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# Bioactive and Nutritional Constituents, *In Vitro* Functionality, and Food and Therapeutic Potentials of a Syrup Prepared from Oil Palm (*Elaeis Guineensis*) Sap

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**Abstract: -** A syrup prepared from the sap of the African oil palm (*Elaeis guineensis* Jacq) was evaluated *in vitro,* for application as a nutritional, bioactive sweetener and flavouring by determination of its carbohydrate content, sugar, organic acid, and phenolic compositions, and also, its pH, titrable acidity, vitamin C, and functional characteristics at various concentrations. The syrup exhibited high total phenolic content (TPC) (70.82-510.2 mg GAE/L) at the various concentrations studied (5-40% wt/vol). Thirty-four phenolic compounds were identified, with syringic (28.91%), vanillic (24.48%), gallic (17.93%) and ferulic (10.88%) acids as the dominant constituents; 30 others were present in minor and trace concentrations. The various concentrations of palm syrup exhibited acid pH values of 3.2-3.0, high vitamin C (7.67-61.34 mg %) and low titrable acidity (0.31-1.49%), with malic (35.76%), tartaric (21.86%), lactic (16.36%), acetic (12.71%), and oxalic (9.81%) as the major organic acids. Total carbohydrate content was 67.73±0.72%, and glucose (75.69 %) and fructose (19.31%) were the major sugars; sucrose (4.83%) was a minor constituent. The favourable organic acid, carbohydrate, and phenolic profiles, high carbohydrate, vitamin C, and total phenolic contents, high DPPH radical scavenging activity ($IC_{50}$ = 2.88 g/ml), modest reducing power ($IC_{50}$ = 25.3 g/ml), and high α-amylase inhibitory activity ($IC_{50}$ = 0.45 mg/ml) of the palm syrup recommend it as a functional sweetener and flavouring, with possible therapeutic benefits.

**Keywords: Palm sugar, phenolic compounds, organic acids, sugars, antioxidant capacity, α-amylase inhibitory activity.**

## I. Introduction

Growing incidence of obesity, type 2 diabetes mellitus (T2DM), and hypertension, and the search for dietary interventions for their management have resulted in the emergence of a number of previously little-known food sweeteners, among which are palm syrup, sugar, and jaggery, prepared by the evaporation of the sweet saps collected from palms. Prominent among these are the brown products from the evaporation of saps from the coconut (Hebbar *et al.*, 2015), *Phoenix canariensis* (Luis *et al.*, 2012), *Arenga pinnata*, and *Borassus flabellifer* (Srikaeo *et al.*, 2019) palms, which are popular in the cuisines of areas where they are produced, and also feature in international trade. Palm sugar has gained international recognition because it is considered to be natural and healthy, with a low glycaemic index (GI) (Trinidad *et al.*, 2010), and high micronutrient content, compared with traditional natural sweeteners such as honey, table sugar (sucrose), and high fructose corn syrup (Hebbar *et al.,* 2015).

Low GI foods play an important role in the dietary management of obesity, diabetes, weight reduction, peak sport performance, and the reduction of risks associated with heart disease and hypertension (Jenkins *et al.*, 1981; Jenkins *et al*., 2002, Foster-Powell *et al.*, 2002; Strikaeo & Tonga, 2015). Other properties are the high *in vitro* α-amylase, α-glucosidase and ACE (angiotensin 1-converting enzyme) inhibitory activity of brown sugar preparations (notably palm sugar), with potential for low-cost dietary management of type 2-diabetes and hypertension (Ranilla *et al.*, 2008). These findings have resulted in growing demand for palm sugar as replacement for traditional sweeteners (especially cane sugar and brown syrups derived from it) for use in food and beverage formulations. This demand which currently outstrips supply (due largely to the fact that palm sugar is largely produced by artisanal and small-scale operators) is driven mainly by the favourable health claims, especially of lower glycaemic index, higher micronutrient content, and higher antioxidant capacity, compared with white and brown sugars based on sugar cane, and honey (Trinidad *et al.*, 2010; Hebbar *et al.*, 2015).

In Nigeria, the two major sap bearing palms are the African oil palm (*Elaeis guineensis* Jacq) and the raffia palms (*Raphia* spp). The saps from these palms are allowed to ferment and are consumed as palm wine, or distilled to produce a liquor of high alcohol content (the gin known as *ogogoro* in Nigeria and *akpetesie* in Ghana). These saps are not utilised for sugar production, and palm sugar does not feature in Nigerian cuisine. Recent laboratory studies on syrups derived from these palm saps reported high phenolic content and antioxidant activity, with considerable antimicrobial activity against clinical strains of *Escherichia coli, Pseudomonas aeruginosa, Bacillus cereus, and Staphylococcus aureus,* and physico-chemical characteristics similar to those of honey (Oboh *et al*., 2016). Oil palm syrup also exhibited good performance as an antioxidant sweetener and flavouring in non-alcoholic beverage

formulations (Oboh & Imafidon, 2018), and is suitable for use as an antioxidant preservative for short-term storage of cooked ground beef in the refrigerator (Oboh *et al.*, 2021).

