Discover Food

https://doi.org/10.1007/s44187-025-00758-z

Article in Press

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Received: 23 July 2025

Accepted: 2 December 2025

Published online: 30 December 2025

Cite this article as: Panda J., Nongbet A., Mishra B. *et al.* Underutilized *Amorphophallus paeoniifolius* trending in food security and sustainable nutraceuticals. *Discov Food* (2025). https://doi.org/10.1007/s44187-025-00758-z

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Underutilized *Amorphophallus paeoniifolius* trending in food security and sustainable nutraceuticals

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Abstract

Background

Amorphophallus paeoniifolius (elephant foot yam) is an underutilised tropical tuber crop that is commonly grown in South and Southeast Asia. Traditionally used as a staple or therapeutic food, it is now being seen as a possible contender for addressing food and nutritional security. The crop contains dietary fibre, resistant starch, vital minerals, and bioactive phytochemicals like flavonoids, phenolics, and alkaloids, which have substantial nutraceutical potential. Despite its nutritional value and suitability for marginal soils, the crop is frequently overlooked in conventional food systems and industrial applications.

Objectives

The purpose of this study is to highlight *A. paeoniifolius'* nutritional, functional, and bioactive profile, investigate its potential involvement in sustainable food systems, and evaluate its suitability for generating nutraceuticals and functional foods that contribute to food and livelihood security.

Key findings

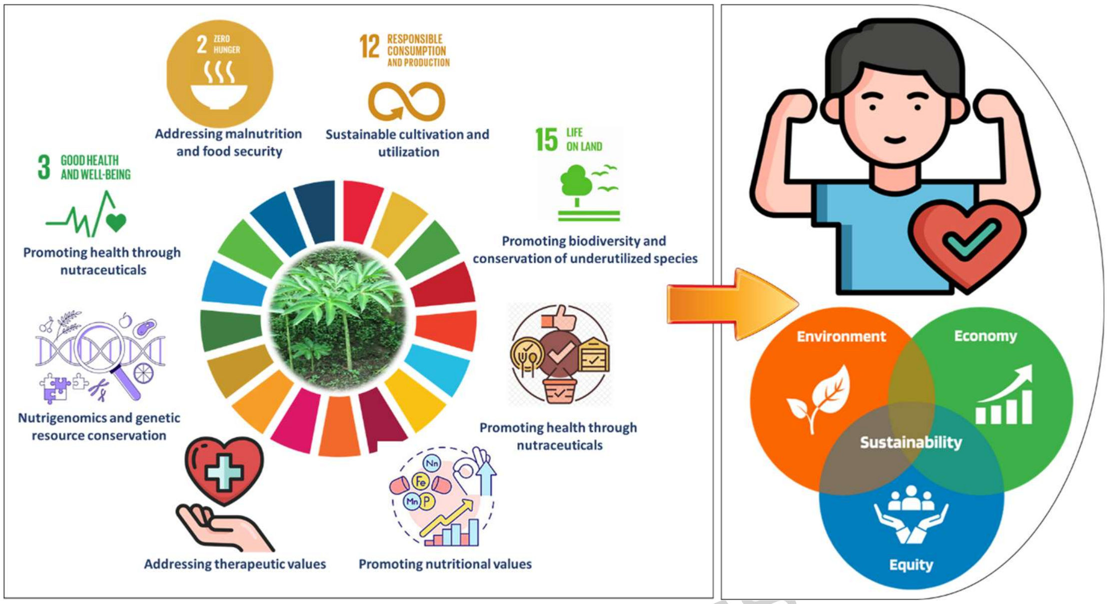
According to compositional analysis, *A. paeoniifolius* includes a high proportion of complex carbohydrates, little fat, and significant levels of potassium, calcium, and iron. Its phytochemical makeup contains powerful antioxidant, anti-inflammatory, and hypoglycemic capabilities. Fermentation, blanching, and enzymatic hydrolysis are examples of processing treatments that can considerably increase bioactive chemical availability while decreasing oxalate concentration, hence increasing taste and safety. Emerging research supports its implementation into value-added products such fortified flours, dietary supplements, and functional snacks, which are consistent with sustainable agriculture and circular bioeconomy concepts.

Conclusion

Underutilised *A. paeoniifolius* provides a dual benefit of boosting food security and long-term nutraceutical development. Its resistance to severe agroclimatic conditions and strong bioactive profile make it a promising crop for future functional food innovation. Further study and industrialisation could transform this underutilised tuber into an important component of sustainable and health-promoting food systems.

Keywords: *A. paeoniifolius,* Sustainable Development Goals, Underutilized crops, Food security, Nutraceuticals, Biomaterials

Graphical Abstract:



Highlights:

- *Amorphophallus paeoniifolius* (elephant foot yam) is rich in fibre, antioxidants, and essential minerals, making it a promising food source for addressing global nutritional deficiencies.
- It is known for its anti-inflammatory, anti-diabetic, and cholesterol-lowering properties, this underutilized plant offers significant potential in the nutraceutical sector for developing natural supplements targeting chronic health conditions.
- As a drought-resistant crop, it contributes to food security by providing an alternative to conventional staples, aligning with the UN's SDG 2, 3, 12 & 15.
- Promoting the cultivation and value-added processing of *A. paeoniifolius* can enhance rural livelihoods, support local economies, and create a sustainable supply chain.

1. Introduction

Plant diversity has contributed to a stable food web by sustaining biodiversity, recycling resources, and providing necessary nutrients to terrestrial creatures. The majority of the world's food, subsistence, improved lives, and economic growth comes from plant species, either directly or indirectly. So, plant species are the first step in guaranteeing food security for the world. There are various issues, despite the fact that food security aims for the sustainable use of common species [1]. There are around 30,000 kinds of plants, with about 7,000 of those being edible and used mostly to ensure human food security. The number has changed significantly over the years due to the widespread creation of high-yielding cultivars and types made possible by contemporary breeding programs [2]. Aiming to provide individuals with enhanced diets, the most recent database lists 27,000 plant species as edible [3]. The main reasons why they are negligent include short life cycles, inadequate supply, unexplored nutritional qualities, a lack of recognition, and customers' lack of awareness. Modern agriculture has caused a catastrophic loss of genetic diversity, putting many species in danger of extinction and making them an object of widespread scorn. Keeping genetic diversity has been difficult because most species are still unknown even if they can supply reliable nutrition. An alarming 77% of the world's plant species are under danger of extinction; this threat is most acute on the African continent, where 97% of the world's undiscovered plant species will see a decrease in variety and 45% of the world's plant species could go extinct by 2085 [4].

Meanwhile, 10.2 million people face hunger every year, rising to 60 million in just five years, according to FAO data. This amounts to 8.9% of the global population. Developing nations face challenges in ensuring food security as a result of rapid population growth, environmental degradation, and urbanization. Access to reliable food on a worldwide scale has been a must ever since that turning point. The primary goals of SDG 2—"Zero Hunger"—and SDG 3—"Health & Well Being"—all of which aim to eradicate hunger, guarantee food security, and improve human nutrition. The problems could be fixed by making good use of species that aren't used enough but are high in nutrients. These could be domesticated, wild, regional, semi-domesticated, traditional, or niche [5]. Finding new natural resources, which may include plant resources, is thus more important than ever. A potential solution to the nutrition and hunger problem in the context of climate change is the underutilization of plants [6]. Food, nutrition, medicine, energy, and economic benefit are just a few of the many potential uses for these unused plant resources. Stopping people from becoming hungry and avail valuable biomolecules are, thus, a step toward achieving sustainable development goals. The underutilized plants with high nutritional and medicinal potential promote good health and ensures that it is available to people of various benefits. Improving the micronutrient composition of the human diet could be significantly aided by the minerals, vitamins, and carotenoids by consuming by underutilized species. Many studies have been conducted on the SDGs of "Zero Hunger" and "Health & Well-Being," but not enough has been done on the medical and nutritional elements, nutrigenomics, economic value, and sustainability [7]. We performed a thorough investigation that is overlooked and underutilised to ascertain what these species may accomplish for food security, famine prevention, sustainable agriculture, revenue generation for small-scale farmers, and genetic diversity preservation.

