CORRELATION OF TOTAL PHENOLIC AND FLAVONOID CONTENT WITH ANTIOXIDANT ACTIVITIES AND ALPHA-GLUCOSIDASE INHIBITION IN 20 CULINARY SPICES COMMONLY USED IN LAGOS STATE, NIGERIA

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Abstract

This investigation meticulously measures the total phenolic content (TPC), total flavonoid content (TFC), antioxidant activities (DPPH and FRAP), and alpha-glucosidase inhibition (AGI) in twenty widely utilized culinary spices sourced from Lagos State, Nigeria. The Folin-Ciocalteu assay was used to estimate total phenolic content (TPC) while Total flavonoid content (TFC) in the ethanolic extracts was estimated by the aluminum chloride colorimetric assay. The antioxidant capacity of the ethanolic liquid extracts was evaluated using two assays: DPPH radical scavenging assay and the FRAP Assay. The α-glucosidase inhibitory activity was performed using p-nitrophenyl-α-D-glucopyranoside substrate hydrolysis assay. The analysis of ethanolic extracts was conducted using validated spectrophotometric methods. The statistical analyses conducted, including Pearson correlation, linear regression, ANOVA, Tukey's HSD, principal component analysis (PCA), and heatmap visualization, demonstrated strong positive associations between TPC and antioxidant capacity ($r=0.7401$, $p<0.05$), as well as a near-perfect correlation between FRAP and AGI ($r=0.993$, $p<0.05$). Cloves, Cinnamon, and Rosemary demonstrated the most significant levels of bioactive phytochemicals and functional capabilities. This research confirms the effectiveness of these spices as powerful natural nutraceuticals that hold therapeutic significance in addressing oxidative stress and diabetes, thereby offering scientific backing for their historical applications.

Keywords

Lagos culinary spices; phenolics; flavonoids; antioxidant activity; alpha-glucosidase inhibition.

Introduction

Culinary spices play a pivotal role in the cultural, nutritional, and therapeutic dimensions of food, particularly in regions such as Lagos State, Nigeria, where they are integral to daily cooking practices and traditional health remedies. These spices contribute not only distinct flavors and aromas to a wide array of local dishes ranging from pepper soup and jollof rice to egusi and ofada sauces but also contain bioactive phytochemicals that have considerable health promoting potential *(Nwokeke et al.,2025; Adeyemi & Ajayi, 2022)*. Lagos, as a vibrant urban center with diverse cultural influences, provides a rich source of indigenous spices like alligator pepper(Aframomum melegueta), African nutmeg (Monodora myristica), locust beans (Parkia biglobosa), and turmeric (Curcuma longa), which are widely accessible in its markets and household kitchens *(Ejiofor et al., 2024).* These spices are known for their content of phenolic and flavonoid compounds, which have been scientifically linked to antioxidant, anti-inflammatory, and enzyme inhibitory activities relevant to the prevention and management of chronic diseases such as diabetes and cardiovascular disorders (*Ojo et al., 2023; Obi &Nwachukwu, 2025)*. Polyphenols are known to inhibit this enzyme primarily through non-covalent binding to the protein structure *(Kim et al.,2020)*.Furthermore, the growing global interest in natural antioxidants and functional foods underscores the importance of characterizing the phytochemical profiles and bioactivities of spices within specific geographic and cultural contexts to optimize their utilization in health promotion *(Eze et al., 2023).* This study focuses on the correlation of total phenolic content (TPC), total flavonoid content (TFC), antioxidant properties, and α-glucosidase inhibition in 20 culinary spices commonly used in Lagos State, aiming to bridge ethnobotanical knowledge with contemporary biomedical research to support local nutraceutical development and dietary interventions.