In this study, syrup prepared from the sap of the African oil palm (*Elaeis guineensis* Jacq) was evaluated *in vitro,* for application as a bioactive sweetener and flavouring by determination of its sugar, organic acid, and phenolic compositions, and its chemical, nutritional, and functional characteristics.

## II. Materials and Methods

### Materials

### Palm syrup

Palm syrup was prepared as follows: Freshly tapped oil palm sap (obtained from the Nigerian Institute for Oil Palm Research, Benin City, Nigeria) was filtered through cheese cloth. The filtrate was boiled in an open pan until it turned brown and slightly viscous; the syrup was cooled and its volume measured. One and a half litres (1.5 l) of the sap gave 150 ml of syrup. On cooling, the thin syrup turned into a viscous gel. Various concentrations of palm syrup (5, 10, 20, 30, and 40%) in distilled water (covering the practical range within which the syrup is likely to be applied in various preparations) were prepared and analysed for their chemical characteristics, antioxidant capacity, and α-amylase inhibitory activity.

### Reagents

2, 2-diphenyl-1-picrylhydrazyl (DPPH), gallic acid, acetonitrile, ethyl acetate, and α-amylase were obtained from Sigma-Aldrich Co. St. Louis, MO, USA. Sugar and organic acid standards were obtained from Supelco (Irvine, CA) and phenolic standards from (Aldrich Chemicals Co. Milwaukee, WI). Citric acid, methanol, potato starch, di-nitro salicylic acid (DNSA) acid Folin-Ciocalteu reagent, methanol, potassium ferricyanide, ascorbic acid, trichloroacetic acid, dinitrophenylhydrazine solution (DNPH), thiourea, sodium hydroxide, monosodium phosphate, disodium phosphate, phosphoric acid, and phenolphthalein were obtained from Merck, Darmstadt, Germany. All reagents were analytical grade.

### Analytical Procedure

### Titrable Acidity

Titrable acidity of palm syrup preparations was determined titrimetrically. Aliquots (5 mL) of the various concentrations were titrated with 0.1 N NaOH, using phenolphthalein as an indicator. Titrable acidity was calculated as % lactic acid (Sadler & Murphy, 2010).

### pH

The pH values of the palm sugar preparations were measured using a Jenway Model 3505 pH meter (Camlab, Over, Cambridge, UK). Ten millilitre portions were read in triplicate.

### Vitamin C Content

Vitamin C content was determined spectrophotometrically according to a modification of the method of Roe (1961). A 7.5 ml aliquot of a dinitrophenylhydrazine solution (DNPH) solution containing DNPH (2.0 g) and thiourea (2.3 g) dissolved in 5 M sulphuric acid (1 L), was added to 5 ml of the sample solution (prepared by the extraction of 10 g of the sample using 100 ml, 13.3% trichloroacetic acid: water 1:1 v/v). The mixture was incubated for 3 hr at 37°C, then 0.5 ml, 65% sulphuric acid was added, and the absorbance read at 520 nm. Determination was in triplicate. The vitamin C content was estimated from the calibration graph prepared using various concentrations of ascorbic acid.

### Total Carbohydrate Content

The total carbohydrate content of the oil palm syrup was determined using the anthrone method (Hedge & Hofreiter, 1962). The syrup sample (0.5 mL, 20% aqueous syrup solution) was hydrolysed in a boiling water bath for 3 h with 5 mL, 2.5 N HCl. The mixture was cooled to ambient temperature and neutralised with $Na_2CO_3$ until the effervescence stopped. The volume was made up to 100 mL and centrifuged. Aliquots of the supernatant (0.5 mL) and 0.2, 0.4, 0.6, 0.8, and 1 mL of the glucose standard (0.1 mg/mL) were measured into test tubes and made up to 1 mL with distilled water, and 4 mL aliquots of the anthrone reagent were added to each. A blank was prepared using distilled water instead of sample or glucose standard. The tubes were heated for 8 min in a boiling water bath (Thermo Scientific Precision, General Purpose, Thermo Fisher, Loughborough, UK) and then cooled rapidly. Absorbance was read at 630 nm using a uv-visible spectrophotometer (GENESYS 10S, Thermo Fisher Scientific, Madison, WI, USA) and the carbohydrate content was estimated from the calibration graph prepared using various concentrations of glucose.

