AJPP Asian Journal of Plant Pathology

OPEN ACCESS

Chemical Composition, FTIR Analysis and Viscosity of *Tamarindus indica* Fruit Pulp for Industrial Applications

[1]Muhammad Aminu Abubakar, [2]Bello Mukhtar, [2]Abdul Hamid Hamza, [1]Chinyere Imoisi and [3]Maryam Sa'ad

[1]Department of Industrial Chemistry, Mewar International University, KM 21, Abuja-Keffi, Expressway, Masaka, Nasarawa State, Nigeria

[2]Department of Chemical Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

[3]Department of Chemistry, Kaduna State University, Kaduna, Nigeria

ABSTRACT

Background and Objective: *Tamarindus indica* is a valuable resource with potential applications in various industries due to its nutritional and functional properties. This study aimed to assess the proximate composition of *Tamarindus indica* fruit pulp and analyze its functional characteristics to understand its suitability for use in value-added industrial products. Additionally, the study sought to determine the functional groups present in the tamarind fruit pulp and measure the viscosity of tamarind pulp to evaluate its applicability in different industrial sectors. **Materials and Methods:** Proximate analysis of *Tamarindus indica* was conducted using standard methods. Moisture content was measured by oven-drying, ash content was determined by incineration, fat content was assessed using solvent extraction via Soxhlet apparatus, protein content was quantified using the micro-Kjeldahl method and crude fiber was measured by sequential digestion and ashing. Carbohydrate content was calculated by difference. The FTIR spectroscopy was employed to identify functional groups and viscosity was measured using a viscometer set at 25°C. **Results:** The proximate analysis revealed the following average compositions for *Tamarindus indica* samples: Moisture (15.05-15.30%), ash (4.10-5.05%), lipid (13.70-14.95%), protein (8.72-8.75%), fiber (5.50-6.00%) and carbohydrates (56.07-58.15%). The FTIR analysis identified key functional groups, including hydroxyl (-OH), methylene ($-CH_2^-$), carboxyl (COOH) and ether (C-O-C) groups. The viscosity of tamarind pulp was measured at 500 cP, indicating a relatively thick and viscous fluid. **Conclusion:** The proximate analysis of *Tamarindus indica* fruit pulp highlights its nutritional and functional potential for industrial applications, while FTIR and viscosity measurements confirm its suitability for use in pharmaceuticals, food and cosmetics.

KEYWORDS

Tamarindus indica, proximate analysis, FTIR spectroscopy, functional groups, viscosity, solvent extraction

INTRODUCTION

Tamarind (*Tamarindus indica*) is a tropical fruit known for its rich flavor and diverse applications across food, pharmaceutical and cosmetic industries. The fruit's unique composition of polysaccharides,

ISSN: 1819-1541 (Print)
https://doi.org/10.3923/ajpp.2024.67.76

Received: 10 Aug. 2024
Accepted: 22 Sep. 2024
Published: 23 Sep. 2024

polyphenols and fatty acids endows it with valuable functional properties that impact its utilization[1-5]. Proximate analysis of *Tamarindus indica* fruit pulp is essential for understanding their nutritional and functional characteristics, which significantly influence their potential applications in industrial products and other value-added goods[6-8].

Proximate analysis provides a comprehensive evaluation of the primary components of the fruit pulp, including moisture, ash, fat, protein, fiber and carbohydrate contents. Each of these components plays a critical role in determining the fruit pulp behavior during processing and its final product characteristics[9-13]. For instance, moisture content affects storage stability and shelf life, while protein and starch contents influence the texture and nutritional value of the product. Understanding these parameters helps in optimizing the formulation of the products to achieve desirable qualities such as texture, taste and nutritional value[14,15].

The importance of functional properties in the fruit pulp analysis has also been emphasized in recent studies. For instance, research on the functional properties of various products, including their starch and protein contents, has demonstrated their significant impact on the texture and quality of bakery products. Understanding these properties helps in designing products with specific functional characteristics that meet the demands of different food applications[15,16].

Viscosity measurements of tamarind pulp, as reported in the literature, highlight its importance in applications requiring thickening or gelling properties. The viscosity range of tamarind pulp is relevant for its use in pharmaceutical, food and cosmetic industries, where its thickening ability can be leveraged in product formulations[17-20].

The primary objective of this study is to conduct a comprehensive proximate analysis of *Tamarindus indica* fruit pulp to evaluate its nutritional and functional properties. Specifically, the study aims to determine the moisture, ash, fat, protein, fiber and carbohydrate contents of *Tamarindus indica* fruit pulp using standardized methods. The study also assessed the functional properties of the fruit pulp, including their starch and protein content and their impact on the formulation of industrial products and analyzed the molecular composition of *Tamarindus indica* fruit pulp using FTIR spectroscopy to identify key functional groups and their implications for product formulation. The study measured the viscosity of tamarind pulp to understand its flow behavior and suitability for various applications in food, pharmaceutical and cosmetic industries[21,22].

