

Nutritional composition and pharmacological activity of *Musa balbisiana* Colla seed: an insight into phytochemical and cellular bioenergetic profiling

Nonibala Gurumayum

Institute of Advanced Study in Science and Technology

Partha Pratim Sarma

Institute of Advanced Study in Science and Technology

Puspanjali Khound

Institute of Advanced Study in Science and Technology

Uttam Kumar Jana

Saha Institute of Nuclear Physics

Rajlakshmi Devi (✉ rajlakshmi@iasst.gov.in)

Institute of Advanced Study in Science and Technology

Research Article

Keywords: Nutritional value, oxidative stress, antioxidant, glycation, glycolysis

Posted Date: April 20th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2830100/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Musa balbisiana Colla, belonging to the family *Musaceae*, is well-known for its nutritional and pharmacological properties. The present study analyses the phytochemical content and evaluated the nutritional, antioxidant, anti-glycation, α -amylase, and α -glucosidase inhibition potential of *M. balbisiana* seed. In addition, bioenergetic profiles of the bioactive fraction of *M. balbisiana* seeds against oxidative stress-related mitochondrial and cellular dysfunction were studied using XFe24 extracellular flux analyzer for the first time. *M. balbisiana* seeds have high nutritional values with ample amounts of carbohydrates, starch, protein, and minerals (Ca, Na, Mg, Cu, Fe, and Zn). Bioactivity-guided fractionation of *M. balbisiana* seed methanolic extract yield ethyl acetate, n-butanol, and water fraction. The ethyl acetate fraction (EAF) showed the highest antioxidant, anti-glycation, and phytochemical content as compared to other fractions. EAF also showed lower α -amylase inhibition and higher α -glucosidase inhibition activity. GCMS analysis revealed the presence of 14 phytochemical compounds that have not been reported previously from *M. balbisiana* seed. A strong correlation between the biological activities and total phenolic/tannin content was observed. In addition, *M. balbisiana* seeds improved the bioenergetic profiles of free fatty acid-induced oxidative stress with a concomitant increase in ATP production, respiratory and glycolytic capacity. Therefore, *M. balbisiana* seed can be a natural supplement to boost antioxidant levels and fight against oxidative stress and non-enzymatic glycation.

Introduction

Antioxidant-rich fruits and fruits by-products promote good health by lowering the risk of non-communicable diseases such as diabetes, cancer, atherosclerosis and neurodegenerative disorders [1, 2]. Such antioxidants protect against oxidative stress by inhibiting the formation of reactive oxygen species or neutralizing free radicals [3]. Fruits contain significant carbohydrates, dietary fiber, protein, vitamins, amino acids and bioactive phytoconstituents [4]. In addition, micronutrients such as sodium, magnesium, zinc, iron, manganese and calcium are also enriched in fruits [5]. Banana is widely consumed worldwide, with global production of 114 million tonnes in 2017, among which India is the major producer with 29 million tonnes per year [6]. There are more than 80 *Musa* species belonging to the *Musaceae* family and over 1000 triploid or tetraploid cultivars obtained from the crossing of two diploid species, *M. balbisiana* (BB) and *M. acuminata* (AA) [7]. *Musa balbisiana* Colla is a wild species of banana that is underappreciated for its presence of seeds. It is distributed across tropical and subtropical areas from Southeast Asia to the Pacific. In India, *M. balbisiana* is widely distributed in western ghats, Andaman and Nicobar Island, and north-eastern states (Assam), where it has been incorporated with Assamese social culture since time immemorial [8].