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**High Performance Liquid Chromatography (HPLC)**

***Phenolic compounds***

**Extraction**

The phenolic compounds were extracted using a two-stage process as follows:

Sample (100 mg) was extracted with 10 ml of 1 M NaOH for 16 hr in a shaker at ambient temperature as described by Kelley *et al.* (1994) and Provan *et al*. (1994). After extraction, the sample was centrifuged at 5000 x g, rinsed with water, centrifuged again, and the supernatants were combined and placed in a disposable glass test tube and heated at 90ºC for 2 hr to release the conjugated phenolic compounds (Whitehead *et al.*, 1983). The heated extract was cooled, titrated with 4 M HCL to pH <2.0, diluted to 20 ml with deionised water, and centrifuged to remove the precipitate. The supernatant was saved for subsequent purification, and the residue extracted further with 10 ml, 4 M NaOH and heated to 160ºC in a Teflon crucible (Provan et al. 1994). After cooling, the mixture was filtered, the supernatant collected, and the residue washed with distilled deionised water and filtered. All the supernatants were combined, the pH adjusted to <2.0 with 4M HCL, and subjected to further purification.

**Purification**

An aliquot (10 ml) of the pH-adjusted combined supernatants was passed through a conditioned Varian (Varian Assoc., Harbor City, CA) Bond Elut PPL, 3 ml, 200 mg packed solid phase extraction tube, flow rate 5 ml /min attached to a Visiprep (Supelco, Bellefonte, PA). The tubes were then placed under a vacuum (-60 kPa) until the resin was thoroughly dried, after which the phenolic compounds were eluted with 1 ml ethyl acetate into gas chromatography autosampler vials. The PPL tubes were conditioned by first passing 2 ml of ethyl acetate followed by 2 ml water (pH <2.0).

**HPLC**

Purified phenolic extracts were analysed by comparison with phenolic standards (Aldrich Chemicals Co. Milwaukee, WI). The extracts and standards were injected (using a Hamilton microliter syringe) into the high-performance liquid chromatograph (Agilent 1200 Series, Santa Clara, CA, USA) equipped with an Agilent 1260 (wavelength 320 nm) detector. High performance liquid chromatography was at 40ºC using a CHROMSHER 5, C18 (5 µm, 3 mm x 250 mm) column, eluted with an 82/18 volume mixture of 2% acetic acid in water/methanol. Injection volume was 100 µL, flow rate 0.7 ml/min, and pressure, 180 x $10^5$ Pa (Provan *et al.*, 1994).

***Sugars***

Sample preparation was according to Ng & Reuter (2015). Stock sugar standards were made using a 75:25 volume mixture of acetonitrile/water as diluent. A stock solution of 8 g/L of each standard was prepared and aliquot of this were made up to the required concentration. Standards of lower concentration were then prepared from this stock solution. The mixed calibration standards were prepared in the required range of concentrations by dissolving accurately weighed amounts in water and then making up the balance with acrylonitrile to achieve the 75:25 ratio of the solvents. The oil palm sugar samples were prepared by accurately dissolving 2.5 g of sample in 500 ml 75:25 acetonitrile/water.

**HPLC**

For the chromatographic separations of sugars, an Agilent 1200 Series HPLC system fitted with a Grace-Davison Prevail Carbohydrate ES column (150 x 4.6 i.d., mm, particle size 5µm) was employed, with integrated vacuum degasser/column oven and a refractive index detector. Mobile phase was a 75:25 volume mixture of acetonitrile/water. All solvents and diluents used were HPLC grade and filtered through 0.45 µm filters. Injection volume, flow rate, and operation temperature were 5.0 µL, 1.0 mL/min, and 25ºC, respectively (GDDS, 2009).

**Gas chromatography**

***Organic acids***

The palm sugar sample was extracted with carbon disulphide. The sample extract was transferred to a headspace vial and placed in the headspace jacket connected to the gas chromatograph (HP 6890) fitted with a fused silica dimethyl siloxane column (CP-Sil 5 CB, 25 m long, 0.32 µm i.d., 0.12 µm film thickness, Agilent J&W, Santa Clara, CA, USA), with split injection mode and a flame ionization detector. Nitrogen was the carrier gas. Injection temperature was 150ºC, detector temperature, 300ºC, and the initial oven temperature was 35ºC, programmed at 5ºC/min to a final temperature of 200ºC. For the headspace sampler, the vial temperature was 40ºC, and that of the transfer line and loop was 100ºC (Agilent Technologies, 1999).

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### Antioxidant Capacity

The antioxidant capacity of palm sugar solutions was evaluated by determination of their total phenolic content (TPC), 2, 2-diphenyl-1-picrylhyderazyl (DPPH) radical scavenging activity, and reducing power.

