Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.55493/5003.v12i2.4505
Vol. 12, No. 2, 80-90.

URL: www.aessweb.com

OVERVIEW OF *THAUMATOCOCCUS DANIELLII* PLANT, HISTORY, USES, BENEFITS, AND CHARACTERIZATION

Hasan M. Agha[1]
Norrizah Jafaar Sidik[2+]
Ali H. Jawad[3]
Amjad Abdulhadi Mohammed[4]
Abdulmutalib Alabeed Alkamil[5]

[1,2,3,5]*Faculty of Applied Sciences, University of Technology MARA, Malaysia.*
[1]*Email: hasanagha586@gmail.com Tel: +601111666409*
[2]*Email: norri536@uitm.edu.my Tel: +60132626737*
[3]*Email: ahjm72@gmail.com Tel: +60164045785*
[5]*Email: alabeed119@gmail.com Tel: +601161757020*
[4]*Department of Biology, College of Sciences, University of Mosul, Iraq.*
[4]*Email: amjsbio33@uomosul.edu.iq Tel: +9647701679696*


(+ Corresponding author)

Article History
Received: 14 March 2022
Revised: 28 April 2022
Accepted: 16 May 2022
Published: 3 June 2022

Keywords
Thaumatococcus daniellii
Pharmaceutical
Thaumatin
Natural sweeteners
Flavour enhancer
Economic plants.

ABSTRACT

*Thaumatococcus daniellii (*Benn.) Benth, known as "katempe" or "katemfe". It grows in humid tropical forests and the coastal areas of West Africa, especially in Nigeria, Ghana, Central African Republic, Uganda, and Cote d'Ivoire. *T. daniellii* contains chemical compounds that have several uses in many fields and contain thaumatin protein, which plays an essential role in the food industry, used as a natural sweetener, and pharmaceutical industry. *T. daniellii* can play a significant role in economic growth in many countries in which it grows. This study summarises some crucial aspects of *T. daniellii.* As the study highlight, some of the chemical components are contained in the plant. In addition to the other medicinal benefits and applications used from *T. daniellii.* the study presented the importance of the plant in the production of thaumatin and highlighted the two types of this protein and the difference between them in the arrangement of amino acids.

Contribution/ Originality: This study contributes to the current literature on the evaluation and how to increase production and benefit from the medicinal benefits of *Thaumatoccocus daniellii* applications. It also draws the attention of this plant in the production of natural sweeteners and attempts to make the plant of economic benefit and additional income in the areas where the plant grows.

1. INTRODUCTION

*Thaumatococcus daniellii (*Benn.) Benth, known as "katempe" or "katemfe". It belongs to the Marantaceae Table 1 family. It grows in humid tropical forests and the coastal areas of West Africa, especially in Nigeria, Ghana, Central African Republic, Uganda, and Cote d'Ivoire. It is also one of the species introduced in Australia and Singapore. This plant is one of the perennial herbaceous monocotyledonous plants. It spreads through the roots (rhizomes) and grows underground in the forest, its natural habitat [1-3]. The plant grows along a slender stalk to a height of 3-4 meters with oval-shaped leaves of different sizes up to 46 cm long depending on the stage of plant growth and the place of growth (in forests or agricultural areas) [4]. The large size of the leaves has made them of great importance to the local population in West African countries as the leaves are used for food wrappers and building roofs. It's also essential in traditional medical uses; for example, leaves are used as antidotes against poison, stings, and bites, and their usage is as painkillers and treatment of insanity [5].

The fruit of this plant is characterised by its pyramid or triangular shape and is crimson colour and be bright red colour at full maturity. The weight of the fruit ranges from 6 to 30 g depending on the number of seeds inside the fruit, which usually contains three seeds. These seeds are black and surrounded by a thin, sticky layer of gel that is soft and fleshy called aril; this part of the plant (aril) is the reason behind the attention of scientists towards this plant. It contains a high concentration of sweet taste protein called thaumatin which is at least 3,000 times sweeter than sucrose. This part of the plant was used as a source of sweetening agent in West African regions, where it was introduced to sweeten bread, palm wine, and sour food. It has been observed that sour food will taste sweet, and the sweetness can be retained for an hour [6, 7]. Since the mid-1990s, thaumatin has been used as a sweetener and flavour enhancer in the food and confectionery industries. It is a natural source of calorie-free sweetener, and it does not contain carbohydrates; thus, it is ideal for patients with diabetes. The fruit of *Thaumatococcus daniellii* is used in the traditional medical field in Congo and Ivory Coast, where it is considered a good laxative. The seeds are emetic and treat pulmonary problems [8]. Growing concern about consuming artificial sweeteners humans raised as it has a clear impact on human health and causes many diseases such as dizziness, headache, and digestive problems [9].

Table 1. Classification of *Thaumatococcus daniellii*.

Level of classification	Name
Kingdom	Plantae-plant
Subkingdom	Tacheobionta – Vascular plants
Superdivision	Spermatophyte – seeds plants
Division	Magnoliophyta – flowering plants
Class	Liliopsida – monocotyledons
Subclass	Zingiberidae
Order	Zingiberales
Family	Marantaceae - Prayer-Plant family
Genus	Thaumatoccocus benth.- thaumatococcus
Species	daniellii (benn.) benth. - Miracle fruit

2. HISTORY AND DESCRIPTION OF *THAUMATOCOCCUS DANIELLII*

George Dawn collected the plant's oldest sterile specimen from San Tom Island in West Africa in 1822. Due to the plant's popularity as a source of sweetening, this plant attracted the attention of the English surgeon, William Daniell in 1856. Samples were obtained from this plant, but the importance of this commercial crop as a source of natural protein sweetener was discovered after a whole century. A 1969 ban on sodium cyclamate in the United States of Americaed to extensive research conducted on *T. daniellii* and thaumatin as an alternative source of natural sweetening agent [10]. This work included UK glasshouse experiments and Ghana, Liberia, Nigeria, and Malaysia field plantations. Commercial thaumatin development reports show that most value increases outside Africa [11]. This plant is called by many names such as the sweet prayers plant, "katemfe" or "katempe", Yoruba soft cane, African serendipity berry, Miracle berry, and Miracle fruit (but this name is not related to the species *Synsepalum dulcificum* known to this name) [12, 13]. *T. daniellii* is a rhizomatous, perennial and monocotylene herb propagating by rhizomes. The plant grows in hot, humid rainforests and coastal areas in West Africa. The plant grows with a long, slender stem reaching (3-4) meters. The plant is characterised by holding large oval leaves of up to 46 cm in length, it is also bear pale purple flowers and carries a soft fruit that contains some bright black seeds Figure 1,2 [14].