The elephant foot yam (EFY), scientifically known as *A. paeoniifolius* (Dennst.) Nicolson, is a tropical tuber crop that is widely available which is a member of the Araceae family. It has been explored extensively by traditional Indian medicine due to its high protein, carbohydrates, minerals, and other nutrients [8,9]. As a vegetable, *A. paeoniifolius* corms are a popular ingredient in many mouth-watering dishes and are considered a culinary specialty. Traditional medicine has made use of *A. paeoniifolius* tuber, which has blood-purifying characteristics, to cure a variety of conditions, including rheumatism, splenomegaly, tumors, asthma, dyspnea, and gastrointestinal diseases [8,10]. It may have cytotoxic effects [11], central nervous system depressants [12], hepatoprotective effects [8], anthelminthic effects [13], and gastroprotective abilities [14] among its pharmacologically possible features. Researchers have studied the phytochemical, pharmacological, and insecticidal properties of *A. paeoniifolius*. Because it contains starch and resistant starch, the tuber can function as a functional meal, which has many positive physiological effects on people, especially those who suffer from degenerative diseases including diabetes, hyperlipidemia, obesity, and diabetes [15] . Modern scientific research and development are interested in *A. paeoniifolius* because it is useful and easy to adapt to different situations. The goal is to learn as much as possible about it so that society can benefit from its value-added products, which will help meet global needs for food security and other industrial product advances.

The present article aims to fill the gap in the existing literature on the prospective industrial crop, *A. paeoniifolius*, that can be cultivated as food at the doorstep and its use in achieving sustainable development goals. It has also been divided into further subsections: The nutritional value and global search of *A. paeoniifolius* are described in Section 2. The next part (part 3) highlights how *A. paeoniifolius's* nutrigenomics contribute to its status as a wonder food. Section 4 lists the several bioactive substances from *A. paeoniifolius* that can help prevent a number of illnesses. A thorough examination of *A. paeoniifolius* and its role in the production of bio-nanomaterials is given in Section 5. The advantages and disadvantages of employing *A. paeoniifolius* as medicines and nutraceuticals are also discussed in Section 6.

The study's findings and *A. paeoniifolius's* research potential for the manufacture of commercial functional foods with novel nutritional and bioactive ingredients are covered in Section 7. A large number of publicly accessible sources, including cited journal articles, book chapters, monographs, and online articles, are used in this manuscript. The bulk of the mentioned data are current estimates spanning the years 2010–2025, which we obtained from the electronic databases Scopus.

2. Bibliometric overview of *Amorphophallus paeoniifolius* (Dennst.) Nicolson research

The most popular database, Scopus, was investigated with the keyword "elephant foot yam" in order to ensure that the most relevant article for this review was chosen with the highest level of accuracy. The prominent nations in this regard include Indonesia, Malaysia, Thailand, Bangladesh, the Philippines, and India. India stands out among these nations for its significant research output, while South and Southeast Asia document minimal research activity [16]. The evaluation and selection process involved approximately 199 articles that were published in English-language journals, conferences, books, and book series publications. Over the course of the period between 2010 and 2025, the majority of these publications include research papers, review articles, conference papers, book chapters, conference reviews, letters, and books. All of these things point to the fact that the publication trends are growing [17]. There is a significant lack of research on clinical trials for *A. paeoniifolius* extracts, despite numerous studies showing potential benefits such as anti-inflammatory and hepatoprotective effects. On the other hand, there is more randomized controlled trial (RCT) literature (weight/constipation studies) for konjac glucomannan (*A. konjac*). Thus, most of the data for *A. paeoniifolius* has come from preclinical studies or human studies conducted on a modest scale. It is also necessary to conduct crop-physiology reviews and agronomic research such as single-site field trials, variety performance papers, and small genotype evaluations. make it clear that there is a lack of comprehensive quantitative data on yield and quality in different settings [18,19]. In **Figure 1(A)**, a network visualization was developed using the Scopus database that was retrieved. This visualization illustrates the co-occurrence of the keyword represented. In addition to this, **Figure 1(B)** represents the regions involved in such type of research.

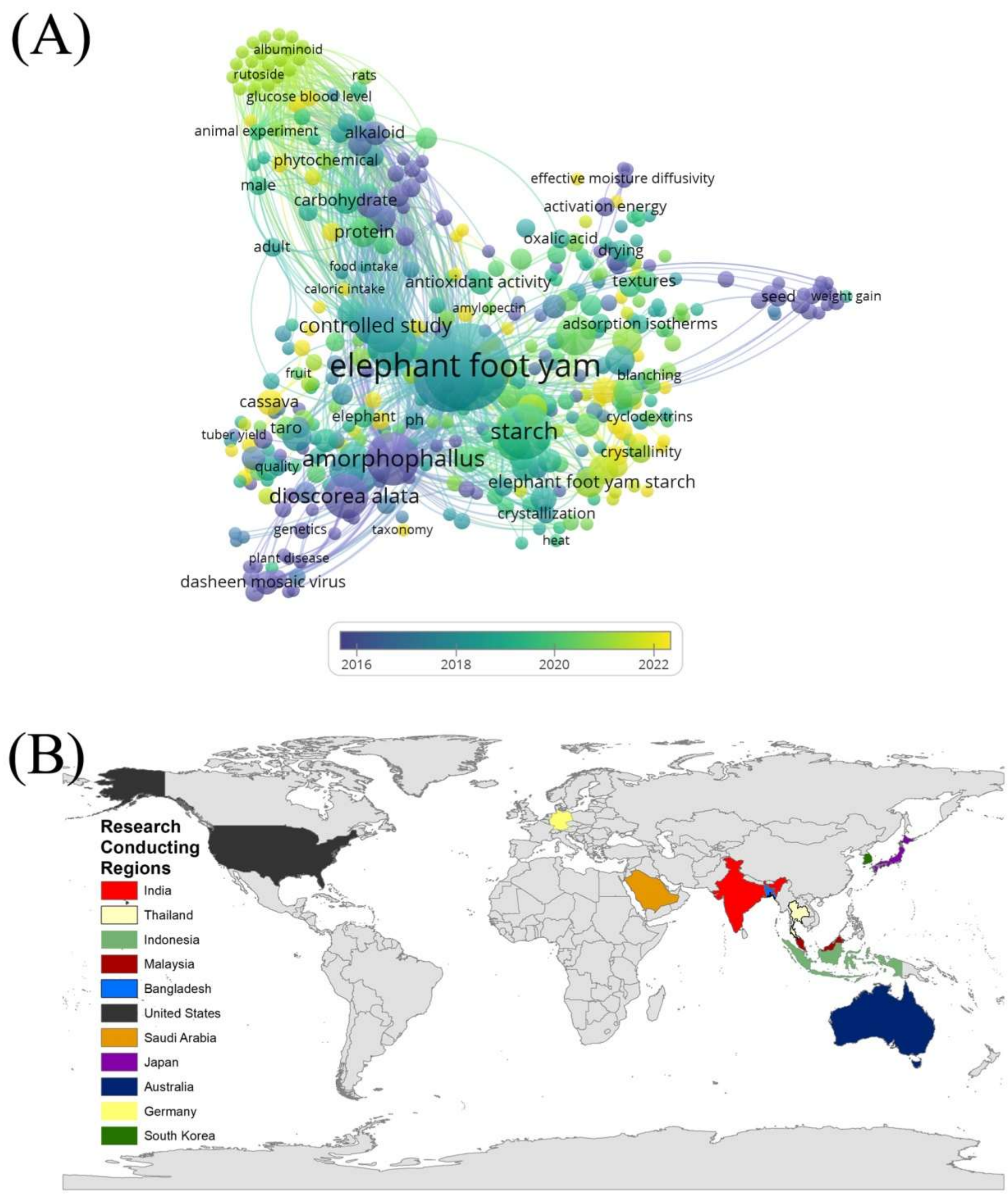


Figure 1: (A) Network visualization *Amorphophallus paeoniifolius* (Dennst.) Nicolson representing the co -occurrence; **(B)** regions involved in this research.