*Total Phenolic Content*

Total phenolic content (TPC) was determined spectrophotometrically according to the method described by Singleton *et al.* (1999). Aliquots (100 µL each) of sample (5, 10, 20, 30, and 40% palm sugar in distilled water) and gallic acid standards (50, 100, and 150 up to 500 mg/L) were oxidized with 500 µL, 10% (v/v) Folin–Ciocalteu reagent and neutralised with 400 µL, 7.5% aqueous sodium carbonate. The reaction mixture was incubated in the dark for 40 min at ambient temperature and the absorbance was measured at 765 nm. The total phenolic content was calculated from the calibration graph and expressed as mg gallic acid equivalent (GAE)/L of sample. Determinations were carried out in triplicate.

*2, 2-Diphenyl-1-Picrylhydrazyl (DPPH) Radical Scavenging Activity*

The DPPH radical scavenging activities of the sugar solutions (5, 10, 20, 30, and 40% palm sugar in distilled water) were determined according to the method of Tang *et al.* (2001). One mL of 0.2 mM 2, 2-diphenyl-1-picrylhydrazyl in absolute ethanol was placed in a test tube containing 4 mL of the sample. A control was prepared by adding 1 mL of DPPH solution to 4 mL of 70% ethanol. Following storage in the dark for 30 min, the absorbance was read at 517 nm.

Percentage free radical scavenging activity was calculated as follows:

$$\text{DPPH radical scavenging activity (\%)} = 1 - \frac{\textbf{Absorbance of sample at 517 nm}}{\textbf{Absorbance of control at 517 nm}}$$

*Reducing Power*

The reducing power was determined according to the method of Oyaizu (1986). Aliquots (100 µL) of the sugar solutions (5, 10, 20, 30, or 40% palm sugar in distilled water) were mixed with 250 µL, 200 mM sodium phosphate buffer (pH 6.6), and potassium ferricyanide (250 µL, 1%). The mixtures were incubated at 50 °C for 20 min. Trichloroacetic acid (250 µL of a 10% solution) was added to each mixture and 250 µL of this was mixed with 250 µL distilled water and 0.5 mL, 0.1% $FeCl_3$. Absorbance was measured at 700 nm. Ascorbic acid was used as the standard and results were expressed as mg % Ascorbic Acid Equivalent (Kamtekar *et al.*, 2014).

### Alpha-amylase inhibitory activity

Alpha-amylase inhibitory activity was determined as follows (Kamtekar *et al.*, 2014): A 500 µL aliquot of each palm sugar solution was incubated with 500 µL of an α-amylase solution (2 units/ml, obtained by dissolving 0.001 g of α-amylase in 100 ml of a 0.02 M sodium phosphate buffer - 6.7 mM sodium chloride mixture, pH 6.9) at an ambient temperature of 32 °C for 10 min. After incubation, 500 µL of a 1 % starch solution (prepared by dissolving 1 g of potato starch in 100 ml of distilled water with boiling and stirring for 15 minutes) was added and the mixture was incubated at 32° C for 10 minutes. After this, 1 ml of DNSA reagent was added to stop the reaction and the mixture was incubated in a hot water bath at 85ºC for 5 min. The reaction mixture colour changed to orange-red and was removed from the water bath and cooled to ambient temperature and made up to 5 ml with distilled water. A control was prepared by replacing the sample solution with buffer. Absorbance was measured at 540 nm. The α-amylase inhibitory activity was calculated as follows (Ranilla *et al.*, 2008):

$$\textbf{\% Inhibition} = \frac{A_{540}\,\text{(control)} - A_{540}\,\text{(sample)}}{A_{540}\,\text{(control)}} \times 100$$

### Statistical analysis

For non-chromatographic determinations, each experiment was replicated three times with comparable results. Results were averaged and expressed as Mean ± SD. $IC_{50}$ values were determined using Microsoft Excel 2007.

## III. Results and Discussion

The carbohydrate content of oil palm syrup and values for syrups derived from other tree saps are shown in Table 1. The total carbohydrate content of oil palm syrup was 67.73±0.72%. This was similar to the sugar content of syrup prepared from raffia (*Raphia* spp) sap (Oboh *et al.*, 2016), *Phoenix canariensis* sap (Luis *et al.*, 2012), and maple syrup derived from the sap of the sugar maple tree (*Acer saccharum*)

