicating that okra remains a valuable source of plant protein. The higher protein content in Mandate may reflect superior agronomic inputs or favorable soil nitrogen levels.

Fat and Oil content was uniformly low across all samples, with a range of 2.26 ± 0.29% (Oja-Oba) to 2.68 ± 0.24% (Ganmo). The slightly higher oil content in Ganmo may be due to varietal factors or maturity stage, as reported by Okon and Nwokolo (2021), who found lipid content to be sensitive to okra ripening stages. Crude Fibre showed minimal variation, with Ganmo recording the highest level (2.78 ± 0.17%) and Oja-Oba the lowest (2.33 ± 0.26%). Fibre content is critical for digestive health and adds to the functional food value of okra. These findings are supported by Oyenuga (1968), who emphasized that dietary fibre in okra can vary based on cultivar and environmental conditions.

Carbohydrate Content, calculated by difference, was highest in Mandate (13.22 ± 0.68%), slightly above Oja-Oba (13.01 ± 0.75%) and Ganmo (11.65 ± 0.55%). The higher carbohydrate levels in Mandate samples may be linked to greater dry matter content, reflecting accumulation of starches and sugars. This supports earlier reports by Adebayo, Adeyemi, and Akinlade (2020), who observed strong correlations between dry matter and carbohydrate fractions in okra. Overall, Mandate market samples showed relatively superior nutritional quality across several main parameters, particularly in dry matter, crude protein, and carbohydrates, while Ganmo samples exhibited higher moisture and fat content. Oja-Oba samples displayed the highest ash content, suggesting richer mineral composition.

These variations show the influence of micro-environmental and post-harvest factors on nutrient composition. The findings advocate for localized food composition profiling as a tool for nutrition-sensitive agricultural interventions and consumer awareness. Further studies should incorporate mineral speciation, phytochemical content, and antioxidant profiling to provide a more comprehensive understanding of nutritional landscape of okra in Nigerian markets.

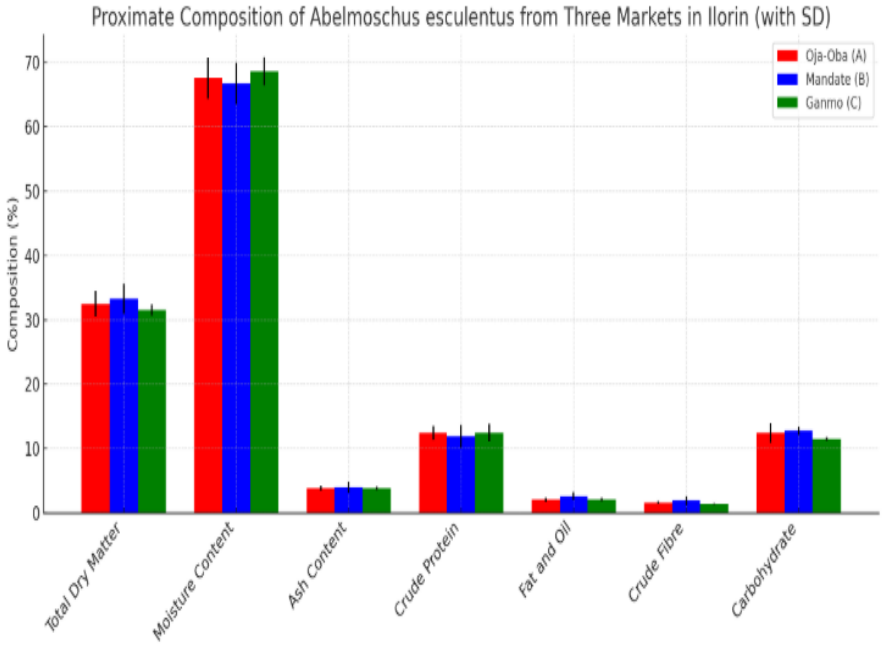

Figure 1: Inter-Market Variability and Chemical Superiority of the Proximate Composition of *Abelmoschus esculentus* samples of Major Agro-Commercial Zones in Ilorin

Qualitative Phytochemical Composition of *Abelmoschus esculentus* in Major Agro-Commercial Zones

All analyzed samples tested positive for a diverse spectrum of secondary metabolites, indicating the phytochemical richness of okra across all market sites (Table 2). The abundant presence of alkaloids (+++), saponins (+++), and flavonoids (++) aligns with earlier findings by *Elkhalifa et al.* (2021), suggesting the potential of okra for anti-inflammatory, antimicrobial, and antioxidant applications. Other phytoconstituents such as tannins, terpenoids, glycosides, steroids, phenols, and cardiac glycosides were moderately expressed (+), suggesting their presence in less dominant concentrations but nonetheless contributing to the cumulative pharmacological potential of the plant.