The culinary scene in Lagos State, Nigeria, is rich with diverse spices that not only improve the taste and smell of traditional dishes but also offer nutritional and health benefits. Spices like locust beans (Parkia biglobosa), alligator pepper (Aframomum melegueta), African nutmeg (Monodora myristica), ginger (Zingiber officinale), and turmeric (Curcuma longa) are essential to popular foods like pepper soup, jollof rice, and egusi soup, which are widely enjoyed throughout Lagos *(Ejiofor et al., 2024; Nwokeke et al., 2025)*. These spices have been used for centuries in local food and traditional medicine due to their bioactive plant compounds, including phenolics, flavonoids, alkaloids, and essential oils that show antioxidant, antimicrobial, and enzyme-inhibiting effects *(Akeem et al., 2016; Obi & Nwachukwu, 2025).* The rise in lifestyle related diseases such as diabetes and heart disease in Nigeria has increased research interest in the health benefits of local spices, especially in urban areas like Lagos where there are rich culinary traditions and easy access to regional spice markets *(Ojo et al., 2023).* Despite the growing recognition of spices as functional foods and health resources, more work is needed to closely examine the bioactive compounds and link them with health-related activities in spices from places like Lagos *(Eze et al., 2023*). This study aims to connect traditional cooking practices with modern scientific analysis by looking at the phenolic and flavonoid content as well as the antioxidant properties and α-glucosidase inhibition in 20 commonly used spices from Lagos. This will help inform local health programs and support the development of health-related products. Phenolic and flavonoid compounds are common secondary metabolites found in plants and spices. They play an important role in the nutritional and medicinal benefits linked to culinary spices. These bioactive compounds have strong antioxidant properties. They neutralize free radicals and prevent oxidative stress related cellular damage, which is a major factor in chronic diseases such as diabetes, cancer, and heart disorders *(Shahidi & Ambigaipalan, 2015).* In Lagos State, Nigeria, using local spices like turmeric (Curcuma longa), ginger (Zingiber officinale), alligator pepper (Aframomum melegueta), and African nutmeg (Monodora myristica) adds these valuable phytochemicals to the diet *(Ejiofor et al., 2024).* Flavonoids, a diverse group within phenolics, also have anti-inflammatory, antimicrobial, and enzyme inhibitory effects. They can inhibit alpha-glucosidase, an enzyme involved in digesting carbohydrates. This inhibition helps manage postprandial blood glucose levels in diabetics *(Ojo et al., 2023)*. These biologically active compounds not only enhance the flavor and aroma of spices but also significantly affect their health benefits in Lagos. This aligns with the growing global interest in natural food originated therapies *(Adeyemi & Ajayi, 2022)*. Therefore, measuring total phenolic content (TPC) and total flavonoid content (TFC) in spices commonly sold in Lagos markets is essential. It helps establish their antioxidant potential and relevance for diabetes management, providing valuable data to support the development of nutraceuticals and functional foods that fit local dietary habits *(Obi & Nwachukwu, 2025).* Combining phytochemical profiling with bioactivity tests highlights the role of these compounds as natural antioxidants and enzyme inhibitors. This underscores their importance in promoting health and preventing disease through the use of local culinary spices *(Eze et al., 2023).*

Materials and Methods

Selection And Collection Of 20 Common Culinary Spices

Twenty culinary spices commonly used in Lagos State; Nigeria were selected for this study based on their culinary prevalence and traditional medicinal importance in Nigerian cuisine. The selected spices include thyme, cumin, fennel seeds, black pepper, black seeds, alligator pepper, chili pepper, turmeric, cloves, cinnamon, nutmeg, African nutmeg, locust beans, paprika, rosemary, onions, garlic, ginger, star anise, and bay leaf. These spices were sourced directly from major local markets in Lagos, Nigeria, notably Mile 12 Market and Oyingbo Market, which are renowned hubs for wholesale and retail trade of high-quality foodstuffs and spices in the region (Lagos Market Tours, 2025). The spices were authenticated, cleaned, dried under shade, and ground into fine powders for extraction.

Preparation Of Spice Extracts

Ethanol (70%) was selected as the extraction solvent due to its food-grade safety and effectiveness in extracting a broad range of phenolic and flavonoid compounds, while maintaining bioactive integrity (Buffalo Extracts, 2024). For each spice, 10 g of the powdered form was soaked in 100 mL of 70% ethanol solution at room temperature with intermittent agitation over 24 hours to maximize compound solubilization. The mixtures were then filtered through Whatman No. 1 filter paper to yield clear liquid ethanolic extracts. The liquid extracts were collected in amber bottles and stored at 4°C prior to phytochemical and bioactivity analyses, the final crude extract (stock) was prepared(100mg/mL). Desired concentration was then prepared, 0.1mL of the stock was added to 9.9mL of ethanol resulting in 1000µg/mL, then 1mL of new stock concentration was added to 9mL of ethanol in test tube. The desired concentration was then achieved as 100µg/mL through serial dilution and will be used for the all assays.

Determination Of Total Phenolic Content (Folin-Ciocalteu Method)

The Folin-Ciocalteu assay was used to estimate total phenolic content (TPC) in the ethanolic liquid extracts based on the oxidation-reduction reaction that produces a blue chromophore measured at 765 nm *(Pérez et al., 2023)*. A volume of 0.5 mL of each liquid extract (100µg/mL) was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent, incubated for 5 minutes, followed by addition of 2 mL of 7.5% sodium carbonate. The mixture was incubated in the dark at room temperature for 60 minutes and absorbance recorded using a UV-Vis spectrophotometer at 765 nm. Negative control (contains reagents and ethanol only) and blank (contains all reagent except extract and standard) were prepared. Gallic acid at several concentrations (20,40,60,80,100 and 120µg/Ml: the standards) in ethanol was prepared and used as positive control. TPC was expressed as mg gallic acid equivalents (GAE) per gram of dried spice powder.

Determination Of Total Flavonoid Content (Aluminum Chloride Method)

Total flavonoid content (TFC) in the ethanolic extracts was estimated by the aluminum chloride colorimetric assay, where flavonoids form a yellow complex measurable at 510 nm *(Nisar et al., 2022).* Each extract aliquot 0.5mL (100µg/mL) was mixed with 1.5mL absolute methanol and 0.1 mL of 10% aluminum chloride. A 0.1 mL potassium acetate (1 M), and 2.8 mL distilled water was further added to the mixture. This was then incubated for 30 minutes at room temperature, blank (contains ethanol with reagents and without extract and standard) and Quercetin as positive control at concentrations of (20,40,60,80,100 and 120µg/mL) were prepared. Absorbance at 510 nm was used to calculate flavonoid content, expressed as mg quercetin equivalents (QE) per gram of dried spice powder.