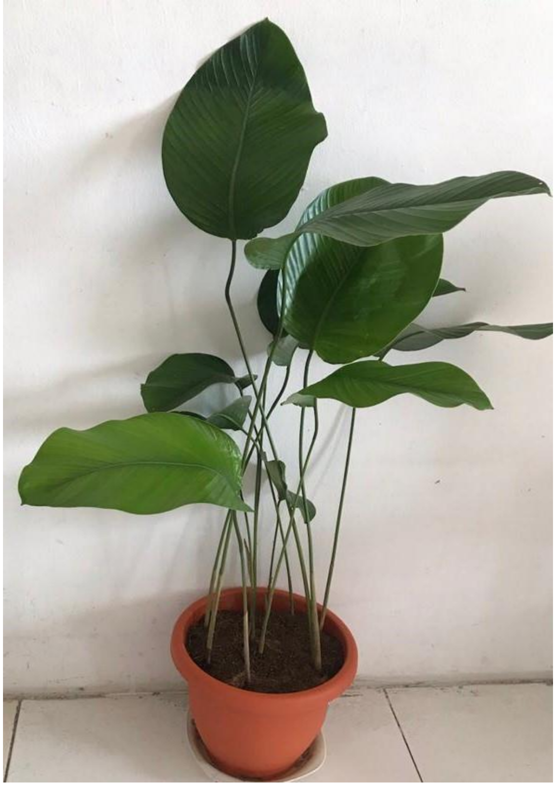


Figure 1. Thaumatococcus daniellii.

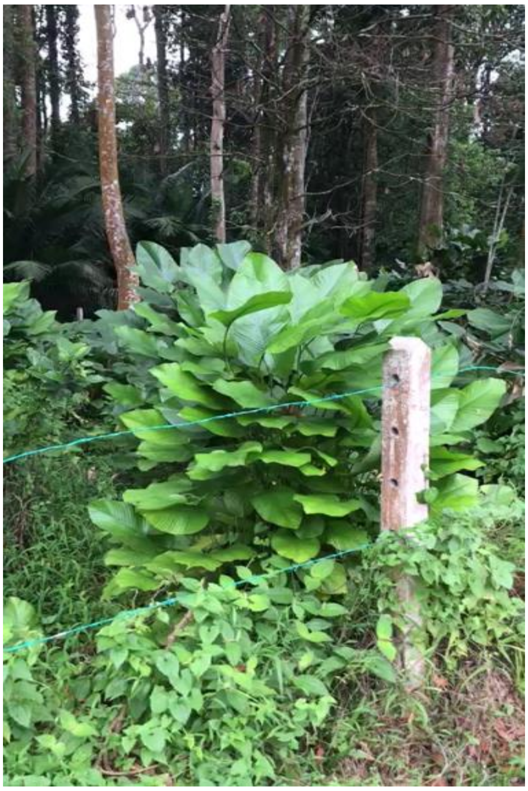


Figure 2. Thaumatococcus daniellii at forest.

The plant flowers most of the year but is at the top of its production from July to late October followed by fruit formation (ripening period) from January to mid-April [15]. The fruit of this plant is distinguished by its pyramid or triangular shape and has a crimson color and a bright red at full maturity the weight of the fruit varies from (6-30 g) depending on the number of seeds in the fruit, which usually contains three seeds. These seeds are black when dry, they look like rocks. It contains aril with a high concentration of Thaumatin in the sweet taste protein which is at least 3,000 times sweeter than sucrose Lim [6]. Chinedu, et al. [16] studied the components of the fruit and leaf found that it consisted of 4.8% aril, 22.8% seeds, and 72.4% fleshy part. The fruit contained 10.04 g of moisture, 21.08 g of gash, 0.93 g of fat 11.53 g of protein, 18.43 g of glib fibre, 37.27 g of carbs, 0.34 g of calcium, 0.30 g of magnesium, 0.01 g of iron and 0.21 g of phosphor. The seed had 15.15 g of water, 11.30 g of ash, 0.21 g of fat, 10.36 g of protein, 20.52 g of raw fibre and 42.46 g of carbohydrate. In both the leaf and the fruit, terpenoids, flavonoids, alkaloids and cardiac glycosoids are substantially present, while phlobatanin, saponin, hormones, anthraquinones ascorbic acid were absent. The fruit is a good mineral source, especially calcium and magnesian; the leaf is also rich in phosphorus.

3. BENEFITS AND USES OF *THAUMATOCOCCUS DANIELLII*

Thaumatococcus daniellii is considered a non-timber forest species that played a big role in the rural economy in the West African regions, but it did not use all its capabilities to improve the economy. This perennial herb is multipurpose as it provides a very wide range of uses through its leaves or fruits or stems and roots [17].

The plant is distinguished by having large oval-shaped leaves. The leaf is 60 cm long and 40 cm wide and grows individually from each rhizome nodule. *T. daniellii* is grown in West Africa, as it has traditionally used the lamina of fresh leaves to cover food to increase the shelf life of the food. The leaves are said to give the food wrapped a unique taste, so they are preferred over banana leaves. The petioles are used in weaving mats and some building tools and can be used for roofing the houses Figure 3 [11, 18].

Figure 3. *T. daniellii* Leaf [5].