By achieving these objectives, the study aims to provide valuable insights into the composition and functionality of *Tamarindus indica* fruit pulp, contributing to the optimization of their use in diverse applications and the development of value-added products.

MATERIALS AND METHODS

Study area and sites: This study was conducted in Zaria, Kaduna State, Nigeria. It is located at 11.12°N Latitude and 7.73°E Longitude and it is situated at an elevation of 640 m above sea level. The population of Zaria is 766,000, making it one of the most populous cities in Kaduna State[23].

Sample collection and analysis: The *Tamarindus indica* A, B and C (Fabaceae) were purchased from a local market in Kano, Kaduna and Katsina respectively; tamarind fruit weighing 5 kg was boiled in distilled water at varying temperatures (50, 60, 70, 80, 90 and 100°C) for varying times (15, 30, 45 and 60 min) in which the temperature and time of each sample were recorded and tamarind pulp was produced. The produced pulp was mashed or stirred with a stirrer to create a homogeneous mixture and the

homogenous mixture was strained or filtered through a cheesecloth or filter paper to separate the slurry from the residue and seeds and the seeds were discarded or utilized for another purpose and a slurry was produced and utilized for further analysis. This study spanned from January 2023 to November 2023[24,25].

Proximate analysis of the *Tamarindus indica*: The proximate composition was assessed according to the methods outlined by Imoisi and Iyasele[26]. The functionality of *Tamarindus indica* A, B and C fruit pulp, influenced by their starch and protein content, significantly impacts the formulation and characteristics of the final product. Hence, the fruit pulps were evaluated for their functional properties, which are essential for creating value-added industrial products. Protein content was determined using the micro-Kjeldahl method (Nx6.25) and fat content was measured via solvent extraction. Carbohydrate content was calculated using the subtraction method[27].

Determination of moisture content: The moisture content was measured using the oven-drying method. Initially, clean and dry Petri dishes were weighed (W_1) using a balance. Approximately 5 g of the sample was placed into the dishes (W_2) and spread evenly. These dishes were then placed in an oven set at 105°C and dried for about 3 hrs. After drying, the dishes were cooled in a desiccator and weighed again. This process was repeated until a constant weight (W_3) was achieved. The percentage of weight loss during drying was considered the percentage of moisture content, calculated using the equation provided by Imoisi and Michael[28]:

$$\text{Moisture (\%)} = \frac{\text{Loss in weight}}{\text{Weight of sample before drying}} \times 100$$

$$\frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

W_1 = Initial weight of empty crucible
W_2 = Weight of empty crucible+Sample before drying
W_3 = Final weight of empty crucible+Sample after drying

Ash determination: Approximately 1 g of finely ground sample was placed into clean, dried, pre-weighed crucibles with lids (W_1). The organic matter was initially burned off with an open flame until the sample became charred. The crucibles, with lids removed, were then placed in a muffle furnace set to 550°C until a light grey or white ash was formed. The ash content was then calculated using the equation provided by Imoisi and Michael[28]. The crucibles were then cooled in a desiccator and weighed (W_2):

$$\text{Ash (\%)} = \frac{W_2 - W_1}{\text{Weight of sample}} \times 100$$

W_2 = Weight of crucible+Ash
W_1 = Weight of empty Crucible

Crude fat determination: Cleaned and dried thimble was weighed as (W_1) and 5 g oven dried sample was added and reweighed (W_2). Round bottom flask was filled with petroleum ether (b.pt 40-60°C) up to ¾ of the flask. Soxhlet extractor was fixed with a reflux condenser and the heat source so that the solvent boiled gently. The thimble plus the sample were inserted into the Soxhlet apparatus and extraction under reflux was carried out with petroleum ether (40-60°C) for over 6 hrs. The thimble was then removed and

taken into the oven at 100°C for 1 hr and later cooled in the desiccator and weighed again (W_3). The percentage fat content was calculated using the following equation as cited by Imoisi and Michael[28]:

$$\text{Fat (\%)} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100$$

$$\frac{W_2 - W_3}{W_2 - W_1} \times 100$$

W_1 = Initial weight of the empty thimble
W_2 = Weight of the thimble plus sample before extraction
W_3 = Weight of the thimble plus sample after extraction

