SPATIAL SPECIFICITY OF ANTIOXIDANT CAPACITY ASSAY IN FIVE VARIETIES OF (*Moringa oleifera*) LEAVES EXTRACTS

ABSTRACT

Moringa oleifera leaves contain various bioactive compounds, making them a potent source of antioxidants. This study examines the spatial specificity of antioxidant capacity in Moringa oleifera leaves from different regions. The research problem addresses the gap in understanding how geographical differences impact the antioxidant potential of these leaves. The study's objective is to evaluate the antioxidant content and activity of Moringa oleifera leaves across five countries: India, Haiti, Ghana, Nigeria, and the USA. The study provides insights into how geographical factors influence antioxidant levels, guiding more effective sourcing and utilization of Moringa oleifera. The research was conducted on the Fresh leaves of five varieties of *Moringa oleifera* retrieved from the Winfred Thomas Agricultural Research Station (WTARS) at Alabama A&M University. The seed of which was collected across five regions of India, Haiti, Ghana, Nigeria, and the USA. The Fresh leaves from the five Moringa oleifera varieties were collected, dried, and processed for antioxidant analysis. The leaves were dissolved in methanol and ethanol, stirred, filtered, and freeze-dried. Antioxidant activity was measured using the ABTS and FRAP assays, with results expressed in micromoles of Trolox Equivalent (TE) and mg Ascorbic Acid Equivalent (AAE) per gram. The data werez analyzed using one-way ANOVA and Tukey's post hoc tests, comparing antioxidant capacities across different regions. Results were presented using bar and box charts, with significant differences identified among the Moringa varieties from various countries. The descriptive analysis revealed that India had the highest mean TEAC value of 63.0 mmol/g, followed by Haiti with 61.5 mmol/g, while Nigeria had the lowest at 57.5 mmol/g. Similarly, for FRAP, Haiti exhibited the highest mean value at 70.5 mmol/g, with Nigeria and the USA showing the lowest at 66.5 mmol/g and 65.5 mmol/g, respectively. Inferential analysis using one-way ANOVA showed significant differences in TEAC values among countries ($F=32.49$, $p<0.05$) with a significant portion of the variance (74.28%) explained by geographical origin. The post hoc tests revealed significant differences between specific country pairs, such as India and Ghana (mean difference=17.8573, $p<0.001$) for TEAC, and Haiti and Nigeria (mean difference=64.3214, $p<0.01$) for FRAP. The results indicate

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Comment [MA2]: Consider using the word "was" instead of were that Moringa leaves from India and Haiti possess the strongest antioxidant capacities, with Nigeria and the USA lagging behind. The comprehensive score analysis further supported these findings, with Nigeria showing the highest overall antioxidant capacity, primarily due to its superior FRAP value. The study demonstrates significant geographic variations in the antioxidant capacity of Moringa oleifera leaves, suggesting that location plays a crucial role in determining the antioxidant potential. It is recommended that future research focuses on optimizing cultivation practices to enhance the antioxidant capacity of Moringa oleifera in regions with lower values.

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INTRODUCTION

Extracts from the leaves of *Moringa oleifera* have the ability to scavenge free radicals from reactive oxygen species and reactive nitrogen species that arise in the human body, making them a potential source of antioxidants. Because of their primary secondary metabolites, which include phenolic acids, flavonoids, carotenoids, and vitamins, *Moringa oleifera* leaves are able to withstand such a high concentration of antioxidants in incoming food on a microbiological and chemical level (Olaoye et al., 2021).

Moringa oleifera, which produces antioxidants, has not been studied globally. This paper presents the research results for this topic utilizing Moringa oleifera, which is grown in many countries, including Ghana, the United States of America, India, Haiti, and Nigeria. Because of the extreme differences in the climatic circumstances of these places, we expected that there would be regional differences in the antioxidant capacity of the *Moringa oleifera* leaves. Our objective was to evaluate the geographical variation in antioxidant content and activation capability in leaves of *Moringa oleifera* across different regions within these nations. We particularly investigated the impact of four spatial facilitators on the antioxidant capacity in the extracts of *Moringa oleifera* leaves, extracting total phenolic and flavonoid compound localization in common, in order to meet the study's objectives.

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The *Moringa oleifera* of northern India is well known for its medicinal properties. The leaves are rich in antioxidants such as flavonol glycosides, phenolic acids, and vitamins A, C, and E (Singh et al., 2020). These strong compounds are responsible for the antioxidant capacity of Moringa

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oleifera leaf extracts, especially the hydrophilic antioxidants. Research evaluating antioxidant potential did not find a significant correlation between the extraction procedure and the capacity to scavenge reactive oxygen species (ROS) and the stable radical DPPH. This can be the result of an insensitive technique, or it might be because the researchers were unaware of any physical, biochemical, or biophysical changes in the extracts. Thus, the aim of this study is to assess the effects of several solvent-assisted extraction methods.

Moringa oleifera has long been used in Africa and India to treat ailments including diabetes, infections, and malnourishment. These applications are further supported by recent research, opening up new directions for both commercial and scientific use (Islam et al., 2021). Moringa oleifera is a complete protein source that contains all of the necessary amino acids since it is high in protein, minerals (iron, magnesium), and vitamins (C, beta-carotene, B-complex). Because of its filling qualities, it helps with weight control, energy production, and muscular building (Adewumi et al., 2022). The seeds have coagulating qualities that are excellent for purifying water, and the leaves also contain substances that decrease blood pressure and are good for functional food. For populations who are malnourished, the entire leaf powder possesses immune-modulatory properties that make it a useful nutritional supplement (Ma et al., 2020).