Table 2: Qualitative Phytochemical Profile of *Abelmoschus esculentus* in Major Agro-Commercial Zones

Phytochemical	A (Oja-Oba)	B (Mandate)	C (Ganmo)
Alkaloids	+++	+++	+++
Flavonoids	++	++	++
Tannins	+	+	+
Saponins	+++	+++	+++
Terpenoids	+	+	+
Glycosides	+	+	+
Steroids	+	+	+
Phenols	+	+	+
Cardiac Glycosides	+	+	+

Quantitative Phytochemical Composition of *Abelmoschus esculentus* in Major Agro-Commercial Zones

The quantitative phytochemical profiling (Table 3) further emphasized the metabolic variability of *A. esculentus* as influenced by market provenance. Alkaloids were most concentrated in Ganmo (20.07 ± 2.35%), followed by Oja-Oba (17.48 ± 2.22%) and Mandate (16.52 ± 1.90%). Alkaloids contribute to diverse pharmacological effects, including analgesic, antimalarial, and hypotensive actions (Letchuman *et al*., 2024). Their elevated levels in Ganmo suggest environmental or genetic factors promoting alkaloid biosynthesis. Saponins were also highest in Ganmo (19.27 ± 2.93%), supporting their known cytotoxic, cholesterol-lowering, and immunostimulatory properties (Timilsena *et al*., 2023). These high saponin levels suggest a greater potential for cardioprotective effects and modulation of blood lipid profiles in okra from this location.

Flavonoid content peaked in Mandate samples (7.32 ± 1.20 mg RE/g), consistent with Li *et al.* (2019), who highlighted their antioxidant potential through radical scavenging activity. Tannin content followed a similar trend, with Mandate showing the highest level (3.49 ± 0.51 mg GAE/g). Tannins contribute to antimicrobial and antidiarrheal activity but also possess chelating properties that may reduce mineral bioavailability when consumed in excess.

Phenolic content showed minimal variation, ranging from 3.17 ± 0.03 to 3.21 ± 0.11 mg GAE/g, supporting their ubiquitous role as antioxidants. Terpenoids (0.47–0.48%), glycosides (0.35–0.39%), and cardiac glycosides (0.25–0.27%) also displayed relatively stable profiles, suggesting their biosynthesis may be under strong genetic control and less influenced by environmental variables (Eze & Akubor, 2012). Steroids were detected in trace amounts (0.002–0.003%), consistent with earlier phytochemical reports.

Inter-Market Variability and Chemical Superiority

This quantitative phytochemical analysis demonstrates significant variability in the concentration of major bioactive compounds in *Abelmoschus esculentus* (Okra) samples sourced from the three different markets in Ilorin (A: Oja-Oba, B: Mandate, and C: Ganmo). This market-based variation underscores the influence of extrinsic factors (e.g., cultivation, handling, storage) on the final chemical profile, an effect that complements the known genotypic variability of the crop (Halilu *et al*., 2023; Patanè *et al*., 2024).

Table 3: Quantitative Phytochemical Composition of *Abelmoschus esculentus* in Major Ago-Commercial Zones

Phytochemical (mg/100g or %)	A (Oja-Oba)	B (Mandate)	C (Ganmo)
Alkaloids	17.48 ± 2.22	16.52 ± 1.90	20.07 ± 2.35
Flavonoids	6.33 ± 0.67	7.32 ± 1.20	6.02 ± 0.58
Tannins	1.78 ± 0.32	3.49 ± 0.51	2.18 ± 0.14
Saponins	18.71 ± 2.64	15.53 ± 2.57	19.27 ± 2.93
Terpenoids	0.47 ± 0.05	0.47 ± 0.07	0.48 ± 0.12
Glycosides	0.38 ± 0.07	0.39 ± 0.07	0.35 ± 0.05
Steroids	0.002 ± 0.000	0.003 ± 0.010	0.002 ± 0.001
Phenols	3.21 ± 0.11	3.17 ± 0.03	3.17 ± 0.08
Cardiac Glycosides	0.26 ± 0.04	0.27 ± 0.04	0.25 ± 0.02

The differences among the three markets were most pronounced in the high-concentration compounds, enabling an assessment of chemical superiority based on overall phytochemical richness. Recent studies confirm that environmental factors and maturity stage can significantly alter these chemical profiles (Halilu *et al*., 2023; Ben Ammar *et al*., 2024).

Market C (Ganmo) consistently yielded the highest mean concentrations for the two most abundant phytochemicals: Alkaloids (20.07%) and Saponins (19.27%). Given the quantitative dominance of these two compounds, Market C represents the richest overall source of the measured phytochemicals, providing the highest bulk yield of these key macro-constituents.