Crude protein determination: Approximately 1 g of the sample was placed into a micro Kjeldahl digestion flask. One selenium catalyst tablet and 15 mL of concentrated H_2SO_4 were added. The mixture was then digested on an electro-thermal heater inside a fume cupboard until a clear solution was obtained. After cooling, the solution was diluted with distilled water to 50 mL. A 5 mL portion of this solution was transferred into a distillation apparatus and 5 mL of 2% boric acid was pipetted into a 100 mL conical flask (receiver flask) with four drops of screened methyl red indicator. The 50% NaOH was gradually added to the digested sample until it became cloudy, indicating alkalinity. Distillation was performed into the acid solution in the receiver flask, with the delivery tube submerged below the acid level. As distillation proceeded, the pink solution in the receiver flask turned blue, indicating ammonia presence. Distillation was carried out until the solution in the round bottom flask was reduced to approximately 50 mL. Subsequently, the condenser's delivery tube was rinsed with distilled water. The resulting solution collected in the conical flask was then titrated with 0.1M HCl. The percentage of protein content was determined following the method referenced by Imoisi and Michael[28]:

$$\text{Nitrogen (wet \%)} = \frac{(A - B) \times 1.4007}{\text{Weight (g) of sample}} \times 100$$

A = Vol (mL) Std HCl×Normality of Std HCl
B = Vol (mL) Std NaOH×Normality of Std NaOH

$$\text{Nitrogen (dry \%)} = \frac{\text{Nitrogen (wet \%)}}{100 - \text{moisture (\%)}}$$

Protein (%) is nitrogen (dry %)×6.25 (protein nitrogen conversion factor)

Crude fibre determination: The 2.0 g (W_1) of the sample was defatted using petroleum ether in a separating funnel and placed into a one-liter conical flask. To this, 200 mL of boiling 1.25% H_2SO_4 was added and the mixture was gently boiled for 30 min. After boiling, the mixture was filtered through muslin cloth and rinsed thoroughly with hot distilled water. The residue was then transferred back into the flask using a spatula and 200 mL of boiling 1.25% NaOH was added. The mixture was gently boiled for an additional 30 min and subsequently filtered through muslin cloth. The residue was thoroughly washed with hot distilled water, followed by rinsing once with 10% HCL and twice with industrial methylated spirit. The residue was then transferred to a crucible, dried in an oven at 105°C, cooled in a desiccator and weighed (W_2). It was then ashed

in a muffle furnace at 550°C for 90 min, cooled in a desiccator and weighed again (W_3). The percentage of crude fiber was calculated using the formula referenced by Imoisi and Michael[28]:

$$\text{Crud fibre (\%)} = \frac{W_2 - W_3}{W_1} \times 100$$

W_1 = Weight of sample used
W_2 = Weight of crucible+Oven dried sample
W_3 = Weight of crucible+Ash

Determination of carbohydrate content: The percentage of carbohydrate content was calculated using the following equation as cited by Ajenu *et al*.[29].
Carbohydrate (%) = 100-(Protein+fat+fibre+ash+moisture content %)

Tools and equipment manufacturers/specifications: The equipment utilized in this study, including the viscometer, desiccator, Soxhlet extractor, oven, rheometer and various other tools, were sourced from manufacturers such as Hanna Instruments (Woonsocket, Rhode Island, USA), Thermo Fisher Scientific (Waltham, Massachusetts, USA) and Mettler Toledo (Columbus, Ohio, USA), among other reputable suppliers. A vacuum desiccator made of glass, with an internal diameter of 200 mm, a Soxhlet extractor made of glass, with an internal diameter of 500 mL and a double wall/glass wool insulation thermostatic oven with a temperature range of 5 to 200°C were utilized for the study[30,31].

Determination of viscosity of tamarind: A known quantity of tamarind fruit pulp was prepared and poured into the viscometer's sample holder and was ensured to fill the recommended level. The viscometer was set to the desired temperature of 25°C, which is a standard temperature for viscosity measurements. The viscometer was started and was allowed to rotate at a constant speed. The viscometer measured the torque required to rotate the spindle, which is directly related to the viscosity of the fluid. It was allowed to run for a considerable amount of time after which the viscosity reading from the screen was recorded and the process was repeated severally to ensure the accuracy and reliability of the result.

Statistical analysis: Statistical analysis was performed using the BMDP 2R program for stepwise multiple regression. Results were expressed as the mean of triplicate analyses[32,33]. The results of the proximate composition analysis of *Tamarindus indica* fruit pulp were obtained at a significance level of $p<0.05$.

RESULTS AND DISCUSSION

Table 1 presents the proximate composition of *Tamarindus indica* (Fabaceae) fruit pulp, including moisture, ash, lipid, protein, fiber and carbohydrate (CHO) content. The data showcases the nutritional and functional attributes of three different samples (A, B and C), highlighting their potential applications in various industries.