3. Nutritional properties of *Amorphophallus paeoniifolius* (Dennst.) Nicolson

3.1. *Steroids*

Compounds with a cyclopentanoperhydrophenanthrene ring are known as steroids. Three 6-carbon rings, A, B, and C, plus one 5-carbon ring, D, make up this structure. Steroids are made up of four rings and many functional groups like hydroxyl groups and side chains attached to them [9,16,17]. *A. paeoniifolius* tubers are good for protecting the liver as they contain steroids (β-sitosterol; **Figure 2)** which can be extracted using water or methanol [8,18]. These phytosterols improve the plant's nutraceutical potential and therapeutic relevance in the management of metabolic and cardiovascular health by stabilising membranes, lowering cholesterol, and modulating inflammatory pathways [19,20].

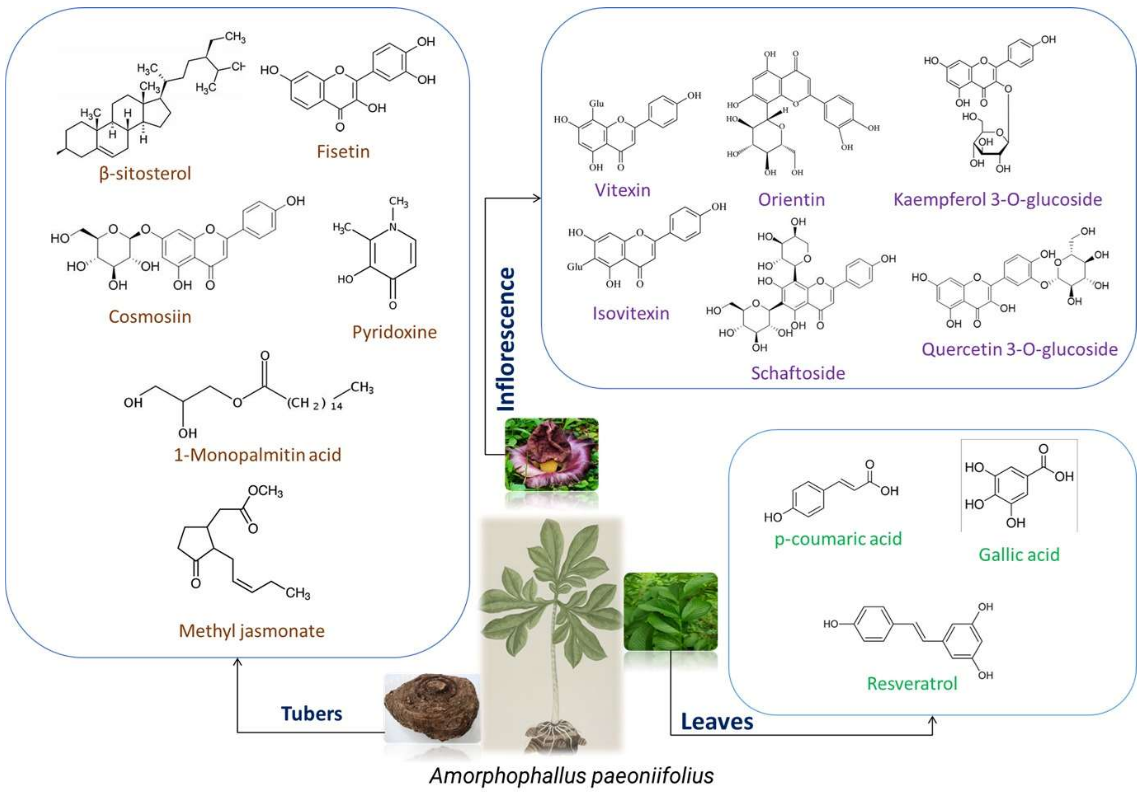


Figure 2: Chemical compounds from the plant part(s) from *A. paeoniifolius*.

3.2. *Flavonoids and Other Phenolic Compounds*

Numerous vascular plants contain chemicals known as flavonoids. Flavonoids such as Vitexin, Orientin, Isovitexin, Schaftoside, Vicenin-2, Quercetin 3-O-glucoside, Kaempferol 3-O-glucoside, Fisetin, Quercetin, Cosmosiin, (**Figure 2**) have several beneficial effects, including protecting the liver, fighting cancer, preventing bacterial infections, and reducing cell death. Other phenolic compounds such as Betulinic acid, p-coumaric acid, Gallic acid, Resveratrol etc. have also high beneficial effect. The key reasons for these effects are their free radical scavenging capabilities, propensity to form metal complexes, and excellent selectivity when attaching to proteins [21]. Nutritional and phytochemical properties of *A. paeoniifolius* are shown in **Table 1.**

3.3. *Vitamins*

Vitamins are a class of chemical molecules that play an important role in many bodily processes. Cellular activities heavily depend on vitamins, which may also contribute to the onset or prevention of cancer. People need to make sure they get enough vitamins in their diet every day because they are vital to human health [22]. Vitamins Pyridoxine (Vitamin B6), which is found in the tuber of *A. paeoniifolius*, helps fight inflammation, cancer, and other illnesses [11,23].

3.4. *Fatty Acids*

For cells, fatty acids are essential for energy production and membrane construction. The biological characteristics of these chemicals have the potential to influence the metabolism, cellular and tissue function, and sensitivity to hormones and other signals. *A. paeoniifolius* contains compounds such as 1-Monopalmitin acid, Linoleic acid, α-linolenic acid and Methyl jasmonate which are belongs to fatty acids derivatives [11,24].

Table 1. Nutritional compositions and phytochemical characteristics of *Amorphophallus paeoniifolius*

Parameter	Constituents	Functional significance	References
Proximate composition	Moisture: 70–80%; Carbohydrates: 20–30 g/100 g FW; Protein: 1.2–3.0 g/100 g; Fat: 0.2–0.5 g/100 g; Fibre: 1.5–5.0 g/100 g; Ash: 0.8–1.2 g/100 g	Provides dietary energy; low fat content; moderate protein and fibre enhance digestibility and satiety.	[25]
Minerals	Potassium: 500–1200 mg/100 g; Calcium: 20–50 mg; Phosphorus: 40–80 mg; Magnesium: 30–60 mg; Iron: 1–2 mg	Essential micronutrients for electrolyte balance, bone health, and enzymatic activities.	[26]

Vitamins	Vitamin C: 4–10 mg/100 g; Thiamine, Riboflavin, Niacin: trace amounts	Acts as antioxidant and co-factors in metabolic processes.	[27]
Major carbohydrates	Starch (~70–80% of total carbohydrate), glucomannan, soluble polysaccharides	Serves as primary energy source; glucomannan contributes to hypoglycaemic and hypolipidemic effects.	[28]
Phenolic compounds	Total phenolic content: 10–40 mg GAE/g extract (depending on solvent and part used)	Strong antioxidant and anti-inflammatory properties; contributes to free-radical scavenging.	[29]
Flavonoids	Total flavonoid content: 5–25 mg QE/g extract	Enhances antioxidant capacity; supports vascular and metabolic health.	[30]
Antinutritional factors	Oxalates: 150–400 mg/100 g; Calcium oxalate raphides; Protease inhibitors (trace)	Responsible for acridity; reduced by cooking, fermentation, or soaking.	[31]
Antioxidant potential	DPPH, FRAP, and ABTS scavenging activity comparable to ascorbic acid standards in methanolic extract	Protects against oxidative stress; potential nutraceutical value.	[9]
Tannins and saponins	Qualitatively present; tannins (1–3%), saponins (trace–moderate)	Exhibit antimicrobial and antidiarrheal activities; contribute to bitterness/astringency.	[29]
Alkaloids and steroids	Alkaloids (trace–1.5%); Steroidal compounds (stigmasterol, β-sitosterol)	Exhibit anti-inflammatory, anticancer and immunomodulatory effects.	[32]