Market B (Mandate) exhibited a statistically significant higher concentration of crucial antioxidant compounds compared to the other markets, specifically Flavonoids (7.32 mg RE/g) and Tannins (3.49 mg GAE/g. This suggests that while Market C has a higher bulk concentration of total active compounds, Market B is superior in its content of certain mg/g -level antioxidant phenolic compounds. This enrichment is particularly relevant as phenolics and flavonoids are suggested to be the primary drivers of documented antidiabetic and antioxidant properties of okra (Liu *et al*., 2024; El-Mesallamy *et al*., 2022).

A (Oja-Oba) generally displayed intermediate values across most compound classes, ranking second in Saponins and Phenols, but did not lead in any major phytochemical category. The samples were overwhelmingly dominated by two major classes of compounds: Saponins and Alkaloids, which were measured as a percentage of the dry sample weight. The substantial concentration of these compounds is consistent with traditional medicinal use of okra, as both are widely associated with significant therapeutic activities, including antihyperlipidemic (saponins) and neuroprotective (alkaloids) effects (Ankita *et al*., 2022; Utami *et al.,* 2025), while the minor

components: Flavonoids, Tannins, and Phenols were present in mg/g levels, with Phenols being relatively consistent across markets (approx. 3.2 mg GAE/g). Terpenoids, Glycosides, Steroids, and Cardiac Glycosides were measured at low percentage levels (typically below 0.5%), showing minimal quantitative variation among the markets.

In conclusion, based on the principle that a higher overall concentration of bioactive compounds is desirable, Market C (Ganmo) is inferred to contain the best quality *Abelmoschus esculentus* in terms of total phytochemical load, predominantly driven by high concentrations of Alkaloids and Saponins. However, Market B should be preferred if the target application specifically requires high levels of Tannins and Flavonoids, which are important for enhancing antioxidant capacity (Halilu *et al*., 2023).

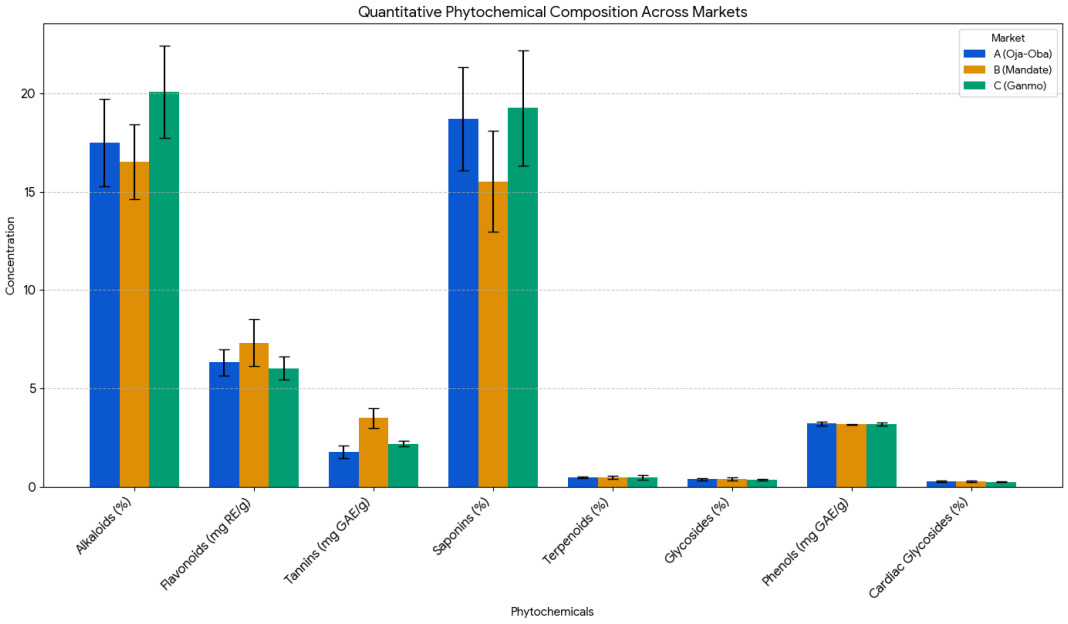

Figure 2: Inter-Market Variability and Chemical Superiority of the Phytochemical Composition of *Abelmoschus esculentus* samples in Major Agro-Commercial Zones