Figure 1 displays the FTIR (Fourier Transform Infrared) spectrum of *Tamarindus indica* fruit pulp, illustrating the presence of various functional groups. Key absorption peaks indicate the presence of hydroxyl, methylene, methyl, ester, carboxyl and ether groups, which are significant in determining the chemical composition and potential industrial applications of the tamarind pulp.

Based on the FTIR spectrum, the peak bands at cm^{-1}: Indicates the presence of hydroxyl (-OH) groups, which are abundant in tamarind's polysaccharides and polyphenols. The 2933 cm^{-1}: Suggests the presence of methylene ($-CH_2^-$) and methyl ($-CH_3^-$) groups, which are present in tamarind's polysaccharides and fatty acids. The 1733 cm^{-1}: Indicates the presence of ester (CO-O-R) or carboxyl (COOH) groups, which are

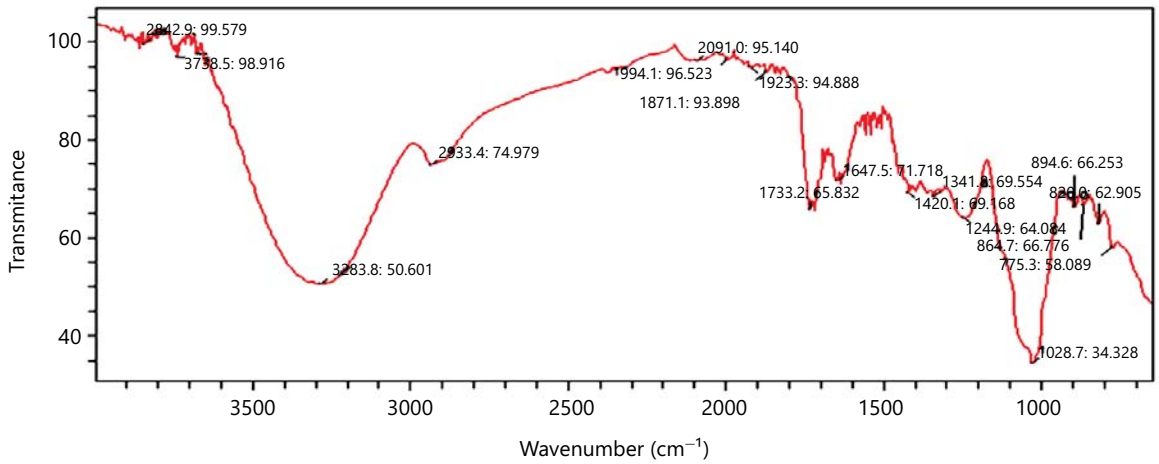

Fig. 1: FTIR spectrum of *Tamarindus indica* fruit pulp

Table 1: Proximate composition of *Tamarindus indica* fruit pulp

Sample name	Moisture (%)	Ash (%)	Lipid (%)	Protein (%)	Fibre (%)	CHO (%)
Tamarindus indica (Fabaceae) A	15.05	4.30	14.95	8.75	6.00	56.95
Tamarindus indica (Fabaceae) B	15.20	5.05	14.96	8.72	5.50	56.07
Tamarindus indica (Fabaceae) B	15.30	4.10	13.70	8.75	6.00	58.15

Table 2: Viscosity ranges of *Tamarindus indica* fruit pulp for various industrial application

Application	Range (cP) or (mPa.s)
Pharmaceutical	500-5000
Food industry	500-5000
Cosmetics	1000-10000
Printing ink	500-2000
Adhesive	1000-5000
Biomedical	1000-10000

present in tamarind's polyphenolic acids and flavonoids. The 1244 cm^{-1}: Suggests the presence of ether (C-O-C) groups, which are abundant in tamarind's polysaccharides. The 1028 cm^{-1}: Indicates the presence of hydroxyl (-OH) groups and/or ether (C-O-C) groups, which are abundant in tamarind's polysaccharides as shown in Fig. 1.

Based on the spectrum the function groups present in *Tamarindus indica* fruit pulp are hydroxyl (-OH), methylene ($-CH_2^-$) group, amide (-CO-NH), methyl ($-CH_3^-$) groups, ether (C-O-C) groups and carboxyl (COOH).

Table 2 presents the viscosity range of *Tamarindus indica* fruit pulp in centipoise (cP) or millipascal seconds (mPa.s), highlighting its suitability across different industries. The pulp exhibits a viscosity range of 500-10,000 mPa.s, making it versatile for use in pharmaceuticals, food, cosmetics, printing ink, adhesives and biomedical applications. The specific viscosity requirements vary by industry and as shown in Table 2.