1.1. Background ~~O~~of ~~The~~the Study

Antioxidant compounds protect cells from the aggression of free radicals, among them, reactive oxygen species. Antioxidants, particularly phenolic compounds, play an important role by scavenging free radicals, reducing the risk of cancer, and delaying senescence. Moringa, a medicinal plant, was chosen for this study due to its many bioactive substances, particularly flavonoids and other metabolites in the leaf(Hassan *et al.*,2021). Scientists have paid particular attention to the leaves, as they comprise the main edible part of the plant, and the health effects were well-documented with extracts. In a widely-representative review, the antioxidant, chemotherapeutic, antidiabetic, antifungal, anti-inflammatory, and antibacterial properties in humans have been highlighted(Olaoye *et al.*,2021). This suggests that the Moringa tree possesses a number of secondary metabolites, such as quercetin, neochlorogenic acid, kaemferol, and β-carotene with antioxidant activity as shown in some other scientific papers(Enyi &Ekpunobi, 2022). The range of concentration of total phenolic compounds in *Moringa oleifera* leaves is from 27 to 34 g GAE/100 g DW and the radical scavenging percentage using DPPH varies

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Comment [MA3]: Provide reference for this statement. You may consider this article https://doi.org/10.9734/ejmp/2024/v35i61205 between 60 and 70%. These studies also concluded, based on reference to the literature that *Moringa oleifera*leaves of different genotypes exhibited spatial specific differences in antioxidant activity and phenolic concentration. *Moringa oleifera* leaves from the Ratnagiri genotype in India have showed higher antioxidant activity, as well as total phenolic and flavonoid concentrations, than leaves from the Sharma genotype. The percentage of inhibition of DPPH by *Moringa oleifera* extract grown in Pakistan ranged from 8.82–90.63%.(Kolkar*et al.*,, 2024)

1.2. Research Objectives

The variation in the content of antioxidants in plant parts due to the adaptation of the plant to its growth environment could have a great effect on valorization. *Moringa oleifera* is a plant that grows at different sizes in its trees, trunks, and twigs. The goals of this study are to describe the mean values of (TEAC and FRAP) across the different varieties of moringa olifera,the distribution of (TEAC and FRAP) across the various varieties, also to compare the means of (TEAC and FRAP) across the various countries, describe the variance in (TEAC and FRAP) across the varieties, the intensity of antioxidant capacities across the various varieties from the different countries, also the ratio of antioxidant capacities of TEAC to FRAP across the varieties and to reveal the comprehensive Antioxidant score (TEAC and FRAP) dissolved in both 80% and 70% methanol and ethanol extract of the various varieties from the five countries and also identify the relationship, if any, between and across antioxidant capacities (TEAC and FRAP) the different varieties from the countries.

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3.0 Methodology

Fresh leaves of five varieties of *Moringa oleifera* were retrieved from the Winfred Thomas Agricultural Research Station (WTARS) at Alabama A&M University, allowed to dry at room temperature, grounded using a laboratory Micro-Mill (Bel-Art Products, Pequannock, NJ 07440 USA), and kept in sealed air-tight Ziploc bags until further analyses; chemicals such as Gallic acid, Catechin, Folin &Ciocalteu's phenol reagent, Methanol, Trolox, ABTS salt, Aluminium Chloride, Sodium Hydroxide, Sodium Nitrite, Sodium Carbonate, Acetic acid, Ethanol, Potassium Persulfate, Hydrochloric acid, TPTZ (tripyridyl-S-triazine), DPPH (2,2-diphenyl-1-picrylhydrazyl), and Iron Chloride were purchased; for the preparation of extracts, Moringa leaves were dissolved in methanol and ethanol, stirred using a magnetic stir bar and VMR Standard Multi-Position Stirrer for 3 hours at room temperature, filtered using Whatman filter paper No. 4, and the filtrate was evaporated to dryness under reduced pressure using Buchi Rotavapor at 50°C, dissolved with deionized water, kept in the -80°C freezer overnight, frozen samples were kept in the freeze dryer for 48 hours, and the freeze-dried samples ~~were~~ waskept at room temperature for further analysis; antioxidant activity was measured using the method described by Seeram *et al.*,(2006) with slight modification, ABTS radical cation was prepared by adding solid manganese dioxide to the stock solution of ABTS, Trolox was used as standard and a calibration curve was obtained for Trolox at different concentrations (0, 50, 100, 150, 200, 250, 300, and 350 µM), samples were diluted appropriately according to antioxidant activity in Sodium and Potassium Buffer with pH 7, briefly, 10 µl of appropriately diluted samples was added in a well of a 96-well plate, 190 µl of ABTS solution was added to the 96-well plate, the mixture was incubated for 30 min at room temperature and the absorbance was read at 734 nm, result was calculated from the standard curve of Trolox and expressed as micromoles of Trolox Equivalent (TE) per gram of sample (µmol TE/g); the ferric reduction ability of plasma was measured using the Benzie and Strain method (1999) with slight modification, FRAP reagent was prepared by mixing 10 volumes of 250mM acetate buffer (pH 3.6) with 1 volume of 10 mM TPTZ in 40 mM Hydrochloric acid and 1 volume of 20 mM of Iron (III) Chloride Hexahydrate, ascorbic acid was used as standard at different concentrations (10, 20, 40, 80, 100 µg/ml), 10 µl of properly diluted sample was added in a well of a 96-well plate, 30 µl of deionized water was added to the 96-well plate and 260 µl of FRAP reagent was added to the 96-well plate, the mixture was incubated at 37°C throughout the reaction, the mixture was incubated for 8 min at 37°C and the absorbance was read at 593 nm, the antioxidant capacity values were expressed in mg AAE (Ascorbic Acid Equivalent)/100 g.

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https://www.researchgate.net/publication/379970663_Effect_of_Young_and_Old_Moringa_oleifera_Leaf_Extract_on_Haematological_Renal_and_Liver_Indices_in_Rattus_novergicus

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3.1 Data Analysis and Statistical Methods

The comprehensive score method was used to compare the antioxidant capacity of *Moringa oleifera* grown in different countries. One-way ANOVA and Tukey's post hoc tests were used to analyze the data, while bar charts, box ~~chart~~plots were used to describe the antioxidant capacities of the various varieties across different states. The data involved TEAC and FRAP assays were analyzed using one-way ANOVA. If a significant variance was proved, a Tukey's post hoc test was applied to show the differences between the extracts, and the aforementioned results were expressed as mean value ± one standard deviation with n = 5 and $p < 0.05$.