The uses of plants and natural products in treating diseases have been known since ancient times [19]. A study by Oboh, et al. [18] verified the role of the leaves of *T. daniellii* as an antioxidant, as this study showed the ability of the plant to prevent degenerative diseases associated with oxidative stress, thus proving that this antioxidant effect can be used as an effective way to preserve food. Ubani, et al. [5] also indicated that the chemical examination of a sample of plant leaves from Calabar, South-south Nigeria contained flavonoids, alkaloids, tannins, glycosides, and steroids in large quantities and that the presence of these substances gives credibility to the medicinal and nutritional importance of plant use in past years. The research results showed the leaves of *T. daniellii* had a higher medicinal value than the banana leaves. Therefore, it is recommended to use them in food packaging instead of plastic bags that cause many cancerous diseases. Due to the high risk of plastic in food packing, there a study was conducted to find out the components of *T. daniellii* leaves and their shelf life in food wrapping, the study found *T. daniellii* leaves contain a group of vitamins B1 1.07 mg/100g, B3 1.32mg/100g, B5 1.11 mg/100g, B6 16.34 mg/100g, B12 11.86 mg/100g, vitamin A 3.1 mg/100g, vitamin C 25.19 mg/100g. results of this study proved it is possible to use *T. daniellii* leaves in food packing and is an excellent alternative to polyethelyn paper and aluminum foil, as well as *T. daniellii* leaves, which can be combined with animal feedo the high value nutritional components and vitamins [12]. Another study was conducted on the economic value of *T. daniellii* leaves and their effect on poverty reduction in Osun State, Nigeria [20]. The average return on investment was 55.88±2.58% (with 19.40% lending rate) showing a high result in plant revenue. To reduce poverty, it is necessary to educate farmers and provide them with full information and agricultural advice [21].

Globally, the increase in pulp and paper production leads to the deforestation of large areas of trees. Massive investment and import of the long pulp fiber and the inability to maintain the fibres' natural source were the main reasonsor the closure of many factories in Nigeria [22]. Recently it was discovered that a *T. daniellii* stalk can be considered a Non-Wood Fiber Source (NWFS) [23].

There was a great trend in Nigeria to study the components of *T. daniellii* stalks, as it was found that these stalks contain a high percentage of fiber that can be used in the production of fiber. The stalk compromises crude fiber holocellulose percentage of *T. daniellii* stalk was as follows crude fiber (33.36%), holocellulose (66.80%), α-cellulose (39.0%), hemicellulose (27.81%) low ash (2.79%), silica (0.85%), lignin (13.03%) and elemental accumulations. The study also showed that the fiber contents are strongly related to each other, but the nutrients were not as it appears that only nitrogen, potassium and iron are closely related with raw fiber and cellulose since these components are the main elements that contribute to the physiological development and fiber quality of the *T. daniellii* stalk. The study suggested using potassium and nitrogen-based fertilisers with *T. daniellii* for high-quality fiber [24].

The dependence on obtaining *T. daniellii* from natural habitats (forests) is not sustainable and does not meet the market needs to obtain the aril. Ultimately, farmers destroy natural ecosystem and feeding sources for other organisms such as insects, rodents and rats of the forest floor to harvest the plant. Since *T. daniellii* are a shade-resistant plant, it has been proposed to grow them in farms with a mixed system (Eco agriculture). This will help obtain large quantities of the plant and help preservehe wild environment in the forests, thus increasing income for farmers in West African regions who lack adequate sources of income [25].

4. CHARACTERISATION OF *THAUMATOCOCCUS DANIELLII*

T. daniellii is a multi-use plant where the local populations use all its parts (leaves, stalk, fruits, rhizomes) in its growing areas. The stalks were used to sweeten food and in the manufacture of thaumatin. The leaves were widely used to wrap different foods in Africa and even in America and South America, where they were considered flavor enhancers. In a study on *T. daniellii* leaves, it was found that they contain flavonoids, polyphenols, alkaloids, and saponins. The same study showed that the aqueous extract of *T. daniellii* leaves contains higher proportions of these substances Flavonoids 0.28 mg %, Polyphenols 0.41 mg%. The analysis of the antioxidants also showed that 100-500 mg/ml of aqueous leaf solution showed the effect exhibited higher DPPH radical scavenging activity than the hexane leaf fraction. Thus, the presence of flavor-enhancing properties in the plant's leaves is attributed to the fact that it contains polyphenols and flavonoids. Its antioxidant activity is also behind its use as a wrapping food [26].

In another study, the components of the gelatinous layer of *T. daniellii* plant were studied, where the phytochemical analysis showed that it contains saponins (0.19 %), flavonoids (0.41%), phenols (0.06 %), HCN (0.81 %), Alkaloid (0.11 %), and Tannin (0.16 %). The analysis also showed that this gelatinous layer contains Calcium 6.68 mg/100 g, Magnesium 0.60 mg/100 gm, Ash 5.80%, Fiber 0.41%, protein 19.01, and nitrogen 3.04%. This high nutritional value makes it easy to replace white sugar and use tomatine to manufacture children's medicines [27]. Intensive research was also conducted on *Thaumatococcus daniellii* to study the biological compounds and the importance and benefits of these components. Samadder, et al. [28]; Thibado, et al. [29] in their research found *T. daniellii* contains anthocyanin, which is an anti-cancer and anti-radical substance as well as an anti-hyperglycemic. *T. daniellii* contains anthraquinones, which act as anti-bacterial, anti-inflammatory, anti-fungal, anti-cancer, anti-coagulant, and neuroprotective [30-34]. Studies have indicated the plant contains rutin pigment, which has a significant role in protecting the heart and is neuroprotective and an anti-diabetic compound and works to protect the kidneys [35-37]. *T. daniellii* contain saponin, which is found in the fenugreek plant, and works as an anti-inflammatory, hypocholesterolemic, and immunomodulatory [38-40]. A study conducted by Matsubara, et al. [41]; Ho, et al. [42] found the compound Geranylgeraniol in *T. daniellii* which improves testosterone and proliferator-activated receptors γ (PPAR γ). In addition, it was found *T. daniellii* consist of many other compounds that have valuable health benefits [3], Catechins [43], Hexadecanoic acid [44], Kaempferol [45], Phytol [46], Spartein [47], Squalene [48, 49], and Terpenoids [50]. Other studies are conducted to know the components of each part of *Thaumatococcus daniellii*, as shown in Table 2.