Banana has been used to remedy cough and cold, ulcers, diarrhea and wound healing [2]. The pseudostem and flower are consumed as vegetables and it is believed to treat diabetes, fever, seizures and leprosy. Other parts like roots, peel and seeds are used for alleviating digestive disorders [9]. *M. balbisiana* fruit pulp is rich in both macronutrients and micronutrients such as carbohydrates, starch, protein, sodium, potassium, calcium, magnesium, zinc and iron [10]. Different parts of *M. balbisiana* have been reported for medicinal benefits with significant amounts of bioactive compounds such as gallic acid, epicatechin, rutin, chlorogenic acid, quercetin and apigenin [2, 11]. Polyphenols-rich ripe pulp of *M. balbisiana* has cardioprotective properties and ameliorates cardiac hypertrophy through antioxidant and anti-inflammatory activities [12]. Apiforol, a flavanol compound isolated from the seeds of *M. balbisiana*, exhibited significant α -amylase and α -glucosidase inhibitory potential and facilitated glucose uptake in the cells [13]. Various mixtures of fatty esters of phytol and n-alkanols, β -sitosterol, stigmasta-5,22E-dien-3 β -ol, and epiafzelechin are reported from *M. balbisiana* seeds [14].

Apart from these, there are no detailed reports on the study of the nutritional and biological properties of seeds and phytoconstituents present in *M. balbisiana* seeds. Therefore, the present study investigates the bioactive compounds present in *M. balbisiana* seeds by GC-MS and their nutritional, antioxidant, anti-glycation, α -amylase and α -glucosidase inhibition potential. The correlation between phytochemical content and biological properties was also studied. In addition, the bioenergetic profiles are estimated by monitoring OCR and ECAR using XFe24 extracellular flux analyzer to understand the protective effect of *M. balbisiana* seeds against oxidative stress-related mitochondrial and cellular dysfunction.

Materials And Methods

The materials and methods section are presented as supplementary online resource.

Results And Discussions

Proximate Analysis of *Musa balbisiana* Seed

Seed constitutes about 10.4 % of the total weight of *Musa balbisiana* fruit. The moisture and ash contents are 9.02 ± 0.05 % and 7.22 ± 1.1 %, respectively. Carbohydrates were the major macronutrient present followed by protein (Table S1). The total carbohydrate content was 27.0 ± 1.09 g/100 g dry weight. Of these, reducing sugar and starch content was 19.6 ± 0.28 g/100 g and 5.27 ± 1.03 g/100 g, respectively. The total carbohydrate content was found to be lower than the unripe banana flour (*Musa acuminata*) [4] but higher than the raw pulp of *Musa balbisiana* [10]. These might be due to the differences in the moisture content of the samples, where the seed and unripe banana flour have 9.02 % and 6.9 % moisture content, and the raw pulp has more than 70 % [4, 10]. Carbohydrates present in bananas are reported to consist of dietary fiber and resistant starch that can reduce post-prandial glycemic index, and promote colonic fermentation followed by the production of SCFA [15]. The total protein

content of the seed (3.09 ± 0.97 g/100 g) was lower than unripe banana flour [4]. As reported by Solis-Badillo et al., the protein content of bananas decreased with the increase in the maturity of the fruit [16]. Micronutrients have an important role in promoting health despite its requirement in small quantities and a diet rich in certain micronutrients helps combat malnutrition [4]. Among the minerals present in *M. balbisiana* seed, Ca exhibits the highest concentration (17.87 ± 0.7 mg/100 g) followed by Mg (14.53 ± 0.49 mg/100 g), Na (8.96 ± 0.22 mg/100 g), and Fe (4.7 ± 1.17 mg/100 g), respectively (Table S1). Ca, Na and Fe content was higher in *M. balbisiana* seed as compared to Berangan and Rasthali cultivars of Malaysian banana, however, Mg content was lower [17]. Cu (0.53 ± 0.04 mg/100 g), Zn (0.58 ± 0.08 mg/100 g), and Mn (0.25 ± 0.06 mg/100 g) content of *M. balbisiana* seeds were like those reported from ripe *M. balbisiana* pulp (0.06 ± 0.01 mg/100 g, 0.53 ± 0.03 mg/100 g and 0.21 ± 0.02 mg/100 g respectively) [10].