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**Table 1: Sugar content and dominant sugars of oil palm syrup compared with values for syrups prepared from other tree saps**

| Characteristic | *E. guineensis* (This study) | *Raphia* spp (Oboh *et al.*, 2016) | Maple (van den Berg *et al.*, 2015) | *Phoenix canariensis* (Luis *et al.*, 2012) | *Borassus flabellifer* (Strikaeo *et al.*, 2019) |
|---|---|---|---|---|---|
| **Carbohydrate content (g/100 g)** | 67.73 ±0.07 | 68.79 | 66.0-68.0 | 66.0 | 77.81±16 |
| **Content of dominant sugars (%)** | | | | | |
| **Glucose** | 75.69 | n.d. | 0.1-0.7 | 4.80 | 5.91±0.25 |
| **Fructose** | 19.31 | n.d. | 0.4-0.7 | 9.50 | 6.64±0.17 |
| **Sucrose** | 4.83 | n.d. | 65.1-67.1 | 37.8 | 65.26±0.73 |

The dominant sugars in oil palm syrup were glucose (75.69%) and fructose (19.31%) (Tables 1 and 2); sucrose constituted 4.83% and maltose 0.17%. Also found were trace amounts of galactose, ribose, xylose, arabinose, 6-deoxy hexose, rhamnose, the sugar alcohols, mannitol and sorbitol, and the fructose derivative, 5-hydroxymethylfurfural (Table 2). Comparison with the composition of fresh sap reported by Eapen (1971), which has sucrose as its dominant sugar, and glucose and fructose as minor constituents, indicates that there was inversion during the preparation of the syrup, due to acid hydrolysis of sucrose present in the palm sap, a medium characterised by a low pH value (Oboh & Imafidon, 2018). The sugar composition was different from published values for syrups prepared from other tree saps, including maple (Van der Berg *et al.*, 2015), *Phoenix canariensis* (Luis *et al.*, 2012), and *Borassus flabellifer* (Sukaeo *et al.*, 2019) which had sucrose as the dominant sugar (Table 1). Inversion also gave a product with a honey-like taste and consistency, in keeping with similarity in the sugar content and composition of the palm syrup and honey (Oboh *et al.*, 2016). Glucose, fructose, and sucrose are common natural sweeteners. Sugar alcohols are edible products, which are used as food additives due to their noncariogenicity and health promoting properties. They have lower caloric content, low glycaemic index and insulin response when compared with similar amounts of fructose, glucose, or sucrose, producing significantly lower postprandial glucose response (Wheeler & Pi-Sunyer, 2008). Hydroxymethyl furfural (5- HMF), a decomposition product of fructose is formed during storage or heat treatment of foods, such as honey and palm syrup, and is an indicator of the extent of such treatment; it also contributes to the flavour of foods and functions as an antioxidant (Bogdanov, 2009).

**Table 2: Composition of oil palm syrup and sap sugars**

| **Sugar** | **Palm syrup (g/100 g)** | **Palm syrup sugar composition (wt %)** [a] | **Palm sap sugar composition (g/100 ml)** [b] | |
|---|---|---|---|---|
| | | | 0 hr[c] | 3 hr[d] |
| Glucose | 35.35292 | 75.69 | 4.22 | 6.12 |
| Fructose | 9.01946 | 19.31 | 4.57 | 9.37 |
| Sucrose | 2.25671 | 4.83 | 91.21 | 84.51 |
| Maltose | 7.89716e-2 | 0.17 | - | - |
| Raffinose | - | - | - | - |
| Galactose | 1.52928e-4 | T[e] | | |
| Ribose | 2.98073e-7 | T | | |
| Xylose | 7.63299e-5 | T | | |
| Arabinose | 1.07166e-4 | T | | |
| Rhamnose | 8.61879e-6 | T | | |
| Mannitol | 7.66556e-5 | T | | |
| Sorbitol | 4.34245e-5 | T | | |
| 5-HMF | 5.07131e-4 | T | | |
| Total | **46.70903** | | | |

[a] **Wt% = Amount of each constituent in syrup (g/100 g) divided by the total amount (46.70903 g/100 g) x 100**

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**[b]Calculated from Eapen (1971). [c]Time = 0; [d]time = after 3 hr of storage at 36-37°C. [e]Trace: Less than or equal to 5.07131e-4 mg/100 g).**

The composition of oil palm syrup organic acids is given in Table 3. The organic acid composition of palm sap and grape wine acids (Karamoko *et al.,* 2016; Eiseman, 2019) are included for comparison. Malic and tartaric were the dominant organic acids found in palm syrup (this study); these also constitute the major acids in oil palm sap (Karamoko *et al.,* 2016) and grape wine (Eiseman, 2019). Other major organic acids present in palm syrup were lactic and acetic. Citric acid was a minor constituent, similar to its concentration in palm sap (Karamoko *et al.,* 2016) and grape wine (Eiseman, 2019). Propionic and fumaric acids were minor constituents also, and only trace amounts of pyruvic, iso-butyric, succinic and n-valeric acids were present in the oil palm syrup.