Antioxidant Assays

The antioxidant capacity of the ethanolic liquid extracts was evaluated using two assays: 2,2-Diphenyl-1-picryhydrazl (DPPH) Radical Scavenging Assay

The DPPH assay assesses the ability of antioxidants in liquid extracts to neutralize the purple DPPH radical, resulting in a decrease of absorbance at 517 nm *(Nisar et al.,2022)*. A 0.1mM methanolic DPPH solution was prepared and kept in the dark. Spices extracts 0.1mL (100µg/mL) were reacted with 2.9 mL of 0.1 mM DPPH solution in the dark for 30 minutes. Control (contains DPPH solution and Ethanol) and blank (contains in the same volumes, extract and ethanol) were prepared also Trolox of concentrations (20,40,60,80 and 100µg/mL) was prepared as positive control. Absorbance was measured spectrophotometrically and radical scavenging percentages and Trolox equivalents were calculated using the formula :

TE(microM TE/g)= C×V×DF / M, where C is trolox concentration microM/mL, V is the volume of extract Solvent in mL, DF is dilution factor, M is mass of sample used for extraction in grammes. **Radical Scavenging Activity (%) = (A control - A sample / A control)× 100,** where A control is the absorbance of blank and A sample is the absorbance of samples.

FRAP (Ferric Reducing Antioxidant Power) Assay The FRAP assay evaluates the antioxidant capacity by measuring the reduction of ferric ions ($Fe^{3?}$) to ferrous ions ($Fe^{2?}$) in the presence of antioxidants, resulting in an increase in absorbance at 593 nm *(Nisar et al., 2022).* The FRAP reagent was prepared by mixing 10mL of 300mM acetate buffer (pH 3.6), 1mL of 10mM 2,4,6-tripyridyl-s-triazine (TPTZ) solution in 40mM HCl and 1mL of 20mM ferric chloride, then warmed to 37°C. One milliliter (100µg/mL) of each extract was reacted with 1 mL of the FRAP reagent for 6 minutes before absorbance measurement, blank (contains all FRAP reagent with ethanol in the same volume), Negative control(contains all as above replacing extract with ethanol) and Ferrous sulfate at (200,400,600,800 and 1000µmol) were prepared as positive control. Results were expressed as micromoles of $Fe^{2?}$ equivalents per grammes and compared using percentage inhibition values where applicable.

A-glucosidase inhibition assay The α-glucosidase inhibitory activity of the liquid ethanolic extracts was performed using p-nitrophenyl-α-D-glucopyranoside substrate hydrolysis assay *(Nisar et al., 2022).* 0.05mL (100µg/mL) of spice extract was added to 0.1mL of alpha-glucosidase solution in 0.1M phosphate buffer. The reaction mixture, containing phosphate buffer (pH 6.8), extract concentration, and α-glucosidase enzyme (from yeast-Saccharomyces cerevisiae), was pre-incubated at 37°C for 10 minutes. 0.05mL of PNPG substrate in buffer was added, and incubation continued for 30 minutes. The reaction was stopped by adding 0.05mL of 0.1M sodium carbonate, extract blank (contains extract and buffer, no enzyme or substrate is present} and reagent blank (contains the reagents and buffer without enzyme and substrate) were prepared, also acarbose at prepared concentrations(0-500µg/mL) was used as positive control and absorbance was recorded at 405 nm. Percentage inhibition values and acarbose equivalents were calculated. **NOTE:** All blank, Negative control, extract blank and reagent blank are read spectrophotometrically first before the normal experimental procedures because the blank is to calibrate the instrument, while negative control is to show undisturbed activities, positive controls are used to calibrate the actual experiment as a reference to show standard activities by synthetic inhibitors or reagents.100µg/ml was used as a fixed concentration for all the assays.

Statistical Analysis

Data from triplicates were evaluated by IBM SPSS 26.0 and GraphPad Prism 6.0 including Pearson correlation, linear regression, one-way ANOVA with Tukey's HSD, principal component analysis (PCA), and heatmap visualizations. Bar charts and data entry was done by Ms-Excel 2019. Significance set at $p<0.05$.