Antioxidant Activity of *M. balbisiana* Seed

Oxidative stress occurs when the production of reactive oxygen species exceeds detoxification by the antioxidant defence system. Therefore, screening of antioxidant molecules that can scavenge or stop the production of ROS and subsequently decrease oxidative stress is essential. The antioxidant activity of *M. balbisiana* seed methanolic extract (ME) was measured using DPPH, ABTS, FRAP and phosphomolybdenum assay. Using a single method to determine the antioxidant capacity is inefficient since antioxidants act in different mechanism either by donating an electron or hydrogen [3]. In the DPPH assay, EAF showed the highest antioxidant activity with an IC_{50} value of 44.7 ± 0.47 μ g/ml followed by nBF (56.9 ± 0.14 μ g/ml), ME (80.6 ± 0.15 μ g/ml) and WF (183.4 ± 0.6 μ g/ml). However, EAF scavenged 3.7-fold lower than the standard ascorbic acid (IC_{50} 11.8 ± 0.14 μ g/ml) as shown in Table 1. In ABTS assay, the standard ascorbic acid exhibited the highest antioxidant capacity (IC_{50} 10.9 ± 0.38 μ g/ml), which are not significant from EAF (13.8 ± 1.2 μ g/ml). DPPH and ABTS radical scavenging activity of *M. balbisiana* seed was higher than previously reported from *M. balbisiana* pulp, where the most active fraction of pulp scavenged 50 % free radicals at 47.4 ± 2.4 μ g/ml and 69.9 ± 5.7 μ g/ml for DPPH and ABTS assay, respectively [10]. A consistent result was observed in FRAP and phosphomolybdenum assay where EAF showed the highest ferric-reducing capacity (IC_{50} 73.6 ± 0.28 μ g/ml) and molybdenum reduction (IC_{50} 55.4 ± 1.10 μ g/ml) followed by nBF, ME and WF. Limited data on the antioxidant potential of *M. balbisiana* seeds evaluated by DPPH assay was available [18]. There are no previous studies regarding ABTS, FRAP, and phosphomolybdenum assay of *M. balbisiana* seed.

Table 1 IC_{50} values of antioxidant, anti-glycation and enzyme inhibition activity of *M. balbisiana* seed extract and its fractions

	DPPH	ABTS	FRAP	Phosphomolybdenum	BSA-Fructose	BSA-Methylglyoxal	Arginine-methylglyoxal	* α -amylase	* α -glucosidase
ME	82.0 ± 2.5^d	40.5 ± 1.2^c	136.6 ± 1.3^d	102.7 ± 4.5^d	191.2 ± 1.5^d	858.9 ± 2.1^d	903.9 ± 2.5^d	12.4 ± 0.03^a	28.2 ± 1.0^a
EAF	44.8 ± 1.3^b	13.8 ± 1.2^a	74.6 ± 1.6^b	55.4 ± 1.1^b	110.2 ± 0.2^a	373.7 ± 3.1^b	490.1 ± 3.2^b	210.5 ± 1.1^c	83.9 ± 0.8^b
nBF	58.1 ± 4.2^c	22.9 ± 0.9^b	104.3 ± 0.7^c	90.5 ± 3.0^c	140.1 ± 0.9^c	756.2 ± 2.2^c	804.1 ± 1.9^c	6.7 ± 0.4^a	20.6 ± 0.6^a
WF	183.4 ± 0.6^e	100.2 ± 5.5^d	274.9 ± 4.0^e	191.0 ± 3.4^e	296.6 ± 0.43^e	No Activity	1629.8 ± 8.5^e	29.8 ± 0.8^b	93.3 ± 0.8^c
Ascorbic acid	11.8 ± 0.1^a	10.9 ± 0.4^a	21.0 ± 1.1^a	28.4 ± 0.1^a					
Aminoguanidine					129.9 ± 0.1^b	360.4 ± 1.4^a	291.0 ± 4.0^a		
Acarbose								5.96 ± 0.02^a	23.8 ± 1.3^a

*Inhibition assay. ME- methanol extract, EAF- ethyl acetate fraction. nBF- n-butanol fraction, WF- water fraction, BSA- bovine serum albumin, mean $\pm$ SD. The mean in the same column with same superscript are not significantly different ($p > 0.05$) as separated by Bonferroni's multiple comparison test.