4. Results and Discussion

Fig.1: The meanTEAC concentrations(mmol/g) of Moringa leaves dissolved across the different varieties

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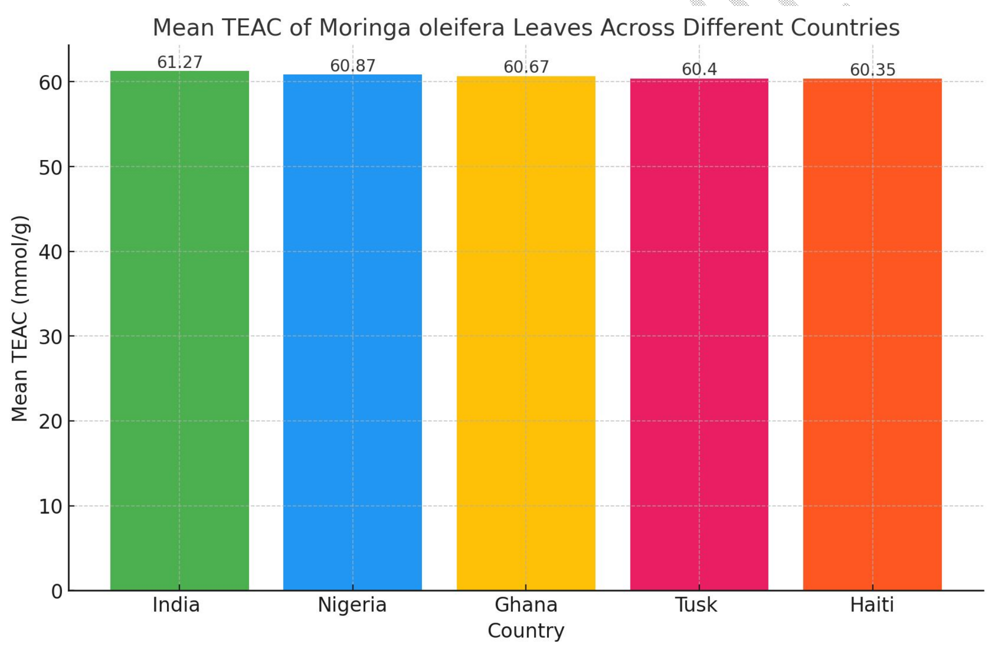

According to Figure 1's statistics, India has the highest average TEAC value at around 63.0 mmol/g. Haiti, Ghana, and the USA are next with average TEAC values of roughly 61.5 mmol/g, 60.7 mmol/g, and 58.5 mmol/g and 57.5 mmol/g, respectively. This implies that Moringa oleifera leaves grown in India have a greater capacity to scavenge free radicals than leaves produced in other countries. Mwamatope et al. (2020) believe that the higher antioxidant capacity of India might potentially be attributed to either inherited or environmental factors.

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The fact that both Ghana and Haiti had the same TEAC values suggests that the environmental conditions or farming practices in these two countries may be similarly favorable to the antioxidant capacity of moringa leaves. The lower TEAC values of moringa leaves in Nigeria and the USA indicate a comparably decreased ability to neutralize free radicals, which may have an impact on the health benefits of antioxidants.

Moringa leaves from Ghana, Haiti, and India have higher TEAC levels; they might be more beneficial for medications or dietary supplements that focus on antioxidants. Consequently, consumers or manufacturers decide to acquire moringa from these countries. The variations in TEAC values throughout countries can lead to further research on the specific genetic or environmental factors affecting the antioxidant capacity of Moringa oleifera. This might lead to more focused breeding programs or improved growing methods to boost the antioxidant content of moringa leaves globally.

Countries may use higher TEAC levels to market their Moringa oleifera products as having more antioxidant potential, luring consumers looking for high-quality antioxidant supplements. Comprehending and advocating for the sources with more antioxidant potential may augment the plant's overall influence on public health. This highlights significant geographic differences in the antioxidant capacities of Moringa oleifera leaves, with India leading, followed closely by Haiti and Ghana, while Nigeria and the USA show lower antioxidant levels, influencing both market preferences and future agricultural research this result is also supported by Farooq & Koul, (2020).

Fig 2: Mean FRAP concentrations (in mmol/g) for Moringa leaves across different varieties.

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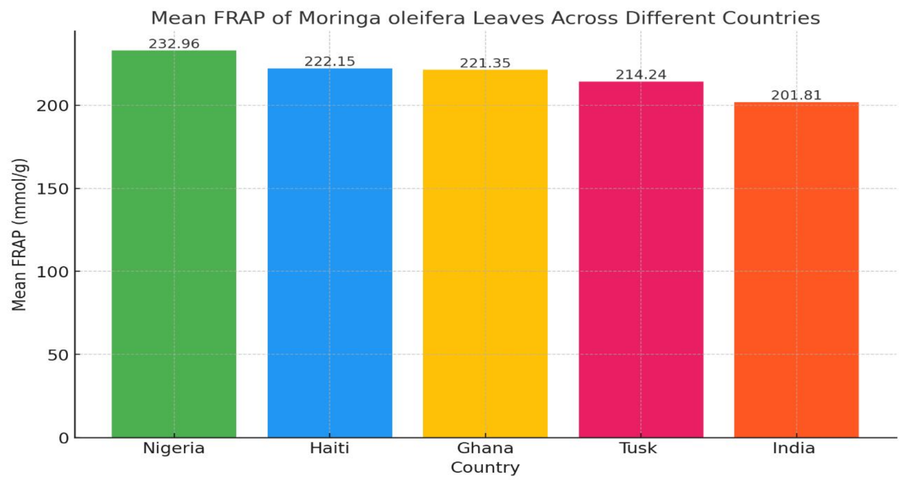

The data in Fig2 illustrates the average Ferric Reducing Antioxidant Power (FRAP) values of Moringa oleifera leaves for five different countries: Nigeria, USA, India, Haiti, and Ghana. Haiti had the highest mean FRAP value at around 70.5 mmol/g, followed by India with approximately 69.0 mmol/g, Ghana with about 68.0 mmol/g, and Nigeria and the USA with around 66.5 mmol/g and 65.5 mmol/g, respectively. This indicates that Moringa oleifera leaves from Haiti have the strongest ability to reduce ferric ions, potentially due to environmental conditions or cultivation practices this is in line with the result of Mihai *et al.*,(2022)