The proximate analysis of *Tamarindus indica* fruit pulp provides valuable insights into their nutritional and functional characteristics, which are critical for their application in industrial products and other formulations as shown in Table 1. The methods used for proximate analysis of moisture content, ash content, fat content, protein content, crude fiber content and carbohydrate content are well-established techniques that offer a comprehensive view of the products' composition and properties[32,33].

The moisture content of *Tamarindus indica* fruit pulp ranged from 15.05 to 15.30%. This level of moisture is relatively high and suggests that the fruit pulp may have a higher water-holding capacity. High moisture content can influence the storage stability of the fruit pulp, making it more susceptible to microbial

growth and spoilage if not properly stored[34]. The ash content, which ranged from 4.10 to 5.05%, provides an estimate of the total mineral content in the fruit pulp. Ash content is an important indicator of the mineral composition and overall quality of the fruit pulp. Higher ash content can indicate higher levels of minerals such as calcium, magnesium and potassium. These minerals can contribute to the nutritional value of the final product but can also affect the color and texture of the fruit pulp[35,36].

The fat content in the *Tamarindus indica* fruit pulp ranged from 13.70 to 14.96%. This relatively high fat content suggests that the fruit pulp is rich in lipids, which can impact the flavor, texture and shelf life of the products. Fats contribute to the tenderness and mouthfeel of the final product. However, excessive fat can also lead to greasiness and affect the overall sensory quality. The protein content of the flours ranged from 8.72 to 8.75%. Protein content is crucial for the structural properties of the fruit pulp, as proteins like gluten play a significant role in dough development and texture. The protein levels observed are moderate and suggest that the *Tamarindus indica* fruit pulp could contribute to the protein content of industrial products, enhancing their nutritional profile[23,25].

The crude fiber content ranged from 5.50 to 6.00%. Fiber is an important component for improving the dietary fiber content of the products. High fiber content can enhance the health benefits of the products, such as improving digestion and promoting satiety. The fiber levels observed indicate that *Tamarindus indica* fruit pulp could be a valuable ingredient for increasing the fiber content[37]. The carbohydrate content, calculated to be between 56.07 and 58.15%, reflects the primary source of energy in the fruit pulp. The high carbohydrate content indicates that *Tamarindus indica* fruit pulps are a substantial source of energy, which can be advantageous in formulating energy-dense products.

The FTIR spectrum analysis reveals the presence of various functional groups in *Tamarindus indica*, including hydroxyl (-OH), methylene ($-CH_2^-$), methyl ($-CH_3^-$), ester (CO-O-R) and carboxyl (COOH) groups. These functional groups are indicative of the presence of polysaccharides, polyphenols and fatty acids in the tamarind fruit pulp. The presence of these groups suggests that *Tamarindus indica* fruit pulp has diverse chemical properties, which can affect their interaction with other ingredients in the products. For instance, hydroxyl groups can form hydrogen bonds, influencing the water retention and texture of the final product, while carboxyl groups can affect the acidity and flavor profile[38,39].

The viscosity was found to be 500 cP (centipoise) at 25°C, indicating a relatively thick and viscous fluid as shown in Table 2. This value is important for understanding the flow behavior of the tamarind fruit pulp, which is crucial for its potential applications in the food, pharmaceutical and cosmetic industries. The viscosity of tamarind pulp measured at 500 cP (centipoise) indicates a relatively thick and viscous fluid. This viscosity is within the range suitable for various applications in the pharmaceutical, food and cosmetic industries. In food products, this viscosity can contribute to the thickness and texture of sauces or dressings. In pharmaceuticals and cosmetics, it may be used as a thickening agent or stabilizer in formulations[26,32].

The proximate composition and functional properties of *Tamarindus indica* fruit pulp demonstrate their potential as versatile ingredients in industrial products and other applications. The high moisture, fat and carbohydrate contents suggest that these fruit pulp can enhance the texture and energy content of bakery products, while the moderate protein and fiber contents contribute to their nutritional value[39]. In Fig. 1, the FTIR and viscosity analyses further highlight the functional versatility of *Tamarindus indica*, supporting its potential in diverse industrial applications. Understanding these properties allows for better formulation and optimization of tamarind-based products, maximizing their benefits and applications across various industries[40-46]. The study's findings on the proximate composition, FTIR analysis and viscosity of *Tamarindus indica* fruit pulp underscore its significant potential for various industrial applications. The high moisture, fat and carbohydrate levels suggest its suitability for enhancing texture and energy content in food

products, while the moderate protein and fiber contents contribute to the nutritional profile[47-50]. The FTIR analysis reveals diverse functional groups, indicating the chemical versatility of tamarind pulp for use in pharmaceuticals, cosmetics and other sectors. However, high moisture content may affect storage stability and the fat content could influence sensory properties. Future research should focus on optimizing storage conditions and exploring additional applications to fully harness the benefits of *Tamarindus indica* in industrial formulations.