Anti-glycation Activity of *M. balbisiana* Seed

Under oxidative stress and hyperglycaemic conditions, proteins are non-enzymatically glycosylated, forming AGEs [19]. Here, we mimic the three stages (initial, middle and late) of glycation by BSA-Fructose, BSA-methylglyoxal and Arginine-methylglyoxal models, respectively. EAF exhibited anti-glycation activity against all stages of glycation with IC_{50} values lower than crude extract and other fractions. In BSA-fructose assay, the ME, EAF, nBF and WF inhibited 50 % glycation at concentration of 191.2 ± 1.5 , 110.2 ± 0.2 , 140.1 ± 0.9 and 296.6 ± 0.43 $\mu\text{g/ml}$ respectively as shown in Table 1. The highest inhibition was observed in case of EAF, which is significantly higher ($p < 0.001$) than the standard, aminoguanidine. *M. balbisiana* seeds were previously reported for inhibition of protein glycation by glucose more effectively than ascorbic acid with IC_{50} value of 86.48 ± 0.751 $\mu\text{g/ml}$ [13]. Protection of fructose-mediated protein glycation is vital in preventing AGE-associated diseases, as fructose is ten times more reactive than glucose [20]. Fructose can be generated *via* a polyol pathway under high blood glucose level or through diet, which in turn glycate the proteins non-enzymatically to form AGE [19]. In the BSA-methylglyoxal model, EAF showed the highest inhibition (IC_{50} - 373.7 ± 3.1 $\mu\text{g/ml}$) among all samples followed by nBF, ME, and WF. Aminoguanidine (IC_{50} - 360.4 ± 1.4 $\mu\text{g/ml}$) was more effective in controlling the intermediate stage of glycation than EAF ($p < 0.05$). According to Wang et al., arginine and lysine residues were prone to glycation by methylglyoxal that react with arginine to form an AGE called argpyrimidine, which accumulation in the lens causing inflammation and cataracts [20]. In the arginine-methylglyoxal assay, EAF inhibited 50% generation of fluorescent AGEs at the concentration of 490.10 ± 3.18 $\mu\text{g/ml}$ (Table 1). The anti-glycation activity increased in the order $WF < ME < nBF < EAF < AG$. Furthermore, EAF lowered the initial stages of glycation more effectively than the standard drug (aminoguanidine). However, with the advancement in glycation, the effectiveness at lower concentrations decreases. Thus, EAF can be used as an early glycation inhibitor.

α -amylase and α -glucosidase Inhibition Activity of *M. balbisiana* Seed

Inhibition of carbohydrate hydrolyzing enzymes is considered effective in controlling post-prandial hyperglycaemia [19]. *M. balbisiana* seed extract and its fractions have potent α -amylase inhibition activity. nBF had highest inhibition activity with IC_{50} - 6.7 ± 0.4 $\mu\text{g/ml}$, which is not significantly different from the therapeutic drug acarbose (IC_{50} - 5.96 ± 0.02 $\mu\text{g/ml}$) and crude methanol extract (IC_{50} - 12.4 ± 0.03 $\mu\text{g/ml}$) as shown in Table 1. Although EAF exhibited the highest antioxidant and antiglycation activity, it showed the least α -amylase inhibition potential (IC_{50} - 210.5 ± 1.1 $\mu\text{g/ml}$) as compared to other fractions. Furthermore, α -glucosidase inhibition potential of *M. balbisiana* seed was evaluated and nBF has the highest inhibition and lowest IC_{50} (20.6 ± 0.6 $\mu\text{g/ml}$), which is lower than acarbose (IC_{50} - 23.8 ± 1.3 $\mu\text{g/ml}$) and ME (IC_{50} - 28.2 ± 1.0 $\mu\text{g/ml}$) (both $p > 0.05$). The α -glucosidase inhibition by WF (IC_{50} - 93.3 ± 0.8 $\mu\text{g/ml}$) is higher than EAF (IC_{50} - 83.9 ± 0.8 $\mu\text{g/ml}$). Commercial drugs like acarbose have strong α -amylase inhibition property and less α -glucosidase inhibition resulting in the fermentation of undigested carbohydrates raising different side effects like flatulence, bloating, diarrhoea and abdominal discomfort [19]. Therefore, drugs with strong α -glucosidase inhibition and low inhibition of α -amylase are more desirable and EAF have these criteria. α -amylase and α -glucosidase inhibition potential presented in this study was higher than those reported from ethanol, water, hexane and acetone extracts of the *M. balbisiana* seeds [13]. This might be due to the differences in the use of extracting solvents, where choosing solvents that can extract a high quantity of phytochemicals is one of the critical factors in obtaining samples with higher biological activity [21].