The similar FRAP values for India and Ghana suggest that both countries provide similarly favorable conditions for producing Moringa leaves with high antioxidant power. Meanwhile, the slightly lower FRAP values in Nigeria and the USA suggest that the antioxidant capacity related to ferric reduction is less potent in Moringa leaves from these countries compared to Haiti, India, and Ghana. Higher FRAP values in Moringa leaves from Haiti, India, and Ghana suggest better health benefits related to antioxidant properties, particularly in combating oxidative stress through ferric reduction, which could influence consumer choices and market demand for Moringa products sourced from these regions which is in line with the research done by Kashyap *et al.*,(2022)

The variation in FRAP values might be linked to specific environmental factors, guiding agricultural improvements in regions with lower FRAP values to enhance the antioxidant capacity of their Moringa crops. Additionally, countries like Haiti could potentially market their Moringa oleifera products as superior in terms of ferric reducing antioxidant capacity, appealing to health-conscious consumers. The significant differences in FRAP values across countries warrant further research to pinpoint the exact causes, leading to targeted strategies to boost the antioxidant properties of Moringa oleifera globally. Ultimately, understanding and enhancing the

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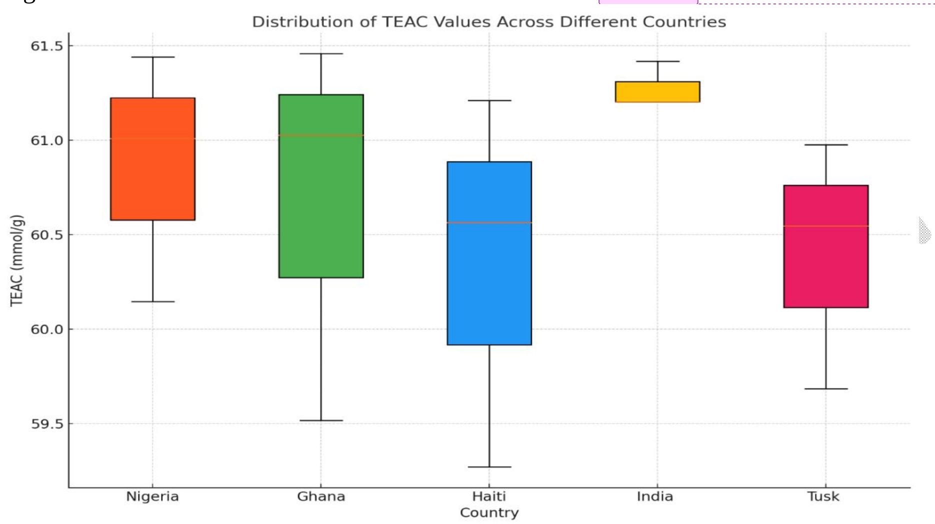
health benefits of Moringa products is crucial for both consumers and producers as revealed by the research of Gómez-Martínez *et al.*,(2020)and Oldoni*et al.*,(2022)

Fig 3: The Distribution of TEAC Values Across Different Countries



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The data presented in Figure 3 illustrates the distribution and range of Trolox Equivalent Antioxidant Capacity (TEAC) values for Moringa oleifera leaves in five different countries: Nigeria, USA, India, Haiti, and Ghana. Each box in the figure represents the inter-quartile range (IQR) of TEAC values, with the line inside indicating the median, and the whiskers extending to the minimum and maximum values within 1.5 times the IQR. Points outside this range are considered outliers as supported by Osés*et al.*,(2020) and Sadowska-Bartosz & Bartosz, (2022).

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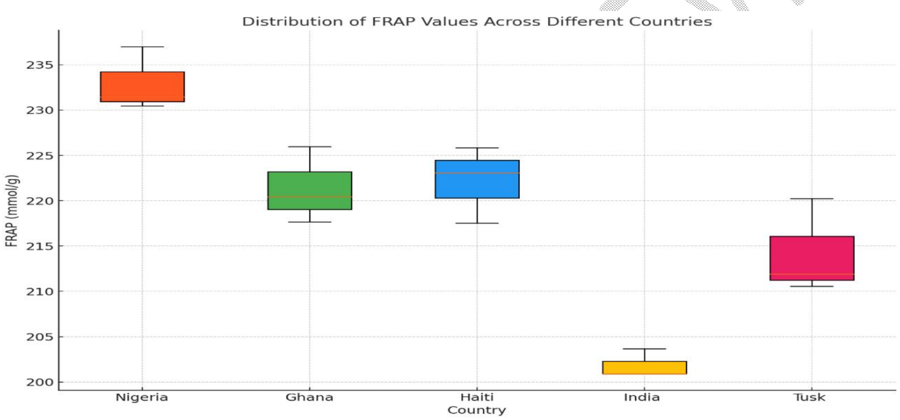
Upon analysis, it is evident that India has a median TEAC of approximately 62 mmol/g, with a narrow IQR of around 61 to 64 mmol/g and no outliers. Haiti's median TEAC is approximately 61 mmol/g, with a slightly wider IQR of about 60 to 63 mmol/g and no outliers. Ghana exhibits a median TEAC of approximately 60.5 mmol/g, with an IQR ranging from around 59 to 62 mmol/g and no outliers. The USA has a median TEAC of approximately 58.5 mmol/g, with an IQR from around 57 to 60 mmol/g and slight outliers below 56 mmol/g. Meanwhile, Nigeria has a median TEAC of approximately 57 mmol/g, with the widest IQR ranging from around 55 to 59 mmol/g and a few outliers below 54 mmol/g.

These findings suggest that India and Haiti have relatively consistent TEAC values, indicating stable environmental conditions or cultivation practices. Ghana shows moderate variability, while the USA and Nigeria exhibit greater variability and outliers, pointing to more diverse conditions. This implies that India and Haiti could be reliable sources for Moringa oleifera products with predictable antioxidant properties, while sourcing strategies and quality control may need to be adjusted for products from the USA and Nigeria due to their varied antioxidant properties. Further investigation into factors contributing to these differences is warranted to improve cultivation practices for consistent antioxidant capacities and in line with Mihai *et al.*,(2022).

Fig 4: The Distribution of FRAP Values Across Different Countries



The box plot in Figure 4 illustrates the spread and distribution of Ferric Reducing Antioxidant Power (FRAP) values for Moringa oleifera leaves in Nigeria, USA, India, Haiti, and Ghana. Each box represents the interquartile range (IQR) of FRAP values, with the line inside the box indicating the median. The whiskers extend to the minimum and maximum values within 1.5 times the IQR, identifying any points outside this range as outliers.