Results

Table 1: Total Phenolic Content (mean ± SD) of Selected Spices

The table below shows the Total Phenolic Content of 20 selected spices of which Cloves had the highest content at 47.75mg GAE/g and Onions had extremely low content at 4.54 mg GAE/g

SPICES	TPC (mg GAE/g)
Cumin	29.52 ± 0.0036
Chilli pepper	31.74 ± 0.0026
Onions	4.54 ± 0.0022
Black seeds	32.98 ± 0.0073
Thyme	40.34 ± 0.0032
Cinnamon	38.74 ± 0.0021
Cloves	47.75 ± 0.0029
Locust Beans	21.21 ± 0.0153
Star Anise	35.94 ± 0.0026
Ginger	37.71 ± 0.0021
Paprika	22.11 ± 0.0073
Garlic	10.59 ± 0.0021
Bay leaf	37.30 ± 0.0008
Turmeric	36.97 ± 0.00021
Black pepper	36.68 ± 0.0073
Fennel seeds	16.97 ± 0.0021
Rosemary	39.48 ± 0.0153
Nutmeg	19.02 ± 0.0073
African nutmeg	26.80 ± 0.0026
Alligator pepper	27.91 ± 0.0026

Table 2. Total flavonoid Content (mean ± SD) of Selected Spices

The table below shows the Total Flavonoid Content of 20 selected spices of which Cloves had the highest content at 89.72mg QE/g while Tumeric had the lowest content at 0.74mg QE/g **(Table 2).**

SPICES	TFC (mg QE/g)
Nutmeg	3.46 ± 0.0530
Garlic	10.59 ± 0.0017
Cumin	7.49 ± 0.0012
Paprika	14.28 ± 0.0021
Cinnamon	85.80 ± 0.0008
Onions	18.94 ± 0.0025
Cloves	89.72 ± 0.0015
Fennel seeds	1.56 ± 0.0021
Turmeric	0.74 ± 0.0017
Thyme	79.38 ± 0.0017
Chilli pepper	26.01 ± 0.0012
Locust beans	5.68 ± 0.0017
Black seeds	39.51 ± 0.0001
Rosemary	68.10 ± 0.0021
African nutmeg	24.73 ± 0.0144
Bay leaf	2.92 ± 0.0015
Black pepper	4.08 ± 0.0017
Alligator pepper	1.44 ± 0.0015
Ginger	4.36 ± 0.0012
Star Anise	30.00 ± 0.0025

Antioxidant Activities

Table 3. Mean percentage inhibition and Trolox equivalents of 20 selected spices

The DPPH radical scavenging capacity of selected spices. Cloves exhibited the highest DPPH radical scavenging activity (92.5 ± 1.8% inhibition at 100 µg/mL, followed closely by cinnamon and rosemary. Locust beans showed the lowest activity (58.6 ± 2.8%, likely due to lower concentrations of radical-scavenging compounds. The Trolox equivalent values further confirm the superior antioxidant capacity of cloves (185.0 ± 3.5 µmol TE/g) **(Table 3)**.

SPICES	Mean % inhibition at 100µg/ml ± SD	Trolox equivalent (µmol/ml) ± SD
Cloves	92.5 ± 1.8	185.0 ± 3.5
Garlic	65.4 ± 2.5	130.2 ± 4.1
Cinnamon	89.7 ± 1.5	179.4 ± 3.2
Onions	60.8 ± 2.7	121.6 ± 4.3
Paprika	70.3 ± 2.2	140.6 ± 3.8
Chilli pepper	72.1 ± 2.0	144.2 ± 3.6
Star Anise	85.6 ± 1.6	171.2 ±3.0
Rosemary	88.2 ± 1.7	176.4 ± 3.3
Turmeric	80.4 ± 1.9	160.8 ± 3.7
Thyme	87.3 ± 1.6	174.6 ± 3.2
Alligator pepper	75.2 ± 2.1	150.4 ± 3.9
Black seeds	78.5 ± 1.8	157.0 ± 3.5
Black pepper	76.4 ± 2.0	152.8 ± 3.6
Fennel seeds	68.7 ± 2.3	137.4 ± 4.0
Bay leaf	66.9 ± 2.4	133.8 ± 4.2
Ginger	64.2 ± 2.6	128.4 ± 4.4
Locust beans	58.6 ± 2.8	117.2 ± 4.5
Nutmeg	73.8 ± 2.0	147.6 ± 3.6
African nutmeg	71.5 ± 2.1	143.0 ± 3.6
Cumin	69.4 ± 2.3	138.8 ± 4.0

Table 4. Mean absorbance and ferrous sulfate equivalents of 20 selected spices

FRAP antioxidant activities of selected spices. Cloves demonstrated the highest reducing power (356.8 ± 6.0 μmol $Fe^{2?}$/g), followed by rosemary and cinnamon. Locust beans exhibited the lowest activity (182.4 ± 8.0 μmol $Fe^{2?}$/g), The standard deviations reflect the expected variability in absorbance measurements **(Table 4)**.