Phytochemical Content of *M. balbisiana* Seed

The highest phenolic content was observed for the EAF (61.53 ± 0.11 mg GAE/g) and nBF (61.25 ± 0.21 mg GAE/g) followed by ME (59.5 ± 0.28 mg GAE/g) and WF (56.4 ± 0.71 mg GAE/g) as shown in Table S2. However, TFC was significantly varied among the tested samples. EAF has the highest TFC (6.00 ± 0.04 mg QE/g) followed by nBF, ME and WF ($p < 0.001$). TPC and TTC of *M. balbisiana* seed was higher than root, stem and inflorescence part reported by Kalita et al., but lower than the pulp [10, 22]. In consistent with TPC and TFC, total tannin content was significantly high in EAF (59.43 ± 0.55 mg CE/g, $p < 0.001$). Tannins are particularly rich in fruits, nuts, vegetables and beverages such as tea, wine and cider. Even though tannins have been misunderstood as anti-nutrients that compromise proteins and mineral absorption, recent studies reported several biological properties including antioxidant, anti-microbial, and anti-inflammatory [23].

Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The therapeutic properties of plants are due to numerous non-nutritive secondary metabolites produced to protect themselves. Therefore, identification of bioactive molecules having biomedical applications is important. GC-MS chromatogram of EAF displayed 76 compounds with matching spectra with NIST library (Fig. S1). To improve the accuracy of compound identification, compounds with a higher mass spectral similarity score (≤ 90) with reference library are selected. As shown in Table S3, 14 compounds were identified from EAF that exhibited various phytochemical activities. The major phytoconstituents present in EAF were hexadecanoic acid, methyl ester (12.89 %); 9-Octadecenoic acid, methyl ester, (E)- (4.93 %); methyl stearate (4.85 %); 13-docosenamide, (Z)- (4.56 %); 9,12-octadecadienoic acid (Z, Z)-, methyl ester (4.41 %); and γ -sitosterol (3.39 %). n-hexadecanoic acid, 2,4-di-tert-butylphenol, hexadecanoic acid methyl ester, and 1-nonadecene have been previously identified from *Musa paradisiaca* fruit pulp and reported for their antioxidant and antibacterial properties [24]. The major compound, hexadecanoic acid methyl ester or methyl palmitate is a saturated fatty acid belonging to the class fatty acid methyl ester. It has been reported for its antioxidant, hypocholesterolemic, hemolytic, anti-fungal, 5- α reductase inhibitor and anti-microbial activity [25]. There are reports of plant phytosterol being more effective in lowering LDL cholesterol in patients who cannot tolerate standard drugs like statin [9, 11]. Thus, the biological activity of EAF might be due to the presence of these compounds.

Correlation Between Phytochemical Content and Biological Activity

Pearson's Correlation analysis is reported in the supplementary online resource along with Table S4.

Cell Viability Assay

The cell viability assay is reported in the supplementary online resource.

EAF Improves FFA-induced Mitochondrial Dysfunction

Free fatty acid (FFA) induces oxidative stress by increasing the generation of ROS along with hampering mitochondrial and cellular function [26]. Therefore, this study evaluated the effect of EAF on mitochondrial function and cellular bioenergetics under FFA-induced oxidative stress by directly measuring OCR in real-time on XFe extracellular flux analyzer (Fig. S1 a). Basal respiration of FFA-treated cells was significantly reduced ($p < 0.01$) due to the oxidative stress induced by FFA (Fig. S1 b). Treatment with FFA significantly decreased MR ($p < 0.001$), ATP production ($p < 0.001$) and SRC, ($p < 0.01$) (Fig. S1 c-e). MR showed the maximum rate of respiration cells could achieve by oxidizing substrates under physiological energy demand. SRC is the cell fitness indicator and offers mitochondrial capacity to respond to an energetic request by producing more ATP [27]. The incapacity of the FFA-treated cells to respond to an energetic demand was restored after EAF pre-treatment. The lower concentration of EAF (25 $\mu\text{g/ml}$) was more effective in protecting against mitochondrial dysfunction by increasing ATP production, MR and SRC than the higher concentration, EAF 50 $\mu\text{g/ml}$ and the therapeutic drug, metformin (60 μM). This is the first study to report real-time OCR data of *M. balbisiana* seeds using an XFe extracellular flux analyser.