Table 2. Some studies conducted about the components of each part of *Thaumatococcus daniellii*.

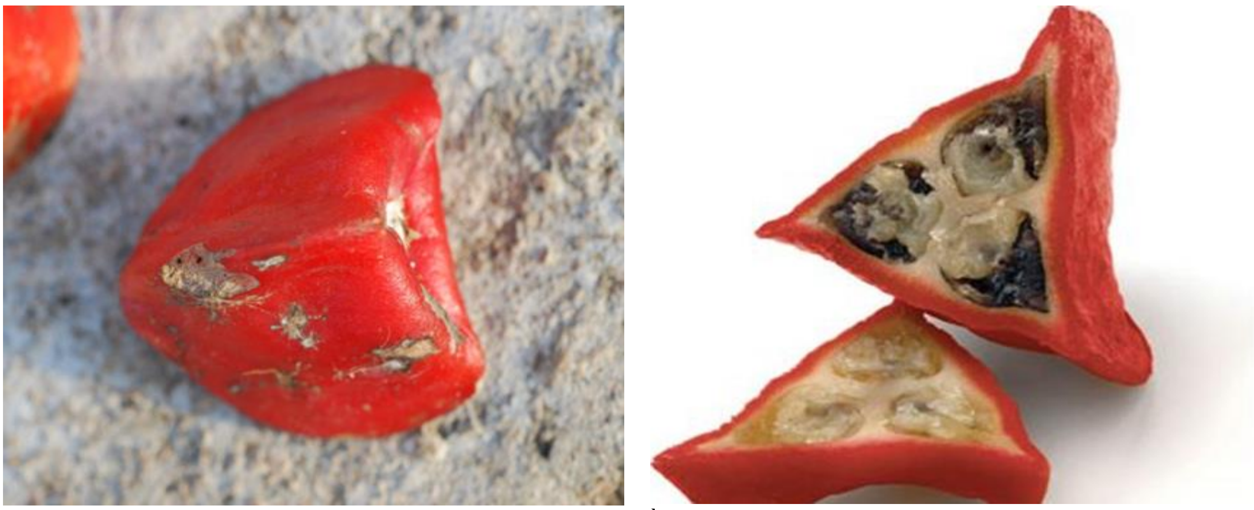
Part of *T. daniellii*	Protein (%)	Carbohydrate (%)	Fat (%)	Ash (%)	Moisture (%)	Crude fiber (%)	References
T. daniellii (seeds)	2.14	40.07	2.35	8.17	10.39	36.92	Abiodun, et al. [51]
T. daniellii (leaves)	14.88	31.25	0.90	10.60	5.16	36.61	Oforibika, et al. [52]
T. daniellii (fruits)	19.02	70.00	3.85	5.80	83.90	0.42	Ndukwe, et al. [27]
T. daniellii (Arils)	33.03	44.17	0.61	4.79	12.20	5.20	Ojo, et al. [53]
T. daniellii (rhizomes)	7.00	18.75	1.80	6.20	17.27	48.98	Oforibika, et al. [52]

5. THAUMATIN

The fruit of *T. daniellii* contains thaumatin protein, which is found in the aril area surrounding the seeds (Figure4 a, b). The people of West Africa used the fruits of this plant as a source of sweetening bread, sour food and palm wine. They found that when they chew the seeds for an hour, they turn sour foods into foods that taste sweet. During the nineties of the last century, the actual trend began to use thaumatin in the food and confectionery industry as an alternative natural sweetener to harmful industrial sweeteners. As this protein is distinguished as not a carbohydrate,t is suitable for people with diabetes [54].

Thaumatin was produced for the first time in 1972 from *T. daniellii* fruits by aqueous extraction. The different types of thaumatin were examined based on the stages of ripening of *T. daniellii* fruits and thaumatin I and thaumatin Π were determined. This study also showed that the two types have the same amino acids and molecular weights. The study also included the relationship between the cultivation area and the amount of protein in the fruit. Where 4.9 g of the extract was obtained from 2.7 kg of fruit, equivalent to 0.18%. It was observed that the sweetness of the aqueous solution of thaumatin decreased when the temperature was increased to more than 75 °C, as well as when the pH was less than 2.5 at room temperature [9].

Between 1990 and 2012, the total production ranged from 10,250 kg to 25,600 kg of *T. daniellii* arils in Cote d'Ivoire. Given the average frozen aril value of $16 for one kilogram, this development gained between $160,000 and $400,000 annually in exports to the United Kingdom. There is, therefore, a seemingly untapped potential for improving rural livelihoods in West and Central Africa through *T. daniellii* cultivation [10]. Thaumatin is one of the sweetening proteins with a sweetness of 2000-10000 times sweeter than sucrose. It is consisting of 207 amino acids. There are two types of thaumatin I and thaumatin Π, it differs from the second in 5 amino acids. Both types are soluble in water and dilute alcohol Figure 5 [9, 55].



a b

Figure 4. a. Fruit of *Thaumatoccocus daniellii*, b. A Cross Section of *Thaumatococcus daniellii* Fruit Showing the Aril.