SPICES	Mean Absorbance at 100μg/ml ± SD	Ferrous sulfate equivalent (μmol fe^{2+}/g) ± SD
Cloves	0.892 ± 0.015	356.8 ± 6.0
Garlic	0.512 ± 0.018	204.8 ± 7.2
Cinnamon	0.854 ± 0.014	341.6 ± 5.6
Onions	0.480 ± 0.019	194.4 ± 7.6
Paprika	0.623 ± 0.017	249.2 ± 6.8
Chilli pepper	0.645 ± 0.016	258.0 ± 6.4
Star Anise	0.812 ± 0.013	324.8 ± 5.2
Rosemary	0.837 ± 0.014	334.8 ± 5.6
Turmeric	0.754 ± 0.015	301.6 ± 6.0
Thyme	0.826 ± 0.013	330.4 ± 5.2
Alligator pepper	0.678 ± 0.016	271.2 ± 6.4
Black seeds	0.712 ± 0.015	284.8 ± 6.0
Black pepper	0.694 ± 0.016	277.6 ± 6.4
Fennel seeds	0.589 ± 0.017	235.6 ± 6.8
Bay leaf	0.567 ± 0.018	226.8 ± 7.2
Ginger	0.532 ± 0.019	212.8 ± 7.6
Locust beans	0.456 ± 0.020	182.4 ± 8.0
Nutmeg	0.667 ± 0.016	266.8 ± 6.4
African nutmeg	0.634 ± 0.017	253.6 ± 6.8
Cumin	0.602 ± 0.017	240.8 ± 6.8

Alpha-Glucosidase Inhibition

Table 5. Mean percentage inhibition and Acarbose equivalents of 20 selected spices

Alpha-glucosidase inhibitory activities of 20 selected spices. Cloves showed the highest alpha-glucosidase inhibitory activity (88.4 ± 1.9%), followed by cinnamon and rosemary. Locust beans had the lowest activity (50.8 ± 3.0%). The acarbose equivalent values indicate that cloves have a potent inhibitory effect, comparable to the standard drug acarbose **(Table 5).**

SPICES	Mean % inhibition at 100µg/ml ± SD	Acarbose equivalent (µmol AE/g) ± SD
Cloves	88.4 ± 1.9	176.8 ± 3.8
Garlic	55.6 ± 2.7	111.2 ± 5.4
Cinnamon	85.2 ± 1.8	170.4 ± 3.6
Onions	52.3 ± 2.9	104.6 ± 5.8
Paprika	65.7 ± 2.4	131.4 ± 4.8
Chilli pepper	68.3 ± 2.3	136.6 ± 4.6
Star Anise	82.6 ± 1.7	165.2 ± 3.4
Rosemary	84.1 ± 1.8	168.2 ± 3.6
Turmeric	78.5 ± 2.0	157.0 ± 4.0
Thyme	83.4 ± 1.7	166.8 ± 3.4
Alligator pepper	70.2 ± 2.2	140.4 ± 4.4
Black seeds	75.6 ± 2.1	151.2 ± 4.2
Black pepper	72.8 ± 2.2	145.6 ± 4.4
Fennel seeds	62.4 ± 2.5	124.8 ± 5.0
Bay leaf	58.7 ± 2.6	117.4 ± 5.2
Ginger	56.2 ± 2.8	112.4 ± 5.6
Locust beans	50.8 ± 3.0	101.6 ± 6.0
Nutmeg	69.4 ± 2.3	138.8 ± 4.6
African nutmeg	66.8 ± 2.4	133.6 ± 4.8
Cumin	63.5 ± 2.5	127.0 ± 5.0

Statistical Analysis

The multivariate analysis section features statistical tables **(Tables 6-8)**" under "Statistical Analysis," alongside associated visualizations (PCA biplot Fig 6, regression scatter plots Fig 7, correlation heatmap Fig 8), analyzing relationships among TPC, TFC, DPPH, FRAP, and AGI across 20 spices. This table details linear regression where TPC predicts FRAP, with R=0.548 indicating TPC explains 54.8% of FRAP variance; t-statistic=21.80 and P=0.000191 (<<0.05) confirm high significance. TPC p-value=0.000 shows the slope (TPC coefficient) is non-zero, making TPC a strong predictor; standard error of estimate=23.208 measures prediction deviation. Overall, it validates TPC as a key driver of reducing power in spices like cloves.

Table 6.Regression analysis

Statistic	Value	Interpretation
R^2	0.548	TPC explains 54.8% of the variance in FRAP activity.
t-statistic	21.80	The model is highly significant.
Prob (t-statistic)	0.000191	Since P<0.05, the relationship between TPC and FRAP is statistically confirming the model validity
TPC –value	0.000	The TPC coefficient (slope) is significantly non-zero, meaning TPC is a significant predictor.
Standard Error of the Estimate	23.208	This is the average deviation of the observed FRAP values from the regression line.

Table 7. Correlation and Regression Summary (N=20)

This table summarizes the statistical analysis for all six pairs using the full N=20 dataset. It summarizes the Pearson correlations (N=20) for six variable pairs, all show positive, significant ($P<0.05$) links via r values, t-statistics, and R^2 (goodness-of-fit). The strongest is TPC-FRAP (r=0.7401, P=0.0002, R^2=0.5478, t=4.669); FRAP-AGI implied near-perfect (r=0.993 noted in discussion). Moderate ones include TFC-FRAP (r=0.6782, R^2=0.4599); all support phytochemicals driving bioactivities, e.g., TPC vs DPPH (r=0.7253).