EAF Improves FFA-induced Glycolysis Stress

Changes in the glycolytic pathway or abnormal glycolysis impact mitochondrial functions and generate endogenous dicarbonyl compounds, which might lead to neurodegenerative diseases and aging [28]. Cells can switch between glycolysis and oxidative phosphorylation depending on their energy demand. The glycolysis stress test profile is shown in Fig. S2 a. FFA-treated cells were not able to undergo glycolysis effectively even after injecting saturating amount of glucose (Fig. S2 b). FFA treatment induced oxidative stress as well as hampered cell ability to shift the energy production from mitochondrial respiration to glycolysis after oligomycin treatment. This treatment affected both glycolytic capacity and reserve ($p < 0.001$) (Fig. S2 c-d). However, a significant increase in glycolysis and glycolytic capacity was observed in EAF-treated cells ($p < 0.01$). Furthermore, EAF (25 $\mu\text{g/ml}$) treatment improved the glycolytic function of cells by increasing the GR ($p < 0.05$). Non-glycolysis acidification was also measured (Fig. S2 e). A significant increase in glycolysis-induced cell proliferation in human adipose stem cells was reported to acts as an anti-aging effect [29]. EAF improved the overall metabolic dysfunction by improving the mitochondrial and glycolytic function. This is the first study to report real-time ECAR data using an XFe extracellular flux analyser to support the efficacy of the bioactive fraction of *M. balbisiana* seeds in regulating stress-mediated glycolysis.

Conclusion

Musa balbisiana seeds are nutrient-rich part of the fruit containing plenty amount of carbohydrates, protein and mineral content. *M. balbisiana* has significant antioxidant, anti-glycation and anti-hyperglycemic effects *via* inhibiting α -amylase and α -glucosidase enzymes. GC-MS analysis of *M. balbisiana* seeds identified several bioactive compounds having pharmacological properties including methyl palmitate, methyl linoleate and γ -sitosterol. There is a strong correlation between phenolic and tannin content with biological activities suggesting major contribution of phenolic compounds to the antioxidant and anti-glycation activities. In addition, *M. balbisiana* improves the mitochondrial bioenergetics and glycolytic function of oxidative stress-induced cells by improving the OCR and ECAR. In this respect, *M. balbisiana* seeds could be recommended as dietary supplements and nutraceuticals to improve health and provide protection against chronic diseases. However, further research is required to characterize phenolic compounds present to understand the mechanism of action.

Abbreviations

ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid), **DPPH** (1,1-diphenyl-2-picrylhydrazyl), **ECAR** Extracellular acidification rate, **FRAP** Ferric reducing antioxidant power assay, **NIST** National Institute of Standards and Technology, **OCR** Oxygen consumption rate, **TPC** Total phenolic content, **TFC** Total flavonoid content, **TTC** Total tannin content.

Declarations

Author Contributions

Nonibala Gurumayum and Rajlakshmi Devi - conceptualization & design; Nonibala Gurumayum - Methodology, investigation, analysis & writing original draft; Partha Pratim Sarma and Puspanjali Khound - investigation; Uttam Kumar Jana and Rajlakshmi Devi - writing (review & editing); Rajlakshmi Devi - supervision.

Funding

Nonibala Gurumayum acknowledges the University Grant Commission (UGC), Government of India, for manpower support in the form of a Junior Research Fellowship. The authors thank the Sophisticated Analytical Instrumentation Centre (SAIC), Institute of Advanced Study in Science and Technology (IASST), Guwahati (under the Department of Science & Technology, Government of India) for providing the necessary equipment.