The maximum solubility at pH 2.7 – 3.0. The advantage is that the sweetness does not disappear by heating where it is kept sweet when heated to a temperature of 80 ºC for a period of 4 hours at pH 2. However, the sweetness disappears when heated with a pH higher than 7 for 15 minutes. This indicates that thaumatin is more heat resistant than neutral or alkaline conditions under acidic conditions. Thaumatin has proven its effectiveness in eliminating the bitterness of some medicines and vitamins, as it was used in the composition of tablets and pills at rate (20-400) ppm as it was taken advantage of the advantage of staying sweet for a long time that leaves a sweet feeling in the mouth. It is considered a one of the sweetest natural sweeteners if compared with sucrose Table 3 [8, 9]. Obtaining thaumatin protein by natural sources is difficult and the percentage of obtaining it is low to obtain large commercial quantities. Using modern technical methods such as protein synthesis through genetically modified organisms [56].

In addition to the fact that thaumatin acts as a first-class sweetener, it can be used as a flavor modifier in the food industries. Its unique and distinctive properties make it an essential component in various food industries. Among these applications is its use in the manufacture of chewing gum, pet food, dairy products, and fodder [57].

```
                                   (I)
         10          20          30          40          50
MAATTCFFFL  FPFLLLLTLS  RAATFEIVNR  CSYTVWAAAS  KGDAALDAGG
         60          70          80          90         100
RQLNSGESWT  INVEPGTNGG  KIWARTDCYF  DDSGSGICKT  GDCGGLLRCK
        110         120         130         140         150
RFGRPPTTLA  EFSLNQYGKD  YIDISNIKGF  NVPMDFSPTT  RGCRGVRCAA
        160         170         180         190         200
DIVGQCPAKL  KAPGGGCNDA  CTVFQTSEYC  CTTGKCGPTE  YSRFFKRLCP
        210         220         230
DAFSYVLDKP  TTVTCPGSSN  YRVTFCPTAL  ELEDE

                                   (II)
         10          20          30          40          50
MAATTCFFFL  FPFLLLLTLS  RAATFEIVNR  CSYTVWAAAS  KGDAALDAGG
         60          70          80          90         100
RQLNSGESWT  INVEPGTKGG  KIWARTDCYF  DDSGRGICRT  GDCGGLLQCK
        110         120         130         140         150
RFGRPPTTLA  EFSLNQYGKD  YIDISNIKGF  NVPMDFSPTT  RGCRGVRCAA
        160         170         180         190         200
DIVGQCPAKL  KAPGGGCNDA  CTVFQTSEYC  CTTGKCGPTE  YSRFFKRLCP
        210         220         230
DAFSYVLDKP  TTVTCPGSSN  YRVTFCPTAL  ELEDE
```

Figure 5. difference in amino acid between thaumatin I and thaumatin Π.

Note: Blue characters denote the signal peptide and red characters denote the differences in the sequences at four positions (www.uniprot.org).

Table 3. Some of natural sweeteners and compared with sucrose.

Plant	Family	Part	Sweetening Principle	Chemical Class	Times Sweeter than Sucrose
1-Achras sapota	Sapotaceae	Latex and fruit	Glycyrrhizin	Triterpene glycosides	100
2- Citrus aurantium	Rutaceae	Peels of the fruits	Neohesperidin dihydrochalcone	Dihydrochalcone	1000
3- Stevia rebaudiana	Asteraceae	Leaves	Steviosides	Tricyclicditerpenoid Glycosides	200-300
4- Symplococos paniculata	Symplocaceae	Leaves	Trilobatin	Dihydrochalcone Glycosides	400-1000
5- Dioscoreophyllum cuminsii	Menispermaceae	Fruit pulp	Monellin	Protein	2500
6- Perilla frutescens	Labiatae	Leaves, seeds and flowering tops	Perillartine	Monoterpenoid	400-2000
7-Thamatococcus daniellii	Marantaceae	Aril of fruit	Thaumatin	Protein	3000

6. CONCLUSION AND RECOMMENDATIONS

The presentation of various previous studies on *Thamatococcus daniellii* found the plant has many benefits and uses in people's lives in the countryside or its use in preparing extracts of high value. In the food industry, animal feed, food packing, and pharmaceutical industry as a flavour enhancers for children's syrup. As *T. daniellii* countians a group of vitamins, flavonoids, saponins, phenols, fibers, and proteins. *T. daniellii* contains thaumatin protein, one of the best natural sweetener and flavour enhancers that can be exploited in several fields. *T. daniellii* can have a role in improving the economy of rural areas in the countries where it grows in abundance.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.
Acknowledgement: The authors thank the Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam Branch for the technical support towards this research.

REFERENCES

[1] R. V. Gallagher, L. J. Beaumont, L. Hughes, and M. R. Leishman, "Evidence for climatic niche and biome shifts between native and novel ranges in plant species introduced to Australia," *Journal of Ecology*, vol. 98, pp. 790-799, 2010.Available at: https://doi.org/10.1111/j.1365-2745.2010.01677.x.

[2] O. Adeogun, A. Adekunle, and A. Ashafa, "Chemical composition, lethality and antifungal activities of the extracts of leaf of Thaumatococcus daniellii against foodborne fungi," *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 5, pp. 356-368, 2016.Available at: https://doi.org/10.1016/j.bjbas.2016.11.006.

[3] O. Fadahunsi, P. Adegbola, S. Olorunnisola, and O. Akinloye, "Phytochemistry, nutritional composition, and pharmacological activities of Thaumatococcus daniellii (Benth): A review," *BioTechnologia*, vol. 102, pp. 101-117, 2021.Available at: https://doi.org/10.5114/bta.2021.103766.

[4] K. Osuocha, E. Ogbonnaya, E. Nweke, D. Ejiofor, and P. Njoku, "Studies on the lipid profiles of wistar rat models treated with aqueous and methanolic leaf extracts of alchornea cordifolia and thaumatococcus daniellii," *Modern Health Science*, vol. 1, pp. p46-p46, 2018.Available at: https://doi.org/10.30560/mhs.v1n2p46.

[5] C. D. Ubani, O. E. Uko, C. A. Wariso, and A. A. Kalu, "Evaluation of the nutrient composition and hepatotoxic potential of Thaumatococcus danielli," *GSC Biological and Pharmaceutical Sciences*, vol. 18, pp. 11–15, 2022.