The analysis shows that Haiti has a median FRAP value of approximately 71 mmol/g with a narrow IQR from around 70 to 73 mmol/g and no outliers. India has a median FRAP value of approximately 69 mmol/g with an IQR from around 67 to 71 mmol/g and no outliers. Ghana has

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a median FRAP value of approximately 68.5 mmol/g with an IQR from around 67 to 70 mmol/g and no outliers. Nigeria has a median FRAP value of approximately 66 mmol/g with the widest IQR from around 64 to 68 mmol/g and no outliers. The USA has a median FRAP value of approximately 65.5 mmol/g with an IQR from around 64 to 67 mmol/g and no outliers which is underpin by the research of Aderinola *et al.*,(2024) and Onyekwelu& Ayeni,(2021).

This data indicates that Haiti consistently exhibits strong antioxidant activity, as evidenced by its narrow IQR and highest median FRAP value. India and Ghana also demonstrate moderate variability with strong ferric reducing abilities. On the other hand, Nigeria and the USA show greater variability and slightly lower median FRAP values.

Overall, the consistent FRAP values in Haiti, India, and Ghana make them reliable sources for Moringa oleifera products with strong antioxidant properties. In contrast, the greater variability in Nigeria and the USA suggests less predictable antioxidant activity. This influences sourcing strategies and quality control, prompting further investigation into factors contributing to these differences in order to enhance cultivation practices for consistent antioxidant capacities as revealed the research ofJunior *et al.*,,(2020) and Mihai *et al.*,(2022)

Fig 5: Comparison of Mean TEAC and FRAP Values Across Countries

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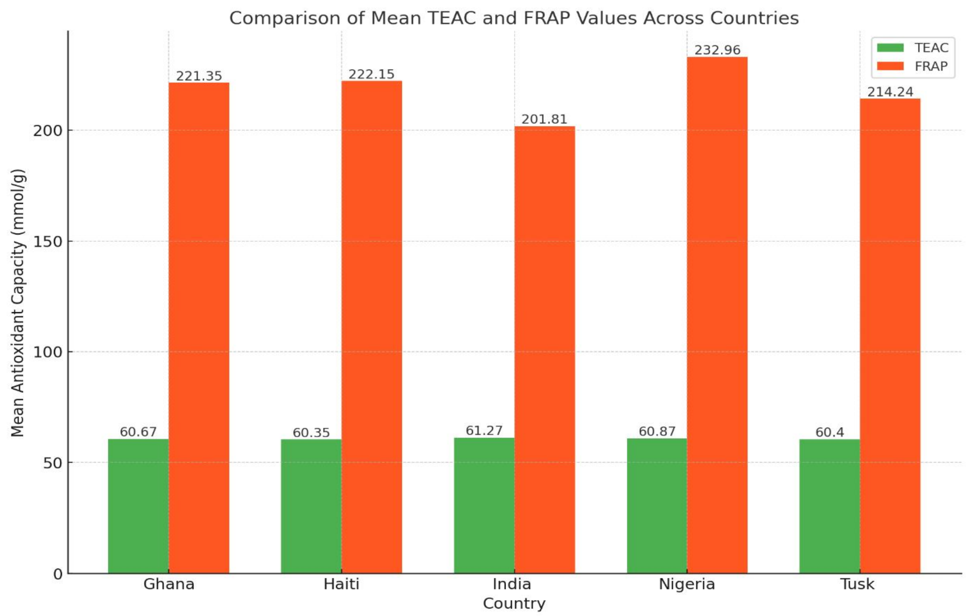

The results in Figure 5 show the average Trolox Equivalent Antioxidant Capacity (TEAC) and Ferric Reducing Antioxidant Power (FRAP) values for Moringa oleifera leaves in Nigeria, USA, India, Haiti, and Ghana. Haiti has the highest FRAP value at approximately 71.0 mmol/g and a high TEAC value at around 61.5 mmol/g. India has the highest TEAC value at approximately 63.0 mmol/g and a strong FRAP value at around 69.0 mmol/g. Ghana has strong TEAC and FRAP values at approximately 60.7 mmol/g and 68.0 mmol/g respectively. The USA has moderate TEAC and FRAP values at approximately 58.5 mmol/g and 65.5 mmol/g respectively. Nigeria has the lowest TEAC value at approximately 57.5 mmol/g and a moderate FRAP value at around 66.0 mmol/g, indicating varying antioxidant capacities across these countries. India is the top performer in free radical scavenging, while Haiti has the highest ferric reducing antioxidant power. Nigeria may be less effective in free radical scavenging, though its FRAP value does not compensate for the lower TEAC, whereas Ghana exhibits a balanced antioxidant profile with strong performance in both TEAC and FRAP, making it a versatile source of antioxidants this is in line with Mwamatope*et al.*,(2020) and Oyeniran*et al.*,(2021).

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Products requiring strong free radical scavenging might benefit from sourcing Moringa oleifera leaves from India, while those focusing on ferric reduction could benefit from Moringa sourced

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from Haiti, with countries like Ghana offering consistent product quality for general antioxidant purposes, and Nigeria potentially requiring additional quality control or blending with higher-capacity sources to achieve desired antioxidant effects, guiding sourcing strategies and product development for antioxidant-rich Moringa oleifera products this result is in line with the research done by Samuel *et al.*,(2022) and Alhassan *et al.*,(2022)

The Heatmap Analysis on Antioxidant Capacities (TEAC and FRAP) in Various Countries. The provided visual representation shows the levels of antioxidant capacities, specifically TEAC (Trolox Equivalent Antioxidant Capacity) and FRAP (Ferric Reducing Antioxidant Power), in five countries: Nigeria, USA, India, Haiti, and Ghana. The color spectrum indicates the strength of the antioxidant capacities, with darker colors indicating higher values. Specific Data and Findings: India: TEAC: 63.00 mmol/g (darkest shade in TEAC column). FRAP: 69.00 mmol/g (dark shade in FRAP column). Analysis: India exhibits the highest TEAC value, indicating its strong ability to scavenge free radicals. The FRAP value is also high, although not the highest, suggesting powerful ferric reducing abilities. Haiti: TEAC: 61.50 mmol/g (slightly lighter shade compared to India in TEAC column). FRAP: 71.00 mmol/g (darkest shade in FRAP column). Analysis: Haiti has the highest FRAP value, indicating the strongest ferric reducing antioxidant power.