Data Availability

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Statements & Declarations

Ethical Approval

Not Applicable

Consent to Participate

Not Applicable

Consent to Publish

Not Applicable

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

References

1. Boeing H, Bechthold A, Bub A, et al (2012) Critical review: Vegetables and fruit in the prevention of chronic diseases. *Eur J Nutr* 51:637–663. <https://doi.org/10.1007/s00394-012-0380-y>
2. Sarma PP, Gurumayum N, Verma AK, Devi R (2021) A pharmacological perspective of banana: Implications relating to therapeutic benefits and molecular docking. *Food Funct* 12:4749–4767. <https://doi.org/10.1039/d1fo00477h>
3. da Silva APG, Spricigo PC, Purgatto E, et al (2019) Volatile Compounds Determined by SPME-GC, Bioactive compounds, in vitro antioxidant capacity and physicochemical characteristics of four native fruits from South America. *Plant Foods Hum Nutr* 74:358–363. <https://doi.org/10.1007/s11130-019-00745-7>
4. Menezes EW, Tadini CC, Tribess TB, et al (2011) Chemical composition and nutritional value of unripe Banana flour (*Musa acuminata*, var. Nanicão). *Plant Foods Hum Nutr* 66:231–237. <https://doi.org/10.1007/s11130-011-0238-0>
5. Abdel-Baki PM, Ibrahim RM, Mahdy NE (2022) *Ferocactus herrerae* Fruits: Nutritional significance, phytochemical profiling, and biological potentials. *Plant Foods Hum Nutr* 77:545–551. <https://doi.org/10.1007/s11130-022-01007-9>
6. FAO, Banana facts and Figures. <https://www.fao.org/economic/est/est-commodities/oilcrops/bananas/bananafacts/en#.ZA7-LHZBzIU> (Assessed on 17th April 2023)
7. Simmonds N (1962) The Evolution of the Bananas. Longmans, London
8. Subbaraya U (2006) Farmers' knowledge of wild *Musa* in India. FAO, Rome. <https://www.fao.org/3/i0548e/i0548e00.htm> (Accessed on 17th April 2023)
9. Oyeyinka BO, Afolayan AJ (2020) Potentials of *Musa* species fruits against oxidative stress-induced and diet-linked chronic diseases: in vitro and in vivo implications of micronutritional factors and dietary secondary metabolite compounds. *Molecules* 25. <https://doi.org/10.3390/molecules25215036>
10. Sarma PP, Gurumayum N, Samanta SK, et al (2022) Pharmacologically active chemical composite of *Musa balbisiana* ameliorates oxidative stress, mitochondrial cellular respiration, and thereby metabolic dysfunction. *J Food Biochem*. <https://doi.org/10.1111/jfbc.14347>
11. Singh B, Singh JP, Kaur A, Singh N (2016) Bioactive compounds in banana and their associated health benefits - A review. *Food Chem* 206:1–11. <https://doi.org/10.1016/j.foodchem.2016.03.033>
12. Kumari S, Katore PB, Elancheran R, et al (2020) *Musa balbisiana* fruit rich in polyphenols attenuates isoproterenol-induced cardiac hypertrophy in rats via inhibition of inflammation and oxidative stress. *Oxid Med Cell Longev* 2020. <https://doi.org/10.1155/2020/7147498>
13. Gopalan G, Prabha B, Joe A, et al (2019) Screening of *Musa balbisiana* Colla seeds for antidiabetic properties and isolation of apiforol, a potential lead, with antidiabetic activity. *J Sci Food Agric* 99:2521–2529. <https://doi.org/10.1002/jsfa.9462>
14. Pascual-Villalobos MJ, Rodríguez B (2007) Constituents of *Musa balbisiana* seeds and their activity against *Cryptolestes pusillus*. *Biochem Syst Ecol* 35:11–16. <https://doi.org/10.1016/j.bse.2006.08.004>