[6] T. K. Lim, *Edible medicinal and non-medicinal plants* vol. 1. Dordrecht, The Netherlands: Springer, 2012.

[7] Y. Igbayilola, F. Olaoye, O. Aina, M. Ashiru, and A. Mofolorunso, "Antioxidant, hypolipidaemic and heptoprotective potentials of perinatal Thaumatococcus daniellii leaf supplemented diet in male offspring of Sprague-Dawley rats," *Journal of African Association of Physiological Sciences*, vol. 9, pp. 95-104, 2021.

[8] K. Priya, V. R. M. Gupta, and K. Srikanth, "Natural sweeteners: A complete review," *Journal of Pharmacy Research*, vol. 4, pp. 2034-2039, 2011.

[9] J. A. Joseph, S. Akkermans, P. Nimmegeers, and J. F. Van Impe, "Bioproduction of the recombinant sweet protein thaumatin: Current state of the art and perspectives," *Frontiers in Microbiology*, vol. 10, p. 695, 2019.Available at: https://doi.org/10.3389/fmicb.2019.00695.

[10] W. S. Waliszewski, S. Oppong, J. B. Hall, and F. L. Sinclair, "Implications of local knowledge of the ecology of a wild super sweetener for its domestication and commercialization in West and Central Africa," *Economic Botany*, vol. 59, pp. 231-243, 2005.Available at: https://doi.org/10.1663/0013-0001(2005)059[0231:iolkot]2.0.co;2.

[11] A. Hamid, M. Aliyu, L. Abubakar, A. Mukadam, A. Shehu, G. Egharevba, M. Adisa, S. Ajibade, A. Zubair, and E. Fagbohun, "Thaumatococcus daniellii leaves: Its chemical compositions, antioxidant and antimicrobial activities," *Ife Journal of Science*, vol. 19, pp. 409-416, 2017.Available at: https://doi.org/10.4314/ijs.v19i2.21.

[12] A. Iwueke, N. Ejekwumadu, E. Chukwu, J. Nwodu, and C. Akalonu, "Nutritional composition and GC-MS phytochemical analysis of thaumatococcus daniellii leaves," *European Journal of Nutrition & Food Safety*, vol. 12, pp. 81-86, 2020.

[13] S. Yeboah, T. Hilger, and J. Kroschel, "Thaumatococcus daniellii(Benn.) Benth.-A natural sweetener from the rain forest zone in West Africa with potential for income generation in small scale farming," *Journal Applied Science*, vol. 6, pp. 854-859, 2003.

[14] N. Shalom, Y. Adetayo, T. Samuel, J. Bolaji, and E. Tamunotonyesia, "Analyses of the leaf, fruit and seed of Thaumatococcus Danielli (Benn.) Benth: exploring potential uses," *Paski*, vol. 2, pp. 37-47, 2013.

[15] N. H. Mohd Khairlani, M. Y. Abdullah, and S. Abdullah, "Thaumatococcus daniellii phenology and growing degree day requirements under different irradiance and fertiliser levels," *Annals of Applied Biology*, vol. 176, pp. 328-341, 2020.Available at: https://doi.org/10.1111/aab.12564.

[16] S. N. Chinedu, A. Y. Oluwadamisi, S. T. Popoola, B. J. David, and T. Epelle, "Analyses of the leaf, fruit and Seed of thaumatococcus tktniellii (Benth.): Exploring potential uses," *Pakistan Journal of Biological Sciences*, vol. 17, pp. 849-854, 2014.Available at: https://doi.org/10.3923/pjbs.2014.849.854.

[17] E. M. Isikhuemen, G. O. Oyibotie, and O. T. Aremu, "Diagnostic assessment of mammals in conservation areas of presco concession, Plogbo, Edo state, Nigeria," *Journal of Research in Forestry, Wildlife and Environment*, vol. 13, pp. 12–25, 2021.

[18] G. Oboh, A. J. Akinyemi, I. S. Oyeleye, and K. Williamsnelson, "Protective effect of phenolic extracts from two species of miracle berry leaves (Thaumatococcus daniellii and Megaphrynium macrostachyum) on some pro-oxidant induced oxidative stress in rat pancreas in vitro," *Journal of Applied Pharmaceutical Science*, vol. 6, pp. 118-124, 2016.

[19] A. A. Allaq, N. J. Sidik, A. Abdul-Aziz, and I. A. Ahmed, "Cumin (Cuminum cyminum L.): A review of its ethnopharmacology, phytochemistry," *Biomedical Research and Therapy*, vol. 7, pp. 4016-4021, 2020.Available at: https://doi.org/10.15419/bmrat.v7i9.634.

[20] D. A. Animasaun, A. Afeez, P. A. Adedibu, F. P. Akande, S. Oyedeji, and K. S. Olorunmaiye, "Morphometric variation, genetic diversity and allelic polymorphism of an underutilised species Thaumatococcus daniellii population in Southwestern Nigeria," *Journal of Plant Biotechnology*, vol. 47, pp. 298-308, 2020.Available at: https://doi.org/10.5010/jpb.2020.47.4.298.

[21] A. Aiyeloja and O. Ajewole, "Potential of thaumatococcus danielli (Benn) for poverty reduction in Osun state, Nigeria," *Journal of Tropical Forest Research*, vol. 21, pp. 1- 7, 2005.Available at: http://ir.library.ui.edu.ng/handle/123456789/3393.

[22] J. S. Udohitinah and A. O. Oluwadare, "Pulping properties of kraft pulp of Nigerian-grown kenaf (Hibiscus cannabinus L.)," *BioResources*, vol. 6, pp. 751-761, 2011.Available at: https://doi.org/10.15376/biores.6.1.751-761.

[23] O. Ogunsanwo, G. Adedeji, and A. Ajibabi, "Pulping potential of thaumatococcus daniellii (Benn) Benth in Omo and Oban forest reserve of Nigeria," *International Journal of Security and Networks*, vol. 3, pp. 580-585, 2012.