4. *Amorphophallus paeoniifolius* (Dennst.) Nicolson - a wonder food from the perspective of nutrigenomics

By leveraging nutrigenomics and plant improvement strategies, *A. paeoniifolius* can be developed into a more nutritious and resilient crop, contributing to better health outcomes and sustainable agriculture. Some of the strategies to consider are:

4.1. Selective breeding

Identifying and choosing cultivars with advantageous nutritional characteristics, like elevated protein levels, vitamins, and minerals. Crossbreeding these cultivars may facilitate the amalgamation of advantageous characteristics. Breeding efforts could focus on increasing the amounts of important nutrients and bioactive substances in the tuber. On the other hand, growing varieties that are more resistant to diseases and pests could reduce the need for chemicals and increase crop production. Selective breeding for features that improve plants' resilience to climate change can guarantee consistent production despite harsh conditions; while selecting for better yield traits can enhance the economic viability for farmers. There are several documented cultivars that have the potential to increase the productivity of *A. paeoniifolius* in various states in India and other settings. Cultivars such as BCA-1, IGAM-1, BCA-5, and AC-28, which possess significant nutritional value, antioxidant characteristics, and adaptability for processing into products such as dry cubes, fried cubes, and pickles, should be promoted for cultivation [33]. Research on hybridization has demonstrated the feasibility of cross-species breeding in *Amorphophallus* [34]. Despite their general resemblance in appearance and various characteristics, wild and cultivated elements show significant differences.

There may be genetic resources of value in the wild relatives of cultivated species. This is especially true since cultivated species are losing their sexual ability due to selective pressures to focus more on tuber production and extreme protogyny in this genus, which encourages cross-pollination [34]. Besides collar rot, Dasheen mosaic virus (DsMV) and *Sclerotium rolfsii* are also devastating diseases that impact cultivated elephant foot yam. However, the primary focus of *Amorphophallus* improvement is on developing varieties with low acidity and increased corm size. Therefore, wild relatives can be employed in breeding programs to enhance palatability by eliminating tuber acridity, improve yield, and develop varieties resistant to collar rot and mosaic diseases [35].

4.2. Soil and Nutrient Management

To encourage healthy growth and nutrient buildup in the tubers, make sure the soil is in ideal conditions and supply enough nutrients. Establishing ideal growing circumstances, such as adequate soil, water availability, and sun exposure, is crucial to support the plant's metabolic processes. The application of growth regulators and plant hormones can activate specific metabolic pathways. Gibberellins and cytokinins, for instance, can improve the synthesis of nutrients. Fertilization is the process of supplying vital minerals and nutrients to support the metabolic activities of plants. It is a lucrative crop with superior dry matter production capacity per unit area compared to most other vegetables [36]. Indeed, mild stressors like controlled drought or salt can increase the production of several beneficial chemicals in *A. paeoniifolius*. This is because plants frequently deploy defensive mechanisms, such as the production of secondary metabolites like flavonoids, phenolic acids, and antioxidants, in response to stress. When ingested by humans, these substances can have positive health effects in addition to helping the plant handle stress. For instance, a variety of plants have demonstrated that modest drought stress increases the synthesis of antioxidants and phenolic compounds.

4.3. Post Harvest Handling

EFY faces several post-harvest challenges, including weight loss, microbial infections, and insect pests. After harvesting, the corms are treated with controlled atmosphere storage and natural elicitors to maintain their nutritional value [37]. During harvesting, the adhering soil and roots were removed, discarding damaged tubers to prevent infection. Curing, a critical process, toughens the skin and heals wounds, reducing post-harvest infection risks [38]. The curing process involves placing tubers in shaded areas for 7 to 15 days to dry and harden. After curing, we grade and carefully pack the tubers for transportation to prevent physical damage. Storage methods include ventilated, cool environments protected from rain, with studies suggesting optimal storage by covering tubers with coarse, dry sand and periodically removing damaged ones [37]. Despite these precautions, tubers may lose up to 25% of their weight in the first month, but they can remain at 10°C for several months. Various regional techniques, such as using cow dung slurry in Kerala and Andhra Pradesh or converting tubers into cakes in Tripura, extend shelf life. In India, traders or middlemen sell EFY immediately after harvest. Healthy, cleaned corms command higher prices, and Mumbai, in particular, exports some of the produce to middle eastern countries. EFY tubers are prone to several post-harvest diseases due to high moisture content and starch. Mechanical injuries during harvesting and transportation predispose them to infections by fungi and bacteria, causing significant losses. To avoid storage rot, tubers must be free from mechanical injury and pre-harvest infections, treated with fungicides, and stored in a cool, ventilated place. Regional practices like spreading ash on cut ends help prevent tuber rot and extend shelf life. Effective post-harvest treatments are crucial for maintaining the quality and market value of EFY tubers [37].

EFY tubers are vulnerable to infestation by scale insects (*Aspidiella hartii*) and citrus mealy bugs (*Pseudococcus cryptus*) during storage. Infestation typically occurs after three months, with mealybugs thriving in high temperatures and humidity, leading to shrivelled, less marketable tubers. These pests can be managed by rubbing the tubers with a soft brush or dipping coir pith in an insecticide solution [37,39]. Use fungicides like Mancozeb and insecticides like *Monocrotophos* to treat the tubers for long-term storage. In India, the root knot nematode (*Meloidogyne incognita*) and the root lesion nematode (*Pratylenchus* sp.) are major pests that hurt the economy of EFY. These nematodes, surviving in soil, infect tubers through roots, creating galls and wart-like projections. Severe infestations lead to tuber tissue dissolution and rot, reducing yield. Pathogenicity tests done at the Central Tuber Crops Research Institute (CTCRI) showed that even a small number of nematodes could greatly lower the yield of tubers [39].

Root knot nematodes continue to feed and multiply inside the tubers post-harvest, during transportation, and storage, causing weight loss and rotting due to moisture evaporation and tissue damage. Infected tubers develop a dry rot appearance and become susceptible to fungal invasion [39]. Nematodes of the genus *Pratylenchus* make sores on roots, corms, and cornels. These sores spread as the number of nematodes grows, which causes the surface to crack. Tamil Nadu grows the *Karunai kizhangu* variety, where this nematode is particularly severe. Additionally, another nematode species, *Tylenchorynchus indicus*, causes severe damage to EFY tubers in storage conditions in Bihar. Effective management of these nematodes is crucial to prevent significant yield and quality losses in EFY tubers [37]. Scale insects, while causing minor weight loss, can lead to tuber shrinkage. They can be controlled using cassava seed extract or chlorpyrifos. Termites and wireworms also present a threat, leading to partial or complete damage to the tubers. Effective pest management is essential for maintaining the quality and market value of EFY tubers during storage.