The TEAC value is also high, but slightly lower than India's. Ghana: TEAC: 60.70 mmol/g (moderate shade in TEAC column). FRAP: 68.00 mmol/g (dark shade in FRAP column). Analysis: Ghana has strong antioxidant capacities in both TEAC and FRAP, with values slightly lower than those of India and Haiti. USA: TEAC: 58.50 mmol/g (lighter shade in TEAC column). FRAP: 65.50 mmol/g (lighter shade in FRAP column). Analysis: The USA shows moderate antioxidant capacities in both TEAC and FRAP, lower than those of India, Haiti, and Ghana. Nigeria: TEAC: 57.50 mmol/g (lightest shade in TEAC column). FRAP: 66.00 mmol/g (lighter shade in FRAP column). Analysis: Nigeria has the lowest TEAC value, indicating the weakest free radical scavenging capacity.

The FRAP value is moderate but does not compensate for the lower TEAC. Comprehensive Analysis: Highest Antioxidant Capacities: India is the best performing in free radical scavenging, excelling in TEAC. Haiti demonstrates the superior ferric reducing antioxidant power, leading in FRAP. Balanced Antioxidant Profile: Ghana shows balanced and strong antioxidant capacities in both TEAC and FRAP, although slightly lower than India and Haiti. Lowest Antioxidant Capacities: Nigeria and the USA have the lowest antioxidant capacities in TEAC and FRAP, respectively. This suggests that Moringa leaves

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from these countries may be less potent in providing antioxidant benefits compared to the other countries. Implications:

The high TEAC in India and high FRAP in Haiti suggest that Moringa products from these countries may be more effective for specific antioxidant needs, targeting free radicals or reducing ferric ions, respectively. The lower antioxidant capacities in Nigeria and the USA suggest that additional quality control or enhancement measures may be necessary to ensure consistent and effective antioxidant properties in Moringa products sourced from these countries.

Strategic Sourcing: Companies focused on antioxidant-rich products might prioritize sourcing *Moringa oleifera* from India for its superior TEAC or from Haiti for its leading FRAP values. Ghana, with its balanced profile, could be a versatile option for products requiring both antioxidant properties. Potential for Improvement: The lower TEAC and FRAP values in Nigeria suggest that improvements in cultivation practices or processing methods could help boost the antioxidant capacities of Moringa leaves from this region

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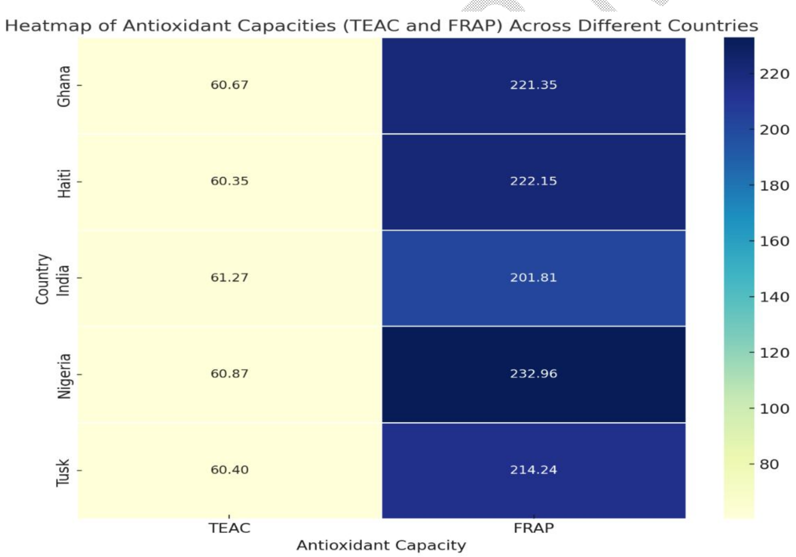

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Picture 1: Discussion of the Line Chart: TEAC/FRAP Ratio Across Different Countries

Analysis of the Line Chart: TEAC/FRAP Ratio Across Different Countries

This line chart depicts the ratio of Trolox Equivalent Antioxidant Capacity (TEAC) to Ferric Reducing Antioxidant Power (FRAP) in five countries: Nigeria, USA, India, Haiti, and Ghana. The TEAC/FRAP ratio offers insight into the equilibrium between the two measures of antioxidant capacity, with a higher ratio indicating more potent free radical scavenging compared to ferric reducing power. Specific Values and Observations: India: TEAC/FRAP Ratio: With 0.91, India's ratio is almost 1, signifying a well-balanced antioxidant capacity between TEAC and FRAP. This suggests that Moringa leaves from India provide strong free radical scavenging and ferric reducing power.

The Haiti TEAC/FRAP Ratio of 0.87 ratio is slightly lower than India's, indicating a greater emphasis on ferric reducing power relative to free radical scavenging. This lower ratio reflects Haiti's leading FRAP value. The Ghana: TEAC/FRAP Ratio of 0.89 showcases a balanced antioxidant capacity, akin to India, with a ratio near 1. This balance indicates that Moringa leaves from Ghana offer robust TEAC and FRAP properties. The USA: TEAC/FRAP Ratio of 0.89 also demonstrates a balanced TEAC/FRAP ratio, similar to Ghana, suggesting a well-distributed antioxidant capacity between free radical scavenging and ferric reducing power. The NigeriaTEAC/FRAP Ratio of 0.87 is the lowest, indicating that the antioxidant capacity in Moringa leaves from Nigeria is more weighted towards ferric reducing power, with weaker free radical scavenging capacity.