CONCLUSION AND RECOMMENDATIONS

The proximate analysis of *Tamarindus indica* fruit pulp highlights its potential for diverse industrial uses. High moisture content impacts shelf life and texture, while significant fat enhances flavor and texture but may cause greasiness. The protein and fiber contents improve nutritional value and health benefits. The FTIR analysis identifies functional groups indicating the presence of polysaccharides, fatty acids and polyphenols, supporting its versatile applications. The viscosity measurement suggests tamarind pulp as a suitable thickening agent for food, pharmaceuticals and cosmetics. These properties position *Tamarindus indica* fruit pulp as a valuable ingredient for innovative and beneficial products across various industries.

SIGNIFICANCE STATEMENT

The study offers a detailed investigation into the biochemical and physical properties of *Tamarindus indica* flours, with a focus on their application in diverse industries. By analyzing the moisture, ash, lipid, protein, fiber and carbohydrate content, the research provides crucial insights into the nutritional and functional qualities of tamarind flours. The FTIR analysis further identified key functional groups, which are instrumental in understanding the chemical composition of tamarind. Additionally, the study's measurement of a viscosity of 500 cP at 25°C underscores its potential as a versatile thickening agent suitable for food, pharmaceutical, cosmetic and biomedical applications. These findings pave the way for future innovations in tamarind-based product development, contributing to advancements in various industrial sectors.

REFERENCES

1. Afoakwa, E.O., E.J. Kongor, G.A. Annor and R. Adjonu, 2010. Acidification and starch behaviour during co-fermentation of cassava (*Manihot esculenta* Crantz) and soybean (*Glycine max* Merr) into *gari*, an African fermented food. Int. J. Food Sci. Nutr., 61: 449-462.
2. Agbon, C.A., E.O. Ngozi and O.O. Onabanjo, 2010. Production and nutrient composition of fufu made from a mixture of cassava and cowpea flours. J. Culinary Sci. Technol., 8: 147-157.
3. Chinyere, I. and I.U. Julius, 2020. Spectroscopic determination of sugar components of *Vitex doniana* fruit syrup following derivatization. Nat. Sci., 18: 67-76.
4. Jitngarmkusol, S., J. Hongsuwankul and K. Tananuwong, 2008. Chemical compositions, functional properties, and microstructure of defatted macadamia flours. Food Chem., 110: 23-30.
5. Ceballos, H., T. Sánchez, N. Morante, M. Fregene and D. Dufour *et al*., 2007. Discovery of an amylose-free starch mutant in cassava (*Manihot esculenta* Crantz). J. Agric. Food Chem., 55: 7469-7476.
6. Imoisi, C., J.U. Iyasele and S.E. Okhale, 2021. Proximate and acute toxicity profile of *Vitex doniana* (black plum) fruit. J. Chem. Soc. Nigeria, 46: 276-282.
7. Imoisi, C., F.I. Omenai and J.U. Iyasele, 2024. Proximate composition and pasting properties of composite flours from cassava (*Manihot esculenta*) and millet (*Panicum miliaceum*). Trends Appl. Sci. Res., 19: 145-155.
8. Imoisi, C., J.U. Iyasele, E.E. Imhontu, U.R. Orji and S.A. Okhale, 2021. Phytochemical and antioxidant capability of *Vitex doniana* (black plum) fruit. J. Chem. Soc. Nigeria, 46: 191-196.
9. Charles, A.L., Y.H. Chang, W.C. Ko, K. Sriroth and T.C. Huang, 2004. Some physical and chemical properties of starch isolates of cassava genotypes. Starch, 56: 413-418.