4.4. Genetic Engineering

The introduction or enhancement of biotechnological tools can identify specific genes involved in nutrient synthesis. This can result in improved health benefits and higher-quality nourishment. Tools like CRISPR/Cas9 and other genetic engineering methods can be used to add or increase genes that make bioactive substances and nutrients to enhance the nutrigenomics of *A. paeoniifolius* [40]. The main focus should be on improving the metabolic pathways responsible for synthesizing essential nutrients and bioactive compounds such as vitamins, antioxidants, and other beneficial compounds. Manipulating gene expression pathways can also boost the production of desired nutrients with techniques like RNA-Seq analysis which can identify genes that are upregulated or downregulated in response to specific nutrients [41]. Additionally, investigating epigenetic changes that influence gene expression and nutrition is a useful factor. metabolism can help develop plants with improved nutritional profiles. Epigenetic modifications can be influenced by diet and environmental factors [41]. Proteomics can identify key proteins involved in nutrient synthesis and metabolism. Moreover, studying the complete set of metabolites in the plant and understanding how they are affected by genetic and environmental factors can help identify metabolic pathways that can be targeted for improvement. Recent studies, such as the complete chloroplast genome and phylogenetic analysis of *A. paeoniifolius* were examined which provided valuable insights into the genetic makeup of the plant and its evolutionary relationships. This information can be used to identify potential genetic targets for enhancing nutrigenomics [42]. Gene prospecting and allele mining can identify these economically important genes, which conventional or biotechnological approaches can use for crop improvement. Effective characterization of crop germplasm, which involves evaluating the extent and distribution of genetic diversity, is crucial for its optimal utilization and conservation. This can be accomplished using both morphological and molecular techniques [43].

4.5. Research and collaboration

Collaborating with research institutions to study the plant's metabolic pathways and identify key enzymes and genes involved in nutrient synthesis of *A. paeoniifolius* and identify key enzymes and genes involved in nutrient synthesis is a great approach. This knowledge can guide targeted interventions. Combination of these approaches, can effectively enhance the metabolic pathways in *A. paeoniifolius*, leading to improved synthesis of essential nutrients and bioactive compounds. **Figure 3** illustrates nutrigenomics perspective of *A. paeoniifolius.*

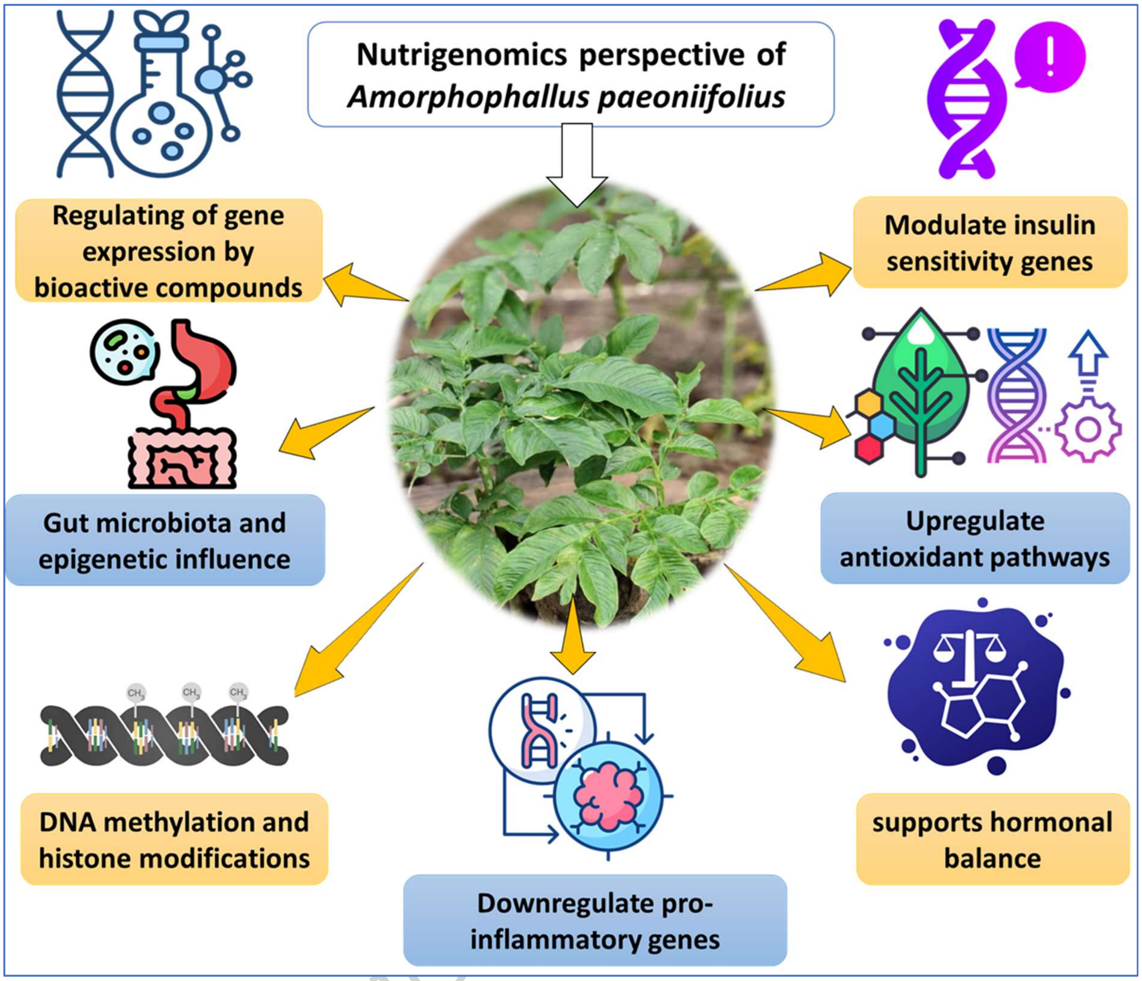


Figure 3: Various aspects of nutrigenomics approach for *A. paeoniifolius*

5. Health benefits of *A. paeoniifolius* from the perspective of nutrigenomics

A. paeoniifolius, referred to as EFY, has several health advantages in the context of nutrigenomics. In Southeast Asian nations, it proliferates naturally and is farmed as a vegetable. In numerous regions globally, the round tuberous rootstock or corm serves as a significant food source [44]. The plant, especially the corm, has been historically utilized for the treatment of various conditions, including tumors, inflammation, rheumatism, hemorrhoids, arthralgia, elephantiasis, bronchitis, asthma, dyspepsia, colic, constipation, splenopathy, hepatopathy, amenorrhea, dysmenorrhea, seminal weakness, fatigue, and general weakness, among others [45]. The corm exhibits a range of properties, including antioxidant, antibacterial, hepatoprotective, apoptotic, antidiabetic, nephroprotective, immunomodulatory, anti-inflammatory, analgesic, neuroprotective, hypolipidemic, anthelmintic, anticancer, anticonvulsant, central nervous system depressant, anti-colitic, anxiolytic, and anti-osteoporotic effects. *A. paeoniifolius* tubers contain several phytochemicals, including diterpenoids, triterpenoids, triacontane, saponin, rutin, lupeol, betulinic acid, gallic acid, resveratrol, quercetin, stigmasterol, β-sitosterol, and its palmitate [46,47]. The elephant foot yam contains thiamine, riboflavin, niacin, carotene, glucose, galactose, rhamnose, and xylose as significant nutritional components. The plant's varied pharmacological qualities are believed to be caused by a variety of active phytochemicals, supporting the long-held belief that it has therapeutic benefits for a broad range of illnesses. Given the potential benefits of *A. paeoniifolius* for human health, efforts should be made to promote both its cultivation and the creation of goods with enhanced nutritional and medicinal value [48].

A. paeoniifolius, commonly known as elephant foot yam, is a tuberous plant that has garnered attention for its nutritional and medicinal properties [49,50]. From the perspective of nutrigenomics, this wonder food offers several health benefits due to its rich phytochemical composition and potential to interact with genetic factors to promote health. EFY has the ability to thrive in marginal soils, even with little annual rainfall, which makes it a reliable source of nourishment during droughts and floods. After being boiled or baked, the corms are eaten as a vegetable and are high in vitamin A, calcium, and phosphorus. Native Indian tribes consume the leaves as a vegetable, and they are also rich in vitamin A. A nutritious, low-fat snack, elephant foot yam is high in the vital Omega-3 fatty acids that raise excellent cholesterol levels. EFY raises women's estrogen levels and helps maintain hormonal balance [51]. It also contains a high amount of vitamin B-6, which helps with premenstrual syndrome. It is a great slimming food because of its high fibre content, which lowers cholesterol and encourages weight loss. Furthermore, it contains a significant concentration of essential minerals. Individuals accustomed to starch-rich diets may lack awareness regarding the nutritional benefits of newly developed high-yielding varieties of EFY. This study seeks to enhance crop productivity and reduce the acridity of corms through the selection of non-acrid cultivars, while highlighting their nutritional importance. Efforts are being implemented to improve the profitability and popularity of this crop.