[24] O. Sotannde and A. Oluwadare, "Fibre and elemental contents of Thaumatococcus daniellii stalk and its implications as a non-wood fibre source," *International Journal of Applied*, vol. 4, pp. 178-185, 2014.

[25] S. Boadi, M. Baah-Acheamfour, F. Ulzen-Appiah, and G. Murtaza Jamro, "Nontimber forest product yield and income from Thaumatococcus daniellii under a mixed tree plantation system in Ghana," *International Journal of Forestry Research*, vol. 2014, p. 8, 2014.Available at: http://dx.doi.org/10.1155/2014/524863.

[26] O. I. Ayodeji, O. Adeleye, O. Dada, O. Adeyemi, and N. God'swill, "Phytochemical constituent and antioxidant activity of Thaumatococcus daniellii Benn (Benth.) leaves (food wrapper)," *Int J Pharmacol Phytochem Ethnomedicine*, vol. 2, pp. 55-61, 2016.Available at: https://doi.org/10.18052/www.scipress.com/ijppe.2.55.

[27] A. A. Ndukwe, E. A. Enoh, and Q. U. Aniere, "Determination of morphological and nutritional properties of Thaumatococcus daniellii and effect of harvesting method on the plant growth," *International Journal of Scientific Research and Innovative Reserch*, vol. 11, pp. 304-311, 2014.

[28] A. Samadder, D. Tarafdar, S. K. Abraham, K. Ghosh, and A. R. Khuda-Bukhsh, "Nano-pelargonidin protects hyperglycemic-induced L6 cells against mitochondrial dysfunction," *Planta Medica*, vol. 83, pp. 468-475, 2017.Available at: https://doi.org/10.1055/s-0043-100017.

[29] S. P. Thibado, J. T. Thornthwaite, T. K. Ballard, and B. T. Goodman, "Anticancer effects of Bilberry anthocyanins compared with NutraNanoSphere encapsulated Bilberry anthocyanins," *Molecular and Clinical Oncology*, vol. 8, pp. 330-335, 2018.

[30] K. Khan, R. Karodi, A. Siddiqui, S. Thube, and R. Rub, "Development of anti-acne gel formulation of anthraquinones rich fraction from Rubia cordifolia (Rubiaceae)," *International Journal of Applied Research in Natural Products*, vol. 4, pp. 28-36, 2011.

[31] J. P. Shrestha, M. Y. Fosso, J. Bearss, and C.-W. T. Chang, "Synthesis and anticancer structure activity relationship investigation of cationic anthraquinone analogs," *European Journal of Medicinal Chemistry*, vol. 77, pp. 96-102, 2014.Available at: https://doi.org/10.1016/j.ejmech.2014.02.060.

[32] T. Jackson, J. Verrier, and P. Kochanek, "Anthraquinone-2-sulfonic acid (AQ2S) is a novel neurotherapeutic agent," *Cell Death & Disease*, vol. 4, pp. e451-e451, 2013.Available at: https://doi.org/10.1038/cddis.2012.187.

[33] J. P. Shrestha, Y. P. Subedi, L. Chen, and C.-W. T. Chang, "A mode of action study of cationic anthraquinone analogs: A new class of highly potent anticancer agents," *MedChemComm*, vol. 6, pp. 2012-2022, 2015.Available at: https://doi.org/10.1039/c5md00314h.

[34] E. J. Seo, T. M. Ngoc, S.-M. Lee, Y. S. Kim, and Y.-S. Jung, "Chrysophanol-8-O-glucoside, an anthraquinone derivative in rhubarb, has antiplatelet and anticoagulant activities," *Journal of Pharmacological Sciences*, vol. 118, pp. 245-254, 2012.Available at: https://doi.org/10.1254/jphs.11123fp.

[35] H.-h. Hao, Z.-m. Shao, D.-q. Tang, Q. Lu, X. Chen, X.-x. Yin, J. Wu, and H. Chen, "Preventive effects of rutin on the development of experimental diabetic nephropathy in rats," *Life Sciences*, vol. 91, pp. 959-967, 2012.Available at: https://doi.org/10.1016/j.lfs.2012.09.003.

[36] A. Annapurna, C. S. Reddy, R. B. Akondi, and S. R. Rao, "Cardioprotective actions of two bioflavonoids, quercetin and rutin, in experimental myocardial infarction in both normal and streptozotocin-induced type I diabetic rats," *Journal of Pharmacy and Pharmacology*, vol. 61, pp. 1365-1374, 2009.Available at: https://doi.org/10.1211/jpp.61.10.0014.

[37] A. R. Gulpinar, I. E. Orhan, A. Kan, F. S. Senol, S. A. Celik, and M. Kartal, "Estimation of in vitro neuroprotective properties and quantification of rutin and fatty acids in buckwheat (Fagopyrum esculentum Moench) cultivated in Turkey," *Food Research International*, vol. 46, pp. 536-543, 2012.Available at: https://doi.org/10.1016/j.foodres.2011.08.011.

[38] T. Sun, X. Yan, W. Guo, and D. Zhao, "Evaluation of cytotoxicity and immune modulatory activities of soyasaponin Ab: An in vitro and in vivo study," *Phytomedicine*, vol. 21, pp. 1759-1766, 2014.Available at: https://doi.org/10.1016/j.phymed.2014.09.002.

[39] J. Lin, Y. Cheng, T. Wang, L. Tang, Y. Sun, X. Lu, and H. Yu, "Soyasaponin Ab inhibits lipopolysaccharide-induced acute lung injury in mice," *International Immunopharmacology*, vol. 30, pp. 121-128, 2016.Available at: https://doi.org/10.1016/j.intimp.2015.12.001.

[40] H. M. Agha, K. A. Radzun, N. J. Sidik, and A. H. Jawad, "Callus induction of fenugreek trigonella foenum-graecum via auxin combined with cytokinins hormones, and assessment of toxicity via brine shrimp assay," *Journal of Asian Scientific Research*, vol. 12, pp. 12-27, 2022.Available at: https://doi.org/10.55493/5003.v12i1.4449.