Figure 3 shows the interrelationships among the quantified phytochemicals and to evaluate the grouping of *Abelmoschus esculentus* samples from the three markets in Ilorin, Principal Component Analysis Biplot (PCA) was conducted. The PCA biplot (Figure 3) revealed distinct clustering patterns that highlight the phytochemical variability among the samples from Oja-Oba, Mandate, and Ganmo markets. The variables analyzed included concentrations of alkaloids, flavonoids, tannins, saponins, phenols, and terpenoids. The PCA revealed two principal components (PC1 and PC2) with values greater than 1, cumulatively explaining the total variance in the data. PC1 accounted for 75.04% of the variance, primarily influenced by high loadings of flavonoids, phenols, saponins, and alkaloids, suggesting their dominant role in phytochemical variation. PC2 contributed an additional 24.96%, mainly shaped by tannins and terpenoids. The PCA biplot (Figure 3) clearly differentiated the samples based on market origin: Mandate Market samples were clustered along the positive PC1 axis, indicating relatively higher levels of flavonoids, phenols, and alkaloids. Oja-Oba Market samples aligned more with the positive PC2 axis, suggesting dominance of tannins and terpenoids. Ganmo Market samples were generally situated closer to the origin or negative quadrants of both axes, indicating relatively lower phytochemical concentrations. The loading vectors overlaid on the biplot further illustrated the contribution of each phytochemical to the principal components. Flavonoids and phenols pointed strongly along PC1, while tannins and terpenoids aligned with PC2. This spatial distribution suggests distinct phytochemical profiles among markets, influenced by environmental, agronomic, or post-harvest factors (Adewale *et al*., 2020; Nwosu *et al*., 2022).

The results show the utility of PCA in reducing data complexity while revealing meaningful patterns in phytochemical variability. Such analysis supports quality control and market differentiation of okra based on phytochemical richness and potential health benefits. The PCA biplot further confirms that the phytochemical profiles of okra from different markets are distinct and may be influenced by factors such as soil composition, post-harvest handling, and micro-environmental conditions (Afolabi *et al*., 2021; Ezeh *et al*., 2023). This multivariate approach provides valuable information about the chemical diversity of okra and supports targeted sourcing for nutritional or therapeutic applications.

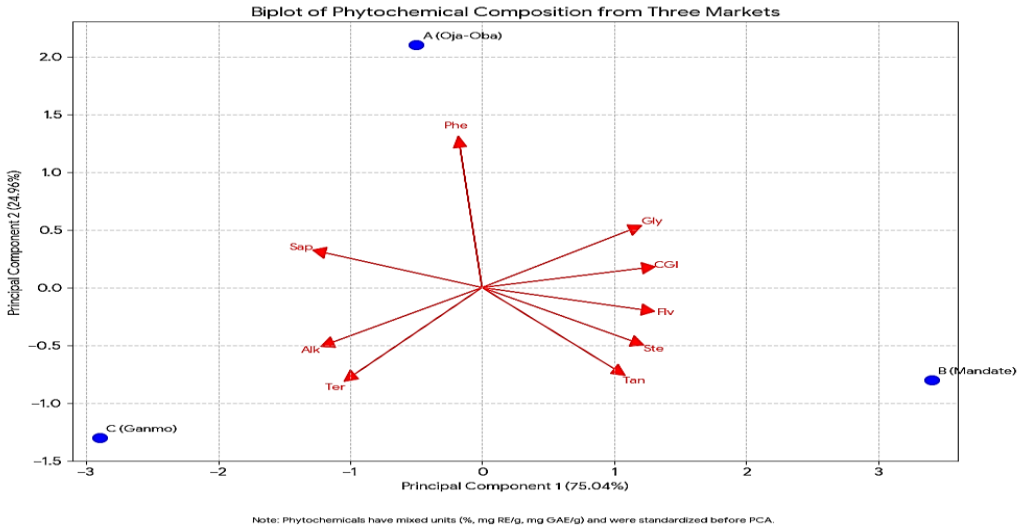

Figure 3: Interrelationships among the Quantified Phytochemicals of *Abelmoschus esculentus*

CONCLUSION AND RECOMMENDATION

The study confirms that market origin influences the phytochemical and nutritional composition of *Abelmoschus esculentus*, with site-specific variations driven by agro-ecological conditions, varietal differences, and post-harvest handling. Despite these variations, all samples provided essential nutrients and bioactive compounds, indicating the role of okra in nutrition, health promotion, and functional food development. Multivariate analysis effectively distinguished okra from different markets, highlighting the impact of environmental and handling factors on chemical diversity.

The study recommends targeted sourcing of okra based on market origin can optimize nutritional and phytochemical intake for dietary or functional applications. Future studies should investigate the relationship between soil nutrient status, agronomic practices, and bioactive compound levels to enhance crop quality and functional potential.

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Author's Contribution

Conceptualization, methodology POBU and TOS; investigation POBU; data curation POBU and TOS; formal analysis POBU and TOS; writing original draft preparation POBU and TOS; writing review and editing POBU and TOS; visualization POBU; supervision POBU; project administration POBU. All authors have read and agreed to the published version of the manuscript.

Ethical Statement

Not Applicable

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