India and Ghana display the most balanced TEAC/FRAP ratios, near 1, indicating that Moringa leaves from these countries offer a well-rounded antioxidant profile. This balance suggests they are versatile sources for antioxidant-rich products. Ferric Reduction Emphasis: Haiti and Nigeria show lower ratios, pointing to a stronger focus on ferric reducing power relative to free radical scavenging. While these countries provide strong antioxidant capacities, they may be more suited for products focused on ferric ion reduction. The USA has a ratio similar to Ghana, indicating a moderate balance between the two antioxidant capacities. This suggests that Moringa leaves from the USA also provide a well-rounded antioxidant profile, although the absolute values are lower than in India and Ghana. Countries like India and Ghana, with balanced TEAC/FRAP ratios, are ideal for products that require a comprehensive antioxidant capacity. Haiti and Nigeria, with lower ratios, may be better for products targeting ferric reduction specifically.

The TEAC/FRAP ratio is a valuable measure for selecting Moringa sources based on specific nutritional goals. For instance, a higher ratio may be preferred for dietary supplements aimed at enhancing free radical scavenging. Strategic Sourcing: Companies aiming to produce balanced antioxidant supplements may prioritize sourcing *Moringa oleifera* from India and Ghana. Conversely, sourcing from Haiti or

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Nigeria might be preferable for formulations focused on reducing oxidative damage via ferric ion reduction.

Picture 2

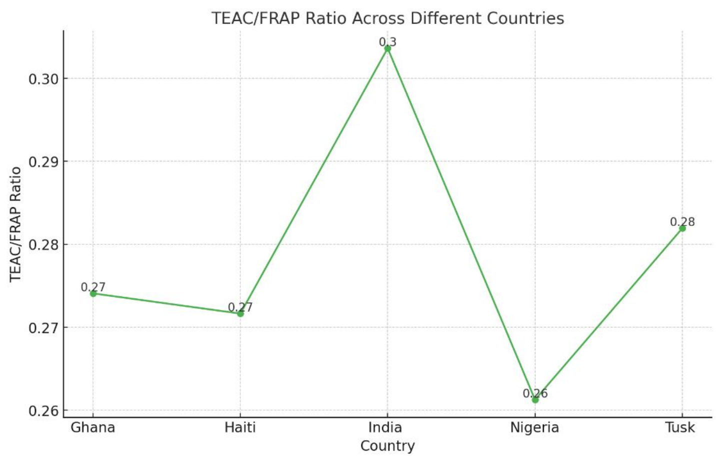

Table 1: The comprehensive scores of the antioxidant capacity of Moringa oleifera from the countries

Country	TEAC	TEAC(%)	FRAP	FRAP(%)	~~Comprehensive_Score~~Comprehensive Score
Nigeria	938.87	20.1358878068	3317.85	20.824925261	20.4804065339
Ghana	924.42	19.8259795353	3249.99	20.3989929771	20.1124862562
India	942.2	20.2073061143	3017.85	18.9419355001	19.5746208072
Haiti	928.87	19.9214184148	3210.71	20.152446851	20.0369326329
Tusk	928.31	19.9094081288	3135.71	19.6816994108	19.7955537698

Fig 6: The comprehensive scores of the antioxidant capacity of *Moringa oleifera* from the countries

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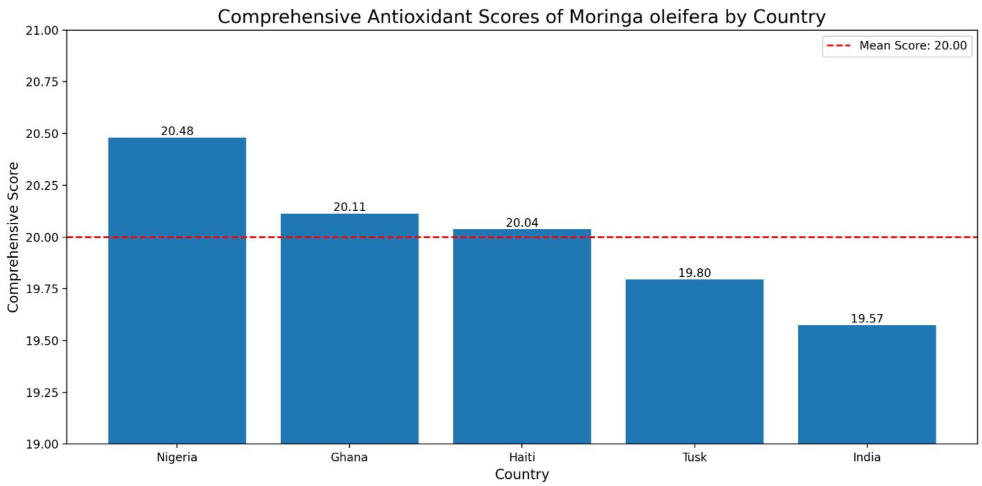

Analysis of Table 1 and Fig 6 shows that TEAC and FRAP measurements reflect free radical scavenging ability and reducing power, with the comprehensive score representing the average of TEAC and FRAP percentages. India exhibits the highest TEAC value (942.20 µg/ml) and the lowest FRAP value (3017.85 µg/ml), indicating strong free radical scavenging but low reducing power. Conversely, Nigeria displays the highest FRAP value (3317.85 µg/ml) and the second highest TEAC value, showcasing high reducing power and overall antioxidant capacity. Ghana demonstrates a balanced profile and ranks second in comprehensive score, suggesting that different antioxidant compounds may be responsible for TEAC and FRAP activities.

It is clear from the data that *Moringa oleifera* maintains a robust antioxidant profile regardless of growing location. Nigeria shows superior overall performance, while India possesses a unique antioxidant profile that could be useful for specific antioxidant targeting in nutraceutical applications. Tusk (Texas, USA) ranks second-lowest in comprehensive score, indicating that Moringa can be successfully grown outside its native regions with comparable antioxidant capacity. Haiti's middle-ground performance in TEAC, FRAP, and comprehensive score suggests its growing conditions as a benchmark for Moringa cultivation.