[41] T. Matsubara, N. Takakura, M. Urata, Y. Muramatsu, M. Tsuboi, K. Yasuda, W. N. Addison, M. Zhang, K. Matsuo, and C. Nakatomi, "Geranylgeraniol induces PPARγ expression and enhances the biological effects of a PPARγ agonist in adipocyte lineage cells," *In Vivo*, vol. 32, pp. 1339-1344, 2018.Available at: https://doi.org/10.21873/invivo.11384.

[42] H.-J. Ho, H. Shirakawa, R. Yoshida, A. Ito, M. Maeda, T. Goto, and M. Komai, "Geranylgeraniol enhances testosterone production via the cAMP/protein kinase A pathway in testis-derived I-10 tumor cells," *Bioscience, Biotechnology, and Biochemistry*, vol. 80, pp. 791-797, 2016.Available at: https://doi.org/10.1080/09168451.2015.1123612.

[43] J.-Y. Fang, T.-H. Tsai, Y.-Y. Lin, W.-W. Wong, M.-N. Wang, and J.-F. Huang, "Transdermal delivery of tea catechins and theophylline enhanced by terpenes: A mechanistic study," *Biological and Pharmaceutical Bulletin*, vol. 30, pp. 343-349, 2007.Available at: https://doi.org/10.1248/bpb.30.343.

[44] L. Ravi and K. Krishnan, "Research article cytotoxic potential of N-hexadecanoic acid extracted from Kigelia pinnata Leaves," *Asian Journal of Cell Biology*, vol. 12, pp. 20-27, 2017.Available at: https://doi.org/10.3923/ajcb.2017.20.27.

[45] W. Y. Boadi, P. K. Amartey, and A. Lo, "Effect of quercetin, genistein and kaempferol on glutathione and glutathione-redox cycle enzymes in 3T3-L1 preadipocytes," *Drug and Chemical Toxicology*, vol. 39, pp. 239-247, 2016.Available at: https://doi.org/10.3109/01480545.2015.1082135.

[46] C. C. De and M. P. Santos, "Antinociceptive and antioxidant activities of phytol in vivo and in vitro models," *Neuroscience Journal*, vol. 2013, p. 9, 2013.Available at: http://dx.doi.org/10.1155/2013/94945.

[47] F. Villalpando-Vargas and L. Medina-Ceja, "Sparteine as an anticonvulsant drug: Evidence and possible mechanism of action," *Seizure*, vol. 39, pp. 49-55, 2016.Available at: https://doi.org/10.1016/j.seizure.2016.05.010.

[48] S. Ravi Kumar, I. Yamauchi, B. Narayan, A. Katsuki, M. Hosokawa, and K. Miyashita, "Squalene modulates fatty acid metabolism: Enhanced EPA/DHA in obese/diabetic mice (KK-Ay) model," *European Journal of Lipid Science and Technology*, vol. 118, pp. 1935-1941, 2016.Available at: https://doi.org/10.1002/ejlt.201600006.

[49] C. Gabás-Rivera, C. Barranquero, R. Martínez-Beamonte, M. A. Navarro, J. C. Surra, and J. Osada, "Dietary squalene increases high density lipoprotein-cholesterol and paraoxonase 1 and decreases oxidative stress in mice," *PloS One*, vol. 9, p. e104224, 2014.Available at: https://doi.org/10.1371/journal.pone.0104224.

[50] M. Huang, J.-J. Lu, M.-Q. Huang, J.-L. Bao, X.-P. Chen, and Y.-T. Wang, "Terpenoids: Natural products for cancer therapy," *Expert Opinion on Investigational Drugs*, vol. 21, pp. 1801-1818, 2012.

[51] O. A. Abiodun, R. Akinoso, O. O. Olosunde, J. A. Adegbite, and O. Omolola, "Nutritional quality and essential oil compositions of Thaumatococcus danielli (Benn.) tissue and seed," *Food Chemistry*, vol. 160, pp. 286-291, 2014.

[52] G. Oforibika, J. Ogoloma, and T. Ezikiel, "Potential of Thaumatococcus danielli in animal nutrition," *Nature and Science*, vol. 15, pp. 97-100, 2017.

[53] A. Ojo, V. Enujiugha, H. Ayo-Omogie, and O. Abiodun, "Comparative study on the effect of Thaumatococcus daniellii (Benn) Benth sweetener on the physicochemical and sensory properties of Sorghum based Kunun-zaki Drink," *Journal of Applied Sciences and Environmental Management*, vol. 21, pp. 1073-1078, 2017.Available at: https://doi.org/10.4314/jasem.v21i6.13.

[54] K. Swiąder, K. Wegner, A. Piotrowska, F.-J. Tan, and A. Sadowska, "Plants as a source of natural high-intensity sweeteners: A review," *Journal of Applied Botany and Food Quality*, vol. 92, pp. 160-171, 2019.

[55] X. Zhao, C. Wang, Y. Zheng, and B. Liu, "New insight into the structure-activity relationship of sweet-tasting proteins: protein sector and its role for sweet properties," *Frontiers in Nutrition*, vol. 8, p. 691368, 2021.Available at: https://doi.org/10.3389/fnut.2021.691368.

[56] A. Firsov, L. Shaloiko, O. Kozlov, L. Vinokurov, A. Vainstein, and S. Dolgov, "Purification and characterization of recombinant supersweet protein thaumatin II from tomato fruit," *Protein Expression and Purification*, vol. 123, pp. 1-5, 2016.Available at: https://doi.org/10.1016/j.pep.2016.03.002.

[57] N. R. Dahal and X. M. Xu, "Sweetest protein-thaumatin," *Journal of Food Science and Technology Nepal*, vol. 7, pp. 112–118, 2012.Available at: https://doi.org/10.3126/jfstn.v7i0.11210.