While consumers often select varieties based on flavour, texture, and colour, it's important to consider those with a better nutrient profile as well [33]. Due to its high tuber productivity and popularity as a vegetable in a variety of cuisines and its therapeutic properties, it is a cash crop in India that provides farmers with significant financial benefits, earning it the title of the 'king of tubers.' The petiole and young inflorescence serve as a delectable vegetable. It is a source of carbohydrates, proteins, minerals such as calcium, iron, and phosphorus, as well as vitamins A, B, C, flavonoids, and fibre [34]. The corms of *Amorphophallus* have aperient, carminative, and uterine stimulant properties, as well as hepatoprotective, antioxidant, and uterine stimulant properties. expectorant properties. The corm extract is utilized to address hemorrhoids, dysentery, piles, diarrhea, and acute rheumatism, and is incorporated into traditional remedies for the treatment of inflammatory diseases and ophthalmia. In traditional medicine, the crushed seed is used to treat toothaches, rheumatic swellings, tumor growth, lung swelling, asthma, vomiting, stomach pain, hemophilic disorders, obesity, dyspepsia, debility, and intestinal worms [34].

6. *Amorphophallus paeoniifolius* (Dennst.) Nicolson as a source of pharmacological compounds: exploring the potential activities

The *A. paeoniifolius* plant has been utilized as a source for a variety of various disease-curing activities; however, the majority of these activities are utilized from an ethnomedicinal perspective [48]. The development of innovative technologies and additional research in the following years led to a thorough investigation of this plant. It has been discovered that it may have pharmacological effects, which justify conducting additional research on it in order to discover what other applications it might have (**Figure 4**).

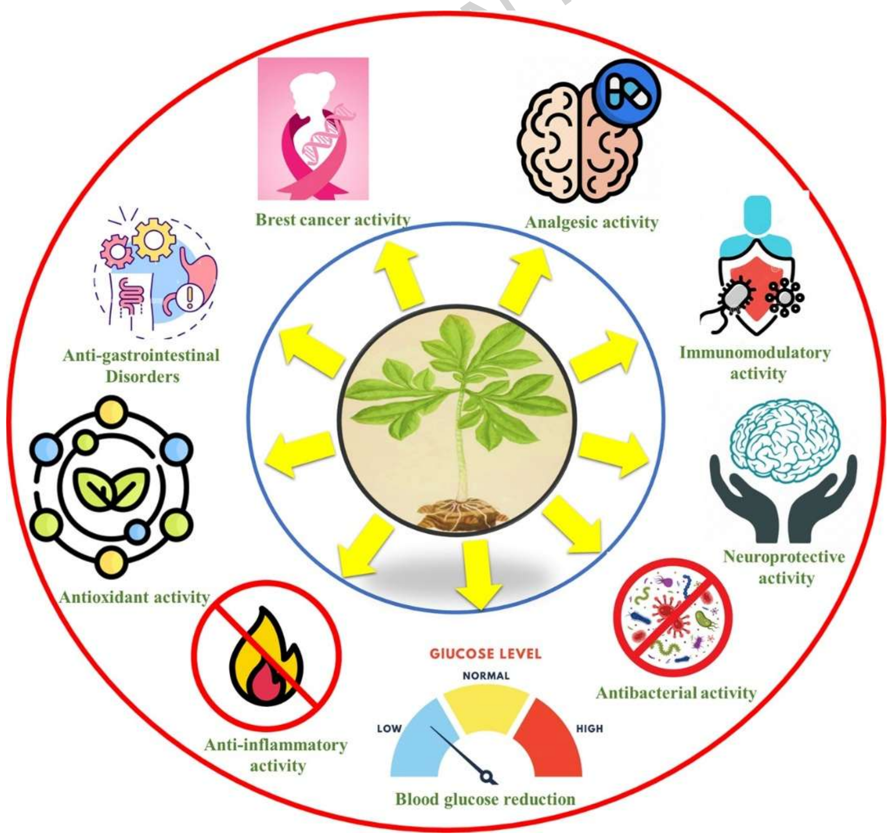


Figure 4: *Amorphophallus paeoniifolius* based different pharmacological activities.

6.1. *Antibacterial Activity*

According to a study conducted four different species of bacteria—*E. coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Streptococcus mutans*—were suppressed by different doses of ethanolic tuber extracts, respectively [52]. The presence of phenols, glycosides, polysterols, tannins, flavonoids, terpenoids, gum, steroids, and mucilage in the *A. paeoniifolius* extract may responsible for bacterial inhibition. Moreover, ethyl acetate extract exhibited activity against *B. subtilis* and *S. aureus*. The *K. pneumoniae* is also inhibited by the aqueous extract of *A. paeoniifolius* [53]. Substantial antibacterial efficacy against *B. subtilis*, *P. aeruginosa*, *S. aureus*, *E. coli*, *S. typhimurium*, and *C. freundii* was demonstrated by *A. paeoniifolius* tuber-derived nanoparticles [54].

6.2. *Antioxidant Activity*

The body produces unstable molecules known as free radicals when exposed to external stimuli [55,56]. These radicals are defended against by antioxidants in the cell. The administration of an ethanol extract derived from *A. paeoniifolius* to Wistar rats at dosages (1-50 µg/mL) resulted in a significant reduction in lipid peroxidation, the formation of free radicals by oxidation, and the activity of H_2O_2 scavenging. The extract contains a number of phenolic components, including gallic acid, resveratrol, and quercetin, all of which show scavenging activity [57].

6.3. *Anticancer effect*

The metastatic change of normal cells into cancer cells is the culmination of a chain of events that is triggered by mutations in DNA. Additionally, polyphenols and phytosterols have the potential to improve cancer treatment when used in conjunction with anticancer drugs [58]. This is because they have the ability to influence a wide variety of signal transduction pathways that are crucial to cancer. In a study with estrogen-positive MCF-7 and triple-negative MDA-MB-231 breast cancer cells at different doses, *A. paeoniifolius* (Dennst.) tuber extract was used for adhesion, migration, invasion, and cytotoxicity tests. These two cell lines exhibited a number of characteristics that were indicative of an increase in cell death. These characteristics included decreased motility, increased levels of pro-apoptotic Bax and anti-apoptotic Bcl-2, production of caspase-7, breakdown of PARP, and apoptosis. Therefore, the significant cytotoxic impact of the extracts was dependent on both the amount of time and the amount of dose [11].

6.4. *Blood glucose reduction*

Mung beans and yams have been shown to be an efficient combination that can considerably lower levels of cholesterol, triglycerides, and low-density lipoproteins (LDL) while simultaneously increasing levels of high-density lipoproteins (HDL). The levels of the hormone leptin were decreased in albino mouse models when they were fed 0.054 g and 0.216 g per 100 g body weight of this mixture. This resulted in a statistically significant improvement in atherogenic indices ($p < 0.01$). In the same way that statins do, glucomannan from A. paeoniifolius could stop HMG-CoA reductase from working and lower the production of LDL, which led to hypolipidemic activity [59]. As much as 100 mg/200 g of body weight of porang glucomannan was given to thirty Sprague Dawley rats with metabolic syndrome, their lipid profiles got better. The researchers found that total cholesterol, total fat, and LDL all decreased while HDL increased.