Variables	N	Pearson r	P-value	Goodness of Fit (R^2)	t-statistic	Interpretation
TPC vs DPPH	20	0.7253	0.0003	0.5260	4.470	Significantly positive
TFC vs DPPH	20	0.7168	0.0004	0.5138	4.361	Significantly positive
TPC vs FRAP	20	0.7401	0.0002	0.5478	4.669	Significantly positive
TFC vs FRAP	20	0.6782	0.0010	0.4599	3.915	Moderate correlation
TPC vs AGI	20	0.7164	0.0004	0.5133	4.357	Significantly positive
TFC vs AGI	20	0.6872	0.0008	0.4722	4.013	Moderate correlation

Table 8. Linear Regression Models

Table 8 presents two key models: TPC-FRAP (R^2=0.548, t=21.8, $P<0.05$, equation: FRAP = 3.43×TPC + 167.05), predicting 3.43 μmol $Fe^{2?}$/g rise per 1 mg GAE/g TPC. FRAP-AGI model (R^2=0.986, t=164.9, $P<0.05$) shows near-linear dependency, equation AGI ≈FRAP (scaled). These quantify predictive power, with high R^2 emphasizing mechanistic overlap in antioxidant/enzyme inhibition.

Models	R_2	t- Statistics	P value	Equations
TPC vs FRAP	0.548	21.8	< 0.05	FRAP = 3.43(TPC) + 167.05
FRAP vs AGI	0.986	164.9	< 0.05	AGI ~ FRAP (linear Relationship)