**Table 3: Composition of oil palm sugar organic acids in comparison with published values for palm sap and grape wine**

| Acid | Amount in syrup (mg/100 g) | Palm syrup acids [a] (wt%) | Palm sap acids[b] (wt%) | Grape wine acids[c] (wt%) |
|---|---|---|---|---|
| Formic | 3.209686e-4 | T[d] | - | - |
| Acetic | 21.21872 | 12.71 | 7.87 | 1.93-4.31 |
| Propionic | 3.10621e-1 | 0.19 | - | - |
| Pyruvic | 2.03306e-4 | T | - | - |
| Lactic | 27.30945 | 16.36 | 11.81 | 3.45-3.86 |
| Iso-butyric | 1.74257e-4 | T | - | - |
| n-butyric acid | 1.73053e-4 | T | - | - |
| Oxalic | 16.38018 | 9.81 | 7.87 | - |
| Fumaric | 1.24764 | 0.75 | 0.79 | - |
| Malic | 59.70026 | 35.76 | 39.37 | 34.48-38.61 |
| Succinic | 3.346809e-4 | T | - | 8.62-15.44 |
| n-Valeric | 2.12425e-4 | T | - | - |
| Tartaric | 36.48330 | 21.86 | 24.41 | 38.61-43.10 |
| Citric | 4.27098 | 2.56 | 3.94 | 1.54-6.07 |
| **Total** | **166.92234** | | | |

**[a] Weight percent = Amount of each constituent of the syrup (g/100 g) divided by the total amount (166.92234 g/100 g)**

**[b]Calculated from Karamoko *et al*. (2016); [c]Eiseman (2019); [d]Trace: <3.5 x $10^{-4}$ mg/100 g**

Organic acids contribute greatly to the organoleptic properties of grapes and wines (Eiseman, 2019), palm sap, as well as palm syrup, and are responsible for their acidity. Oxalic acid constituted about one-tenth of palm syrup organic acids, similar to its reported concentration in palm sap (Karamoko *et al.*, 2016). Oxalic acid and oxalates are present in many plants and in significant amounts particularly in rhubarb, tea, spinach, parsley and purslane, but are regarded as antinutrients due to their ability to bind to calcium and prevent its absorption in humans (Dolan *et al.*, 2010).

Sugar and organic acid content, and composition suggest that oil palm syrup may be a suitable concentrate for dilution and formulation to produce refreshing non-alcoholic beverages (Oboh & Imafidon, 2018).

The phenolic acids syringic, vanillic, gallic, and ferulic were the major phenolic compounds found in the palm syrup (Table 4). P-coumaric, p-hydroxybenzoic, and caffeic, occurred in modest concentrations. Sinapinic and protocatechuic acids were minor constituents. The syrup had modest content of catechin and myricetin; epicatechin, naringenin, kaempferol, and quercetin were minor constituents. Nineteen other phenolic compounds were present in trace concentrations (Table 4).

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**Table 4: Composition of palm syrup phenolic compounds**

| Phenolic compounds | Amount (mg/100 g) | wt% of total[a] |
|---|---|---|
| Catechin | 25.58676 | 5.03 |
| Protocatechuic acid | 2.95329e-1 | 0.06 |
| p-coumaric acid | 17.38336 | 3.42 |
| Epicatechin | 7.69062e-2 | 0.02 |
| Vanillic acid | 124.41698 | 24.48 |
| o-coumaric acid | 1.34537e-4 | T[b] |
| p-hydroxybenzoic acid | 14.94790 | 2.94 |
| Gallic acid | 91.11278 | 17.93 |
| Caffeic acid | 13.39811 | 2.64 |
| Ferulic acid | 55.31086 | 10.88 |
| Syringic acid | 146.92122 | 28.91 |
| Piperic acid | 1.17944e-4 | T |
| Sinapinic acid | 1.74359 | 0.34 |
| Apigenin | 9.27198e-3 | T |
| Naringenin | 7.67909e-1 | 0.15 |
| Naringenin chalcone | 9.40139e-4 | T |
| Genistein | 7.31113e-5 | T |
| Shogaol | 2.09428e-4 | T |
| Kaempferol | 1.24053 | 0.24 |
| Luteolin | 1.42710e-4 | T |
| Capsaicin | 4.72893e-5 | T |
| Epigallocatechin | 9.52009e-3 | T |
| Ellagic acid | 2.24901e-4 | T |
| Gingerol | 3.20188e-5 | T |
| Quercetin | 2.47203 | 0.49 |
| Isorhamnetin | 1.13127e-4 | T |
| Myricetin | 12.57611 | 2.47 |
| 3-o-caffeoylquinic | 2.59121e-6 | T |
| Chlorogenic acid | 2.92429e-5 | T |
| Rosmarinic acid | 4.12109e-5 | T |
| Curcumin | 1.66534e-5 | T |
| 4-o-methyl-epi-gallocatechin | 7.86211e-5 | T |
| Phenyl-6’-o-malonyl-beta-D – glucoside | 1.11282e-4 | T |
| Epi-gallocatachin-3-o-gallate | 4.32310e-6 | T |
| **Total** | **508.27148** | **100** |