6.5. *Immunomodulatory activity*

Evidence of the immunomodulatory effects of tuber-derived MEAC was shown by a sub charcoal clearance in rats given 250 and 500 mg/kg doses, indicating that the immune system was suppressed in a dose-dependent manner according to the results [60]. Figure 4 shows the dose-dependent suppression of the immune system by charcoal extracts in rats given dosages of 250 and 500 mg/kg [60]. The adult Indian earthworm, *Pheretima posthuma*, was given extracts of *A. paeoniifolius* at 25, 50, and 100 mg/mL of concentrations, and both the adult and tubifex parasites were effectively killed by the extracts. It was both vermifugal (paralyzing) and vermicidal (killing) to the earthworms.

6.6. *Analgesic Activity*

The development of analgesics aimed to alleviate or eliminate pain. Numerous diseases and pathologic situations have been associated with them. It is essential to establish whether analgesics are required, for instance, for the treatment of headaches and muscle aches, in the meanwhile making sure that becoming dependent on the drug isn't a possibility. It was shown that *A. paeoniifolius* extracts (250 and 500 mg/kg body weight) can ease pain when given intraperitoneally to male Swiss albino mice. There are a number of chemicals that have analgesic effects, including steroids, alkaloids, and flavonoids. Because these chemicals can either stop the cyclooxygenase enzyme from working or make the β receptors in the brain work harder [61], they can have two different effects.

6.7. *Neuroprotective Effects*

A therapy is neuroprotective if it blocks or reverses the pathogenetic cascade that promotes cell dysfunction and death [62]. The *A. paeoniifolius* tuber PEEs made animals very tired and slowed them down at the given doses (100-1000 mg/kg). Disrupting cortical functions could be the source of this central nervous system depression [12]. The PEEs components can cause the cells to hyperpolarize and observe depressive effects in the central nervous system by blocking the GABA-mediated Cl^- channel opening. Based on these findings, PEEs have calming effects on the central nervous system through the GABAA receptor [63]. The *A. paeoniifolius* PEEs (at 100, 150, and 200 mg/kg), which are made up of lipids, steroids, and fixed oils [64], showed more neuroprotective effects.

6.8. *Anti-Inflammatory Activity*

Reducing OS can lower inflammation, but prolonged stress raises inflammation and the blood control level [65,66]. The anti-inflammatory actions of the *A. paeoniifolius* methanol extract are significantly higher than those of the chloroform extracts. Following three hours of carrageenan administration, methanol extract at 200 mg/kg blocked 37.55% of the enzymes activated by carrageenan, whereas at 400 mg/kg it blocked 45.83%, in comparison to the control group. This is because AP has flavonoids and alkaloids, which have anti-histaminic properties and prevent the secretion of serotonins and histamines [67].

6.9. *Anticonvulsant Activity*

It can be hypothesized that the anticonvulsant effects of *A. paeoniifolius* PEEs are caused by the presence of steroidal chemicals. It is possible that these medicines will enable allosteric receptors or minimize rendering them inactive through augmentation the production and release of GABA into the body. It is possible that the PEEs exhibited a dose-dependent effect with regard to the beginning of convulsions in male albino mice that were induced with isoniazid at dosages of 200, 300, and 400 mg/kg [68].

6.10. *Prevention of Gastrointestinal Disorders*

In developing countries, acute diarrhoea is one of the leading causes of mortality among infants. Despite the fact that these plants have anti-diarrheal properties, there is no scientific evidence to support the therapeutic procedures used by traditional practitioners [69]. Prostaglandins were made more and spasms happened when the water and methanolic extracts of *A. paeoniifolius* were used. This was because they contained betulinic acid and glucomannan, respectively. Giving the doses (250 mg/kg - 500 mg/kg) of these extracts to Wistar rats while making their stomachs move caused a lot more gastric emptying, intestinal transit, faeces volume, faeces water content, and faeces frequency [70]. By giving APMEs (250 and 500 mg/kg) to albino male rats, the free acidity, stomach volume, total acidity, ulcer score, and pH all went down. The polyphenols in the extract may have helped prevent ulcers by raising GSH levels and lowering lipid peroxidation [71]. This may be why the protection rate was 67% at 250 mg/kg and 85.5% at 500 mg/kg. When given to Swiss albino mice in doses of 100, 200, and 400 mg/kg, the leaf extracts of *A. paeoniifolius* greatly decreased the number of times they had diarrhoea and how bad it was. Rats that had trouble going to the toilet were given 125, 250, or 500 mg/kg of APME and APAE, which are tuber extracts of the plant. These extracts contain glucomannan and betulinic acid. The animals' faeces and intestinal transit time got a lot better. Since betulinic acid shows a spasmogenic effect as a result of partial agonistic action in the 5HT receptors, it is possible that it is responsible for this behaviour [46].

7. Culinary and different food habits through *Amorphophallus paeoniifolius* (Dennst.) Nicolson

In the Indian states of West Bengal and Assam, as well as in neighbouring Bangladesh, *A. paeoniifolius* is most commonly served mashed, fried, or added to curries; pickle or chip recipes call for it less frequently [35]. Certain cultures also consume the stems and leaves, either raw or cooked, as a type of vegetable. Chutney, pickles, and curry are common in Bihar. The people of Chhattisgarh consider it a delicacy, and they consume it like curry. In Odisha, people consume it as curry, chutney, and paste. In Tripura, people remove the raphides (needles of calcium oxalate) by making a paste with water and sodium bicarbonate (baking soda). After shaping the buns, they boil the paste in water containing baking soda. The water is then discarded. After that, the buns are sliced and mixed with mosdeng, a spicy paste made of dried shrimp and chili peppers, and fresh garlic paste. You may also cook up some chopped leaves and stems to eat. The tuber has a long history of use in the cuisine of southern Indian states like Kerala. Curry is a popular accompaniment to rice in Tamil Nadu, but steaming portions with a traditional chutney of green chile, coconut oil, shallots, and garlic is the most usual way to eat it. Typically, people cook it into a thick chutney to serve as a side dish with rice. In Andhra Pradesh, the tuber is a traditional vegan stew that is made with Indian spinach leaves, tamarind pulp, and spices. People serve and eat it during devotional feasts and significant festivities like baby showers and housewarmings. People also fry it in thin strips or slices, similar to potato fries, as a snack [72]. Along with the more well-known tapioca, it has been the primary source of carbs for millennia, particularly during times of famine in the region. Curry can also be made from the flower bud, just before it opens its petals. You may utilize every component of the flower to make a variety of side dishes. As a curry, it is a staple during the Jitiya and Deepawali celebrations in Nepal. In the Philippines, people consume the young stems, leaves, and corms either raw or cooked as a vegetable. The stinging oxalate crystals are destroyed by cooking them completely.

8. Biomaterials from *Amorphophallus paeoniifolius* (Dennst.) Nicolson

While exploring *A. paeoniifolius* as a potential food and nutraceutical entity, it is also another important issue to make appropriate preservation for extending the shelf life as well as transportation over a long distance. Although *A. paeoniifolius* has already gained recognition as a potential and nutritious food, the long-term preservation of food packaging has become a major concern [73]. The long-standing practice of using plastics or other materials for food packaging has become a global concern due to environmental pollution and its detrimental effects, prompting the "zero plastic" movement. Given its composition of numerous macromolecular complexes, *A. paeoniifolius* presents itself as a promising candidate for the production of various food packaging materials.

Nanotechnology is rapidly emerging as the primary solution for almost all human problems. Starch nanoparticle modification can aid in the development of starch-based biofilms. In general, starch is not very soluble, quite thick, easily gelatinized, and has a retrograde tendency. However, according to Le Corre and Angellier-Coussy, (2014), natural starch molecules can be enhanced with nano-starch (NS) to provide better mechanical and thermal properties. According to Amigo et al., (2019), starch nanocomposites can have better physical properties and be more biodegradable when NS is added. In addition, new research has shown that the surface functionalization of polymeric molecules with bioactive chemicals has further benefits. For instance, according to Abdullah et al., (2020), ZnO nanoparticles improved starch-based biofilms' tensile strength, density, hydrophobicity, thermal stability, and antibacterial characteristics.