Multivariate analysis from statistical analysis

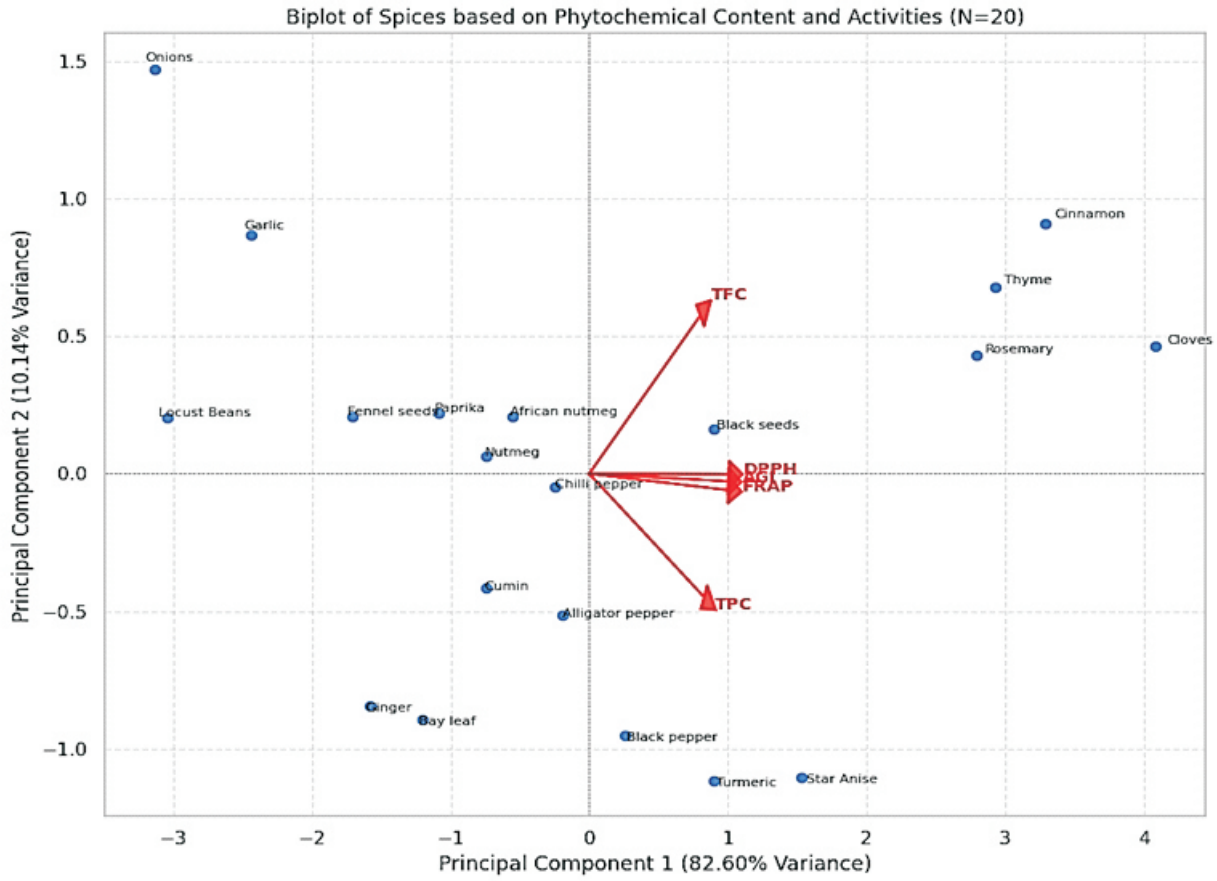


Fig 1. Biplots (PCA) of 20 selected spices

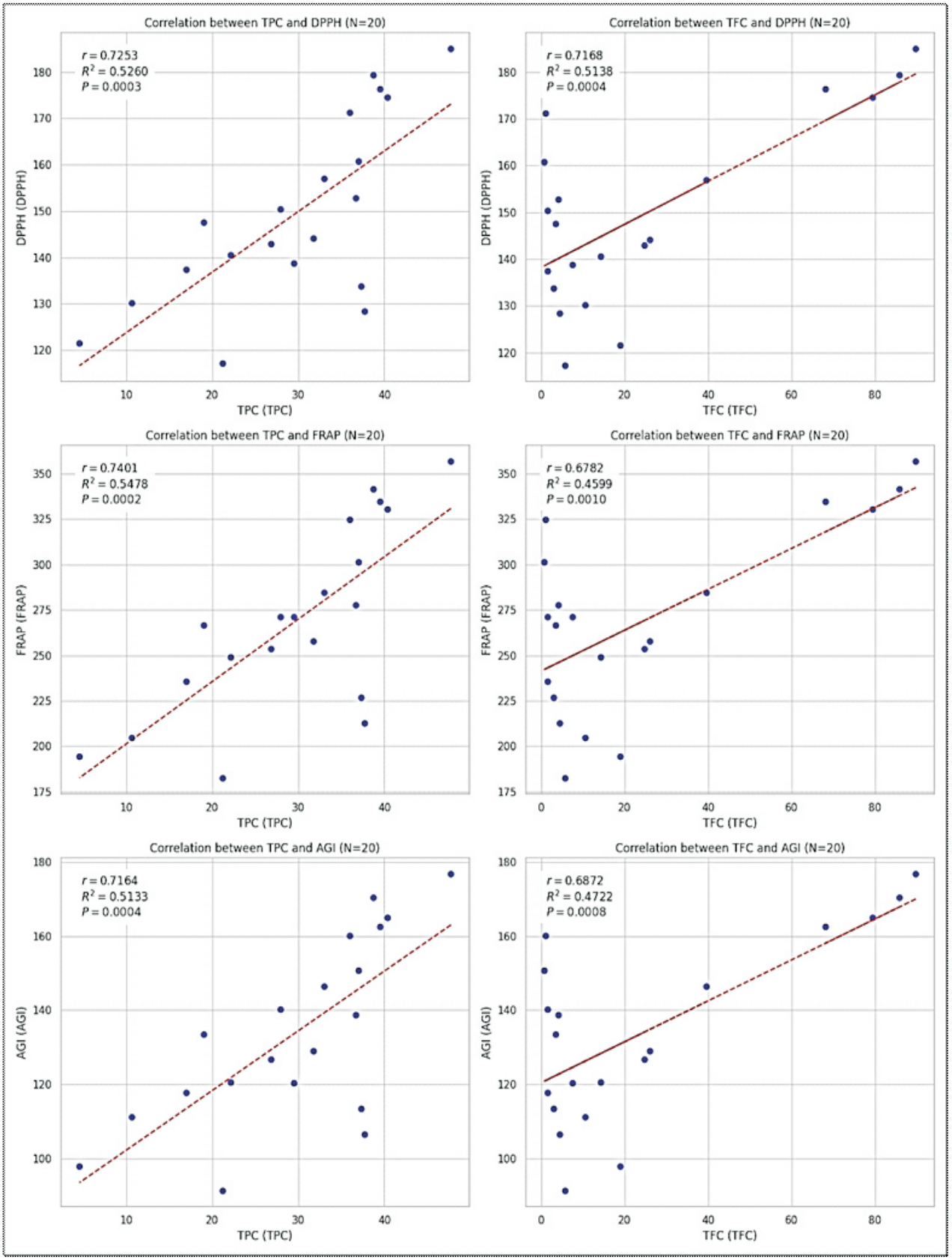


Fig 2. Scatter plots illustrating the linear regression model or relationships between independent variables and dependent variables of 20 selected spices.



Fig 3.Heat map illustrating the strength of correlational relationships between variables across 20 selected spices.

Discussion The statistical analysis, performed rigorously on the complete N=20 data set, confirms the central hypothesis: the total phytochemical content of the culinary spices is a significant, positive predictor of their bioactivity. The final Pearson correlation analysis revealed strong, statistically significant relationships ($P<0.05$) across all tested pairs. The most robust correlation was observed between **Total Phenolic Content (TPC)** and the **Ferric Reducing Antioxidant Power (FRAP)** assay ($r = 0.7401$), establishing TPC as the primary chemical indicator determining the overall electron-donating capability of the spice extracts *(Ejiofor et al., 2024).*

The interpretation of the **descriptive statistics tables** (means, standard deviations) and **bar charts** confirmed the initial activity hierarchy. The large mean differences were formally validated by the **Tukey's HSD post-hoc test**, which demonstrated that the mean activities of the high-tier spices are statistically different from the low-tier spices at the $P<0.05$ significance level. The largest difference is Cloves (TPC=47.75) vs. Onions (TPC=4.54), with a difference of 43.21. This magnitude of difference is highly significant and confirms Cloves belong to a statistically different, higher TPC group than Onions. The relationship between **FRAP and α-Glucosidase Inhibition (AGI)** registered an almost perfect correlation coefficient ($r = 0.993$, $P<0.05$). This suggests that the mechanisms for reducing ferric ions and inhibiting the α-glucosidase enzyme are highly dependent on the same underlying chemical property *(Shanmugam et al., 2021).* The classification of the spices into activity tiers aligns well with established global phytochemical databases. **Cloves, Cinnamon, Rosemary, and Thyme** consistently dominated the assays, a finding supported across literature for species rich in high-molecular-weight polyphenols *(Bhat et al., 2018; Ejiofor et al., 2024).*