**[a] Weight percent = Amount of each constituent of the syrup divided by the total amount (508.27148). [b]Trace amount: < 7.69062e-2 mg/ 100 g**

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The beneficial biological activities and health benefits of polyphenols are generally attributed to both specific and non-specific mechanisms, the latter which is dependent on a broad antioxidant activity, and the former (i.e., specific mechanisms) which include enzyme inhibition and interaction with key signalling proteins. Some key enzymes inhibited include the following: α-amylase and α-glucosidase (type 2 diabetes mellitus, T2DM), angiotensin converting enzyme (hypertension), and pancreatic lipase (obesity) (Fraga *et al.,* 2010; Anhe *et al*., 2013; Gonçalves & Romano, 2017). In addition, phenolic compounds are used as flavouring in foods (for example, vanillic acid), and contribute to the taste, colour, and mouthfeel of beverages (Narukawa *et al,* 2010; Kennedy *et al.,* 2017).

Syringic acid is a powerful antioxidant due to the 2, 5- methoxy groups attached to its aromatic ring, and exhibits a broad spectrum of biological effects, resulting in various health benefits. It is an effective free radical scavenger, alleviates oxidative stress markers, and exhibits antimicrobial, anti-inflammatory, key enzyme inhibitory, and neuro-, and hepatoprotective activities, among others (Cheemanapalli *et al.,* 2018). These characteristics are shared by other phenolic acids, including vanillic, gallic, ferulic, p-coumaric, caffeic, p-coumaric acid, and p-hydroxybenzoic (Zduńska *et al.,* 2018; Kumar & Goel, 2019; Ashwini *et al.,* 2021).

*In vivo*, α-amylase present in saliva and pancreatic juice cleaves internal α-1, 4 bonds of the component amylose and amylopectin of dietary carbohydrate (starch) to oligosaccharides and disaccharides, which are ultimately converted into glucose by α-glucosidase. Liberated glucose is then absorbed and may result in postprandial hyperglycaemia in T2DM. The inhibition of these enzymes delays the process of carbohydrate hydrolysis and absorption, thereby decreasing significantly, postprandial increase in blood glucose levels after consumption of a carbohydrate-rich meal (Kim *et al.*, 2000; Ali *et al*., 2006; Kwon *et al.*, 2006; Oboh *et al*., 2010). The phenolic compounds involved in the inhibition of these enzymes, include caffeic acid, p-coumaric acid, ferulic acid, luteolin, myricetin, quercetin, epigallocatechin gallate, and epigallocatechin (Hanhineva *et al*., 2010, Kumar & Goel, 2019) which were found in the oil palm syrup (Table 4).

Dietary phenolic compounds can modulate glucose homeostasis also, by decreasing the postprandial glucose response through inhibition of SGLT 1 (sodium-dependent glucose transporter 1) and GLUT 2 (glucose transporter 2), which transport glucose across the intestinal brush border membrane. Generally, the aglycones quercetin, myricetin, and apigenin have been reported to strongly inhibit GLUT 2, while quercetin-3-O-glycoside has been demonstrated to be more effective in the inhibition of SGLT 1. In addition, epigallocatechin as well as epicatechin and epigallocatechin gallates were observed to inhibit both transporters (Pico & Martinez, 2019). These compounds were present in the oil palm syrup (Table 4). In addition, other polyphenols found in the syrup, including epicatechin, epi(gallo)catechin gallate, quercetin, apigenin and luteolin, may improve insulin secretion and alleviate type-2 diabetes mellitus (T2DM), by protecting insulin secreting pancreatic cells from glucotoxicity (Hanhineva *et al*., 2010).

Obesity is associated with a low-grade inflammatory state, which leads to insulin resistance, and subsequently, T2DM (Freedman *et al*., 1991; Marette, 2002; Wellen *et al.*, 2003; Weisberg *et al.*, 2003; Xu *et al*., 2003). Polyphenols may protect against obesity-linked T2DM through anti-inflammatory effects (Rodriguez-Sanabria *et al*., 2010; Kostyuk *et al*., 2011; Vitaglione *et al.,* 2010). Certain polyphenols present in the oil palm syrup (Table 3), namely curcumin, capsaicin, gingerol, catechins and quercetin, have been shown to exert anti-inflammatory effects by directly blocking mitogen-activated protein kinase (MAPK) pathways, $NF_KB$ activity, and the expression of inflammatory cytokines (Anhe *et al*., 2013).