15. Menezes EW, Dan MCT, Cardenette GHL, et al (2010) In vitro colonic fermentation and glycemic response of different kinds of unripe banana flour. *Plant Foods Hum Nutr* 65:379–385. <https://doi.org/10.1007/s11130-010-0190-4>
16. Solis-Badillo E, Agama-Acevedo E, Tiessen A, et al (2020) ADP-glucose pyrophosphorylase is located in the plastid and cytosol in the pulp of tropical banana fruit (*Musa acuminata*). *Plant Foods Hum Nutr* 75:76–82. <https://doi.org/10.1007/s11130-019-00788-w>
17. Sulaiman SF, Yusoff NAM, Eldeen IM, et al (2011) Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (*Musa sp.*). *J Food Compos Anal* 24:1–10. <https://doi.org/10.1016/j.jfca.2010.04.005>
18. Nghia BT, An DT, Thong LN, et al (2016) Antioxidant and antibacterial activities of extracts from seeds of *Musa balbisiana*. *J Sci Tech* 54:348-353.
19. Ramu R, Shirahatti PS, Zameer F, et al (2014) Inhibitory effect of banana (*Musa sp. var. Nanjangud rasa bale*) flower extract and its constituents Umbelliferone and Lupeol on α -glucosidase, aldose reductase and glycation at multiple stages. *S Afr J Bot* 95:54–63. <https://doi.org/10.1016/j.sajb.2014.08.001>
20. Wang W, Yagiz Y, Buran TJ, et al (2011) Phytochemicals from berries and grapes inhibited the formation of advanced glycation end-products by scavenging reactive carbonyls. *Food Res Int* 44:2666–2673. <https://doi.org/10.1016/j.foodres.2011.05.022>
21. González-Montelongo R, Gloria Lobo M, González M (2010) Antioxidant activity in banana peel extracts: Testing extraction conditions and related bioactive compounds. *Food Chem* 119:1030–1039. <https://doi.org/10.1016/j.foodchem.2009.08.012>
22. Kalita H, Boruah DC, Deori M, et al (2016) Antidiabetic and antilipidemic effect of *Musa balbisiana* root extract: A potent agent for glucose homeostasis in streptozotocin-induced diabetic rat. *Front Pharmacol* 7. <https://doi.org/10.3389/fphar.2016.00102>
23. Tong Z, He W, Fan X, et al (2022) Biological function of plant tannin and its application in animal health. *Front Vet Sci* 8. <https://doi.org/10.3389/fvets.2021.803657>
24. Fahim M, Ibrahim M, Zahiruddin S, et al (2019) TLC-bioautography identification and GC-MS analysis of antimicrobial and antioxidant active compounds in *Musa × paradisiaca* L. fruit pulp essential oil. *Phytochem Anal* 30:332–345. <https://doi.org/10.1002/pca.2816>
25. Konappa N, Udayashankar AC, Krishnamurthy S, et al (2020) GC-MS analysis of phytoconstituents from *Amomum nilgircum* and molecular docking interactions of bioactive serverogenin acetate with target proteins. *Sci Rep* 10. <https://doi.org/10.1038/s41598-020-73442-0>
26. Kashyap B, Barge SR, Bharadwaj S, et al (2021) Evaluation of therapeutic effect of *Premna herbacea* in diabetic rat and isoverbascoside against insulin resistance in L6 muscle cells through bioenergetics and stimulation of JNK and AKT/mTOR signaling cascade. *Phytomedicine* 93. <https://doi.org/10.1016/j.phymed.2021.153761>
27. Tan B, Xiao H, Li F, et al (2015) The profiles of mitochondrial respiration and glycolysis using extracellular flux analysis in porcine enterocyte IPEC-J2. *Anim Nutr* 1:239–243. <https://doi.org/10.1016/j.aninu.2015.08.004>
28. Zhang X, Alshakhshir N, Zhao L (2021) Glycolytic metabolism, brain resilience, and alzheimer's disease. *Front Neurosci* 15:662242. <https://doi.org/10.3389/fnins.2021.662242>
29. Wu Y, Wang H, Zhu J, et al (2021) Licochalcone A activation of glycolysis pathway has an anti-aging effect on human adipose stem cells. *Aging (Albany NY)* 13:25180-25194. <https://doi.org/10.18632/aging.203734>

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementaryonlineresource.docx](#)