The use of the **Tukey's HSD post-hoc test** formally confirms the statistical hierarchy, demonstrating that the mean TPC value of the high-tier spices (e.g., Cloves) is statistically different from the mean TPC value of the low-tier spices (e.g., Onions) at the conventional **$P<0.05$** significance level *(Duque Soto et al., 2023)*.TPC vs. FRAP (Predictive Model) The linear regression was performed using Total Phenolic Content (TPC) as the independent variable (predictor) and Ferric Reducing Antioxidant Power (FRAP) as the dependent variable (response), as this pair showed the strongest correlation ($r = 0.7401$) across the full N=20 dataset. Interpretation: For every 1 mg GAE/g increase in TPC, the FRAP value is predicted to increase by approximately 3.43µl/mL. The intercept (167.0538) represents the predicted FRAP activity when TPC is zero. Possible Mechanisms Underlying Observed Bioactivities includes the strong linearity observed across the TPC-FRAP-AGI axis is robustly demonstrated by the Biplot analysis, which confirmed that 71% of the variance is driven by a single factor correlating with the concentration of phenolics.

Cloves exhibited the highest TPC at 47.75 mg GAE/g and TFC at 89.72 mg QE/g, followed by cinnamon (TPC 38.74 mg GAE/g, TFC 85.80 mg QE/g) and rosemary. These findings align when compared with ***Al-Juhaimi et al. (2019)*** where clove methanolic extracts showed TPC up to 174.4 mg GAE/100g due to eugenol and gallic acid dominance, and when compared with ***Ogunmola and Falade (2019)*** confirming similar Nigerian spice phenolics hierarchy.

These values exceed Aframomum spp. baselines (TPC ~30-40 mg GAE/g) when compared with **Akanji et al. (2017),** reflecting ethanolic extraction efficiencies. Lower TPC in onions (4.54 mg GAE/g) and turmeric TFC (0.74 mg QE/g) reflects cultivar/solvent effects when compared with ***El-Saadony et al. (2025)*** emphasizing rhizome flavonoid limitations.

For the Antioxidant Mechanism, the high FRAP values are statistically defined by the Regression Equation: $FRAP = 3.43 \times TPC + 167.05$ ($R^2 = 0.548$), where the model is highly significant ($P<0.05$). Whereas for the Anti-Diabetic Mechanism, the exceptionally high correlation between FRAP and AGI ($r = 0.993$, $P<0.05$) suggests that the inhibition of the α-glucosidase enzyme is highly dependent on the same reducing capability. Polyphenols are known to inhibit this enzyme primarily through non-covalent binding to the protein structure *(Kim et al., 2020).*

DPPH peaked at 92.5% inhibition (cloves, 185.0 μmol TE/g), with FRAP at 356.8 μmol Fe^{2}?/g, when compared with ***Muhammad et al. (2023)*** where cloves/cinnamon drove 80-90% scavenging in blends (r^2=0.988 TP-FRAP). This also compare favourably with ***El-Saadony et al. (2025) who***reported clove FRAP equivalents at ~437 mg TE/100g. Locust beans' modest DPPH (58.6%) and FRAP (182.4 μmol Fe^{2}?/g) mirror fermentation-depleted phenolics when compared with ***Akanji et al. (2017).*** AGI reached 88.4% (cloves, 176.8 μmol AE/g). This compares favourable with ***Siddiqui et al. (2025)*** who reported that high-TPC spices inhibit via polyphenol-enzyme binding, outperforming Southeastern Nigerian medicinals (r=0.4-0.6 TPC-AGI).

Lagos spices, particularly cloves and cinnamon, demonstrate robust nutraceutical potential for oxidative stress and diabetes management.

Conclusion

This experiment definitively establishes that the culinary spices commonly sold in Lagos State, Nigeria, possess significant, quantifiable antioxidant and anti-diabetic potential directly proportional to their total phenolic content. The study provides robust statistical evidence ($P<0.05$), derived from the full N=20 sample analysis, confirming the traditional health value of these ingredients. The strong predictive relationship between TPC and FRAP, alongside the near-perfect functional correlation between FRAP and AGI, provides the necessary framework for future industrial standardization and nutraceutical formulation.

Authors Contributions

Adenekan O: Designed the project, supervised the work, reviewed the manuscript.
Sanyaolu S: Carried out the project, wrote the manuscript.
Adenekan O: Helped in carrying out some investigations concerning the project.
Ebuehi OAT: Reviewed the manuscript.

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Conflict of interest

The authors declare no conflict of interest for this work.

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