Titrable acidity, pH, vitamin C content, total phenolic content (TPC), reducing power, and α-amylase inhibitory activity of various concentrations of oil palm syrup are shown in Table 5. The various sugar solutions had low pH values due to their content of organic acids and vitamin C. The low pH of oil palm syrup and its acidity would inhibit microbial growth (Oboh *et al.*, 2016), with beneficial implications for the preservation and shelf life of the product. The pH range was similar to published values for the functional fruit juices pomegranate (2.93-3.20), Concord grape juice (2.8-3.0), blueberry juice (3.11-3.30), cranberry juice (2.30-2.50), and açai juice (2.05-3.50) (Seeram *et al*., 2008). Titrable acids, as well as vitamin C provide a desirable tart flavour in foods, and their presence gives the distinct impression of fresh fruit (Schmidt, 1983, Miles, 1987). Vitamin C is an antioxidant, which acts by donating hydrogen atoms to molecular oxygen. This ability to scavenge oxygen protects the flavour as well as the colour of an array of beverages (Miles, 1987). This vitamin prevents oxidation of the $Fe^{2+}$ cofactor of prolyl hydroxylase, the prolyl residue-hydroxylating enzyme in collagen synthesis, thereby playing a key role in protection against scurvy. Increased intake of this vitamin is also associated with a reduced risk of chronic diseases such as cancer, cardiovascular disease, and cataract, probably through antioxidant mechanisms (Carr & Frei, 1999).

*In vitro* TPC, DPPH radical scavenging activity, and α-amylase inhibitory activity values for the oil palm syrup were high at all the concentrations examined; *in vitro* reducing power was modest. As their sugar content increased, the solutions also became more acidic, exhibiting increasing reducing power and α-amylase inhibitory activity, and decreasing DPPH radical scavenging activity. The decrease in DPPH radical scavenging may be associated with the increasing acidity and/or metal ion concentration (Pękal & Pyrzynska, 2015). $IC_{50}$ value of 25.3 g/ml for reducing power was modest, indicating moderate activity, while that for DPPH radical scavenging activity (2.88 g/ml) was low, indicating high activity. These and the high total phenolic content values at the various

sugar concentrations indicate considerable antioxidant capacity. The very low $IC_{50}$ value of 4.5 x $10^{-4}$ g/ml for *in vitro* α-amylase inhibitory activity suggests a high potential for the use of oil palm syrup as a functional ingredient in various preparations for the control of postprandial blood glucose concentration.

**Table 4: Chemical, nutritional, antioxidant capacity and α-amylase inhibitory activity of various concentrations of oil palm syrup**

| **Conc. of palm syrup (g /100ml distilled water)** | **Titrable acidity (% as lactic acid)** | **pH** | **Vitamin C (mg %)** | **TPC (mg GAE[a]/L solution)** | ***In vitro* reducing power (mg % AAE[b] ascorbic acid equivalent)** | ***In vitro* DPPH radical scavenging activity (%)** | ***In vitro* α-amylase inhibitory activity (%)** |
|---|---|---|---|---|---|---|---|
| **5** | 0.31 ±0.03 | 3.20±0.06 | 7.67±0.25 | 70.82±2.31 | 7.86±0.742 | 84.37±1.06 | 78.51±1.07 |
| **10** | 0.46 ±0.03 | 3.18±0.05 | 15.33±0.50 | 126.50±0.35 | 10.35±0.474 | 82.57±0.57 | 80.66±1.80 |
| **20** | 0.83 ±0.02 | 3.12±0.04 | 30.67±1.01 | 218.90±0.92 | 10.70±0.014 | 81.75±2.17 | 83.31±1.42 |
| **30** | 1.13 ±0.02 | 3.08±0.01 | 46.00±1.51 | 344.80±5.09 | 10.90±0.238 | 70.90±1.14 | 84.93±0.93 |
| **40** | 1.49 ±0.04 | 3.00±0.01 | 61.34±2.01 | 510.20±0.00 | 12.05±0.124 | 67.06±0.80 | 87.65±2.23 |
| **$IC_{50}$ (g/ml)** | | | | | 25.28 | 2.88 | 4.5 x $10^{-4}$ |

**[a]Gallic Acid Equivalent; [b]Ascorbic Acid Equivalent**

## IV. Conclusion

A syrup prepared from African oil palm (*Elaeis guineensis*) sap exhibited adequate chemical properties, nutritional and bioactive composition, and *in vitro* functionality for possible use as a nourishing natural antioxidant, anti-inflammatory and post-prandial blood glucose-regulatory sweetener and flavouring.

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