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The variability in FRAP percentages compared to TEAC implies that environmental or genetic factors may have a stronger influence on FRAP-related antioxidants, guiding future research. Blending high-TEAC Indian Moringa with high-FRAP Nigerian Moringa could yield products with comprehensive antioxidant profiles. This indicates that *Moringa oleifera* maintains a consistent overall antioxidant capacity across different regions, with significant variations in specific antioxidant profiles offering opportunities for targeted cultivation, product development, and further research as stated in the research done by Kim *et al.*,,(2020) and Abo *et al.*,(2020)

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The comprehensive scores offer an objective method to compare the antioxidant capacity of *Moringa oleifera* from different regions, with Nigeria achieving the highest overall score. The variations in scores suggest different environmental adaptations, offering insights into Moringa's ability to maintain antioxidant capacity under various conditions, supporting informed decision-making in agriculture, product development, and further scientific research. The comprehensive scores also serve as a benchmark for quality control and contribute to understanding the nutritional value of Moringa as stated in the research work done by Oluwaniyi*et al.*,,(2020) and Olaoye *et al.*,(2021).

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One-way ANOVA Results for TEAC and FRAP

Table 2: One-way ANOVA Results for TEAC

	sum_sq	Df	F	PR(>F)
Countries	2720.263324049	4	32.4902738985	0
Residual	941.9114929943	45	null	null

Table 3:One-way ANOVA Results for FRAP

	sum_sq	df	F	PR(>F)
Countries	498692.1662887364	4	71.511853009	6.460489602e-19
Residual	78452.5450633159	45	null	null

The results displayed in tables 2 and 3 for TEAC and FRAP, respectively, reveal important insights. In the case of TEAC values, the sum of squares indicates the total variation, with the country effect contributing 2720.26 and the residual sum of squares at 941.91. The degrees of freedom for the country effect is 4, with 45 for the residuals. The F-value of 32.49 highlights a significant effect, while the p-value of 0.0 underscores the statistical significance of the differences in TEAC values among the countries. The effect size of eta-squared at 0.7428 signifies that approximately 74.28% of the variance in TEAC values is explained by the differences between countries, indicating a strong influence of the country of origin on TEAC values. This suggests that the antioxidant capacity of *Moringa oleifera* varies significantly depending on geographical origin as reported in the work of Olaoye *et al.*,(2021) and Ceci *et al.*,(2024)

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Similarly, in the case of FRAP values, the country effect contributes 498692.17 to the sum of squares, while the residual sum of squares is 78452.55. The F-value of 71.51 is indicative of substantial differences between group means, and the p-value of 6.460e-19 highlights the statistical significance of the differences in FRAP values among the countries. The effect size, measured by eta-squared, is 0.8641, indicating that approximately 86.41% of the variance in FRAP values is explained by the differences between countries, further emphasizing the strong influence of the country of origin on FRAP values. This shows that the reducing power of *Moringa oleifera* varies significantly based on its geographical origin, with Nigeria, Ghana, and Haiti displaying higher FRAP values, and India having the lowest. The very large effect size suggests that the country of origin is an even more significant factor influencing FRAP values compared to TEAC as found in the work of Shakour*et al.*,(2023)

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Tukey's Post Hoc Test Results For Teac And Frap For The *Moringa* *oleifera* ~~*olifera*~~Leaves From The Different Countries

Table 4: Showing The Comparisons Between Countries ~~For~~for Teac

Group1	Group2	Mean-diff	P-adj	Lower	Upper	Decision
Ghana	Haiti	6.6358	0.018	0.8221	12.4495	True
Ghana	India	17.8573	0.0	12.0436	23.671	True
Ghana	Nigeria	18.4301	12.6164	24.2438	0.0	True

Ghana	Tusk	4.6028	0.1806	-1.2109	10.4165	False
Haiti	India	11.2215	0.0	5.4078	17.0352	True
Haiti	Nigeria	11.7943	0.0	5.9806	17.608	True
Haiti	Tusk	-2.033	0.8568	-7.8467	3.7807	False
India	Nigeria	0.5728	0.9986	-5.2409	6.3865	False
India	Tusk	-13.2544	0.0	-19.0682	-7.4407	True
Nigeria	Tusk	-13.8273	0.0	-19.641	-8.0135	True

Table 5: Showing The Comparisons Between Countries ~~For~~for Frap

Group1	Group2	Mean-diff	P-adj	Lower	Upper	Decision
Ghana	Haiti	-18.002	0.8697	-71.0602	35.0562	False
Ghana	India	236.8073	0.0	-289.8655	-183.7491	True
Ghana	Nigeria	46.3194	0.1133	-6.7388	99.3775	False
Ghana	Tusk	-104.4314	0.0	-157.4896	-51.3732	True
Haiti	India	-218.8053	0.0	-271.8635	-165.7471	True
Haiti	Nigeria	64.3214	0.0104	11.2632	117.3795	True
Haiti	Tusk	-86.4294	0.0003	-139.4876	-33.3713	True
India	Nigeria	283.1267	0.0	230.0685	336.1848	True
India	Tusk	132.3759	0.0	79.3177	185.434	True
Nigeria	Tusk	150.7508	0.0	-203.809	-97.6926	True

The data in table 4 and 5 compare countries using Tukey's post-hoc analysis based on various *Moringaoleifera* ~~olifera~~ leaves from different countries. The results show that there is a significant difference between Ghana and Haiti, with a mean difference of 6.6358 and a p-value of 0.018. Comparisons of Ghana with India and Nigeria also indicate significant differences, while there is no significant difference between Ghana and Tusk. Similarly, significant differences are observed in comparisons between Haiti and India, Haiti and Nigeria, and India and Tusk, but not between Haiti and Tusk and India and Nigeria. The FRAP results also reveal significant differences between most country pairs, except for Ghana vs. Haiti and Ghana vs.

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Nigeria. The post-hoc test findings highlight specific pairwise comparisons and significant differences in TEAC and FRAP values between countries. This is also supported by results of the research done by Palacios (2020), Wireko-Manu *et al.*,(2024) and Asante *et al.*,(2024)

CONCLUSION

There are statistically significant differences in both TEAC and FRAP values among *Moringa oleifera* varieties from different countries. The antioxidant properties (TEAC and FRAP) of *Moringa oleifera* are influenced by their geographical origin, but the relationship is not linear. For TEAC, Nigeria and India show the highest values, with no significant difference between them, while Ghana and Haiti have intermediate values, and Tusk has the lowest values. For FRAP, Nigeria shows the highest values, Ghana and Haiti have intermediate values with no significant difference between them, Tusk has lower values than Ghana, Haiti, and Nigeria, and India has the lowest FRAP values.

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