Ali et al., (2023), assert that the production and marketing of bioplastics and biofilms are impeded by insufficient sophisticated technology and marketing challenges concerning feedstock availability, supply, and cost. Nonetheless, in the context of sustainable bioresource utilization and environmental conservation, biodegradable polymers are unequivocally significant. Starch-based biopolymers can facilitate the growth of the bioplastics industry by offering a sustainable substitute for synthetic plastics.

Starch follows cellulose as the most common natural biopolymer. There are repeating units of α-D-glucose residues and is the main food source for all photosynthetic organisms [78]. The two main building blocks of this semi-crystalline biopolymer are linear amylose and amylopectin branches. Corn (82%), wheat (8%), potatoes (5%), and cassava (5%) are the primary ingredients in commercially available starches [78,79]. On the other hand, according to Ahmad et al., (2020), starch can be found in plant roots and subterranean modified stems of Araceae family members. The size of the microscopic granules that make up the native starch ranges from 2 to 100 µm. Starch is extensively utilized in various food products such as sauces, yoghurts, puddings, snacks, bread, and pasta, attributed to its bioavailability, cost-effective production, renewability, and distinct physicochemical properties [81].

EFY corms are a potential source of starch for biofilm preparation. The ability to form films was also improved by replacing native starch molecules in conjunction with NS and tannic acid-coated nano-starch (T-NS). These new types of starch were made by physically and chemically changing the original starch molecules [82]. Reinforcing with NS and T-NS made the material much thicker, denser, and stronger by lowering its solubility, water vapour transfer, light transmission % and contact angle. The biofilms coated with T-NS showed increased toughness in the salt, acid, and alkaline solutions. They also showed antimicrobial properties that could potentially inhibit both gram-negative (*Salmonella typhimurium*, *E. coli*) and gram-positive bacteria (*Bacillus megaterium*, *Staphylococcus aureus*) and remarkable biodegradation potential **(Figure 5)**. The results of this study shed light on the possibility of using nano-starch and antibacterial chemicals to functionalize them as a material for food packaging. Further research is necessary to increase the mechanical strength of these biofilms and control their production cost before they can potentially replace synthetic polymers in commercial settings [83].

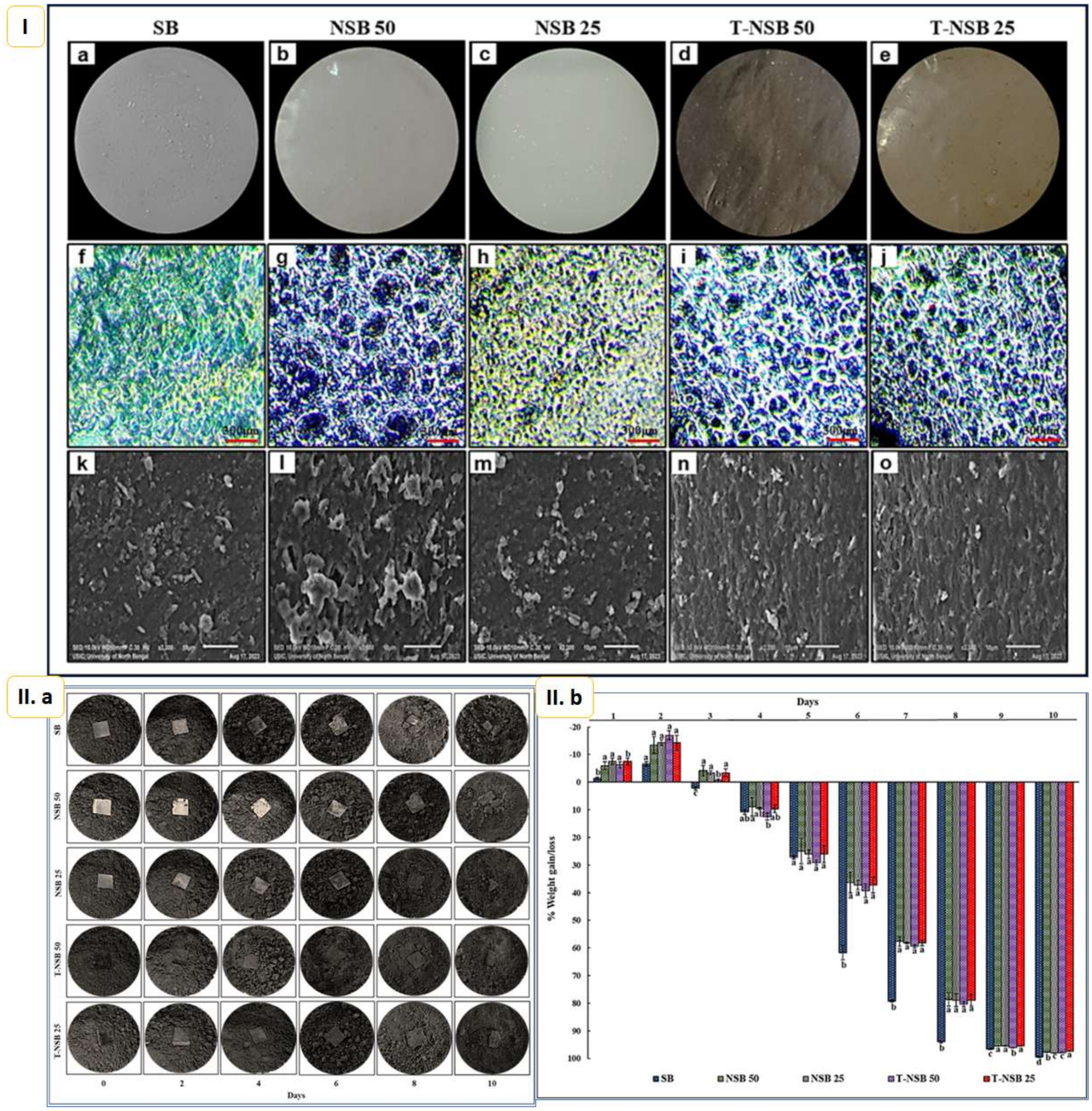


Figure 5: **(I)** Morphological appearance and transverse section of the biofilm made using Elephant foot yam. **(II)** Biodegradation of the biofilm samples **– (a)** timely digital images of the biofilm after being buried in the soil **(b)** graphical representation of the biofilm degradation percentage. Reproduced with permission from [82] Copyright © [2025] [Elsevier]. All rights reserved.

EFY starch nanocomposite film showed promise as a material for eco-friendly packaging after adding nanocrystal cellulose nanoparticles, which enhanced the film's physicochemical, mechanical, and permeability characteristics [83]. In addition to their usage in food packaging biomaterials, nanomaterials developed from A. paeoniifolius have potential in the delivery of drugs to combat disorders linked to cancer. Zinc oxide nanoparticles encapsulated in chitosan (Ch-Ap-ZnONPs) were found to be less hazardous to normal cells and more toxic to MCF-7 cells in an in vitro model developed by *A. paeoniifolius*. Ch-Ap-ZnONPs were discovered to be an effective anticancer drug that induced cell death in breast cancer cell lines, therefore regulating their proliferation in vitro [84]. The use of fluorescence labelling A/O:EB and DAPI techniques confirmed the induction of apoptosis by Ch-Ap-ZnONPS within IC50 concentrations, and they further removed the nuclear fragmentation and chromosome condensation. When administered in a dose-dependent fashion, the nanocomplex successfully halted cell cycle progression in a specific G2/M phase. The results showed that compared to normal cells, the MCF-7 cell line's apoptotic gene and protein expressions were up-regulated and down-regulated by Ch-Ap-ZnONP$_S$ treatment. The antibacterial activity of *A. paeoniifolius* tuber-mediated synthesized AuNPs and AgNPs was investigated against two Gram-positive (*Bacillus subtilis* and *Staphylococcus aureus*) and four Gram-negative (*Pseudomonas aeruginosa, E. coli, Salmonella typhimurium, and Citrobacter