10. Egbeneje, V.O., S.E. Okhale, C. Imoisi, I.O. Ogbogo and O. Ojo, 2023. Evaluation of the inhibitive properties of silver nanoparticles in *Senna occidentalis* root extract as corrosion inhibitor of mild steel. Tanzania J. Sci., 49: 655-663.
11. Curvelo, A.A.S., A.J.F. de Carvalho and J.A.M. Agnelli, 2001. Thermoplastic starch-cellulosic fibers composites: Preliminary results. Carbohydr. Polym., 45: 183-188.
12. Okhale, S.E., N. Amuzie, C. Imoisi and J.A. Ibrahim, 2022. Phytochemical and HPLC-UV-DAD chromatographic characterization of stem bark extracts of *Pentaclethra macrophylla* Benth used for management of diabetes mellitus in Nigeria. N. Y. Sci. J., 15: 41-49.
13. Imoisi, C., J.U. Iyasele, U.C. Michael and E.E. Imhontu, 2020. The effects of watermelon rind flour on the functional and proximate properties of wheat bread. J. Chem. Soc. Nigeria, 45: 978-986.
14. Rolls, B.J., E.A. Bell, V.H. Castellanos, C. Mosuk, C.L. Pelkman and M.L. Thorwart, 1999. Energy density but not fat content of foods affected energy intake in lean and obese women. Am. J. Clin. Nutr., 69: 863-871.
15. Daramola, B. and K.O. Falade, 2006. Enhancement of agronomical values: Upstream and downstream opportunities for starch and starch adjuncts. Afr. J. Biotechnol., 5: 2488-2494.
16. Josiah, J.G., J.Y. Adama, Z. Jiya, O.M. Abah and C. Imoisi, 2023. *In vitro* anthelmintic activities of stem and root barks extracts of *Parkia biglobosa* on infective larvae and adult of *Haemonchus contortus*. Afr. J. Biotechnol., 22: 26-38.
17. Ozoh, C.A., C. Imoisi and J.U. Iyasele, 2023. Effect of pH and duration of fermentation on the quality characteristics of garri. Pak. J. Nutr., 22: 45-51.
18. Imoisi, C., J.U. Iyasele, D.O. Ikpahwore and A.O. Okpebho, 2023. The effects of watermelon rind flour on the proximate properties of wheat cake. Int. J. Nutr. Res. Health, Vol. 2. 10.59657/2871-6021.brs.23.004.
19. Okhale, S.E., I. Chinyere, S.A. Fidelis and M.I. Aboh, 2021. Antiproliferative, growth inhibitory and antibacterial activities of thymol isolated from the leaf of *Ocimum gratissimum* L. Life Sci. J., 18: 67-76.
20. Kurhade, A., S. Patil, S.K. Sonawane, J.S. Waghmare and S.S. Arya, 2016. Effect of banana peel powder on bioactive constituents and microstructural quality of chapatti: Unleavened Indian flat bread. J. Food Meas. Charact., 10: 32-41.
21. Butt, M.S. and R. Batool, 2010. Nutritional and functional properties of some promising legumes protein isolates. Pak. J. Nutr., 9: 373-379.
22. Okhale, S.E., P.O. Oladosu, M.I. Aboh, C. Imoisi and J.J. Gana, 2022. *In-vitro* evaluation of *Eucalyptus citriodora* leaf essential oil and extracts on selected pathogens implicated in respiratory tract infections. Int. J. Pharmacogn., 9: 195-201.
23. Omenai, F.I., C. Imoisi and J.U. Iyasele, 2024. Physico-chemical and pasting characteristics of cassava, wheat flours and their composite blends. Asian Sci. Bull., 2: 333-344.
24. Umanya, O.J., P.I. Edogun and C. Imoisi, 2024. Comparative study of chitosan and alum for water purification: A case study of Jesse River, Nigeria. Trends Appl. Sci. Res., 19: 104-111.
25. Imoisi, C., D.O. Ikpahwore and J.U. Iyasele, 2024. Investigation of heating time effects on viscosity profiles of wheat flour and watermelon flour blends. Singapore J. Sci. Res., 14: 13-23.
26. Imoisi, C. and J.U. Iyasele, 2024. Investigation of heating time effects on viscosity profiles of cassava flour and citrus flour blends. Asian J. Emerging Res., 6: 22-30.
27. Imoisi, C., F.I. Omenai and J.U. Iyasele, 2024. Investigation of heating time effects on viscosity profiles of cassava flour and wheat flour blends. Res. J. Bot., 19: 10-20.
28. Imoisi, C. and U.C. Michael, 2020. Comparative physicochemical and proximate analyses of different extracts of *Persea americana*. J. Chem. Soc. Nigeria, 45: 1139-1146.
29. Ajenu, C.O., C. Imoisi, E.E. Imhontu and U.R. Orji, 2021. Comparative evaluation of the proximate and micro-nutritional benefits of pawpaw, carrot, turmeric and coconut. J. Food Technol. Nutr. Sci., 3: 1-5.
30. Imoisi, C. and S.E. Okhale, 2024. Chemical composition analysis of *Eucalyptus citriodora* essential oil using GC-MS and NMR spectroscopy. Trends Agric. Sci., 3: 83-90.

31. Edogun, P.I., C. Imoisi and J.U. Iyasele, 2024. Study on the effect of *Ficus exasperata* aqueous leaf extract on the rate of lactic acid formation of fermented milk. Trends Appl. Sci. Res., 19: 72-82.
32. Imoisi, C., J.U. Iyasele, E.E. Imhontu, D.O. Ikpahwore and A.O. Okpebho, 2020. Pasting properties of composite of cassava and wheat flours. J. Chem. Soc. Nigeria, 45: 1157-1163.
33. Okhale, S.E., C. Imoisi, A. Aliyu, J.G. Josiah and V. Egbeneje, 2024. Synergistic antimicrobial activities and phytochemical analysis of leaf extracts from *Sarcocephalus latifolius*, *Morinda lucida* and *Anogeissus leiocarpus*. Asian Sci. Bull., 2: 425-434.
34. Yaich, H., H. Garna, B. Bchir, S. Besbes and M. Paquot *et al*., 2015. Chemical composition and functional properties of dietary fibre extracted by Englyst and Prosky methods from the alga *Ulva lactuca* collected in Tunisia. Algal Res., 9: 65-73.
35. Okhale, S.E., H.O. Egharevba, C. Imoisi, J.A. Ibrahim and I.A. Jegede, 2022. Gas Chromatography-Mass Spectrometry (GC-MS) analysis of the essential oil from Nigerian *Artemisia annua* L. at different growth stages. Nat. Sci., 20: 49-54.
36. Chinyere, I., I.U. Julius and O.E. Samuel, 2021. Determination of the flavoring components in *Vitex doniana* fruit following hydrodistillation extraction. Am. J. Food Nutr., 9: 69-75.
37. Daramola, B. and S.A. Osanyinlusi, 2006. Production, characterization and application of banana (*Musa* spp) flour in whole maize. Afr. J. Biotechnol., 5: 992-995.
38. Imoisi, C., J.U. Iyasele and A.O. Okpebho, 2023. The effects of citrus vesicle flour on the functional and proximate properties of cassava bread. Pak. J. Nutr., 22: 19-26.
39. Ajenu, C.O., M.E. Ukhun, C. Imoisi, E.E. Imhontu, L.E. Irede and U.R. Orji, 2021. Characterization and stability studies of egusi melon seed oil (*Citrullus colocynthis* L.). J. Chem. Soc. Nigeria, 46: 238-244.
40. Delcour, J.A., J. Vansteelandt, M.C. Hythier and J. Abécassis, 2000. Fractionation and reconstitution experiments provide insight into the role of starch gelatinization and pasting properties in pasta quality. J. Agric. Food Chem., 48: 3774-3778.
41. Aremu, M.O., O. Olaofe and E.T. Akintayo, 2007. Functional properties of some Nigerian varieties of legume seed flours and flour concentration effect on foaming and gelation properties. J. Food Technol., 5: 109-115.
42. Josiah, J.G., J.Y. Adama, E.H. Edim, I. Chinyere and J. Zipporah, 2024. Acute toxicity profile of crude methanolic stem bark extract of *Parkia biglobosa* in West African Dwarf (Wad) goats. J. Biosci. Biotechnol. Discovery, 9: 10-22.
43. Saikia, S. and C.L. Mahanta, 2016. *In vitro* physicochemical, phytochemical and functional properties of fiber rich fractions derived from by-products of six fruits. J. Food Sci. Technol., 53: 1496-1504.
44. Okhale, S.E., V.O. Egbeneje and C. Imoisi, 2021. GC-MS evaluation of palm oil as benign extraction medium for bioactive constituents of *Ocimum gratissimum* L and *Bryophyllum pinnatum* (Lam.). J. Am. Sci., 17: 46-53.
45. Macagnan, F.T., L.P. da Silva and L.H. Hecktheuer, 2016. Dietary fibre: The scientific search for an ideal definition and methodology of analysis, and its physiological importance as a carrier of bioactive compounds. Food Res. Int., 85: 144-154.
46. Blazek, J., E.P. Gilbert and L. Copeland, 2011. Effects of monoglycerides on pasting properties of wheat starch after repeated heating and cooling. J. Cereal Sci., 54: 151-159.
47. Ağar, B., H. Gençcelep, F.T. Saricaoğlu and S. Turhan, 2016. Effect of sugar beet fiber concentrations on rheological properties of meat emulsions and their correlation with texture profile analysis. Food Bioprod. Process., 100: 118-131.
48. Cummings, J.H. and A.M. Stephen, 2007. Carbohydrate terminology and classification. Eur. J. Clin. Nutr., 61: S5-S18.
49. Okhale, S.E., I. Chinyere, M.I. Aboh and U.A. Osunkwo, 2021. Effects of semisynthetic modifications on the antimicrobial activities of ethyl acetate extract of *Mitracarpus villosus* (Sw.) DC aerial part. Nat. Sci., 19: 36-41.
50. Ozoh, C., C. Imoisi and J.U. Iyasele, 2024. Effect of pH and duration of fermentation on the sensory, physicochemical and proximate characteristics of garri. Trends Appl. Sci. Res., 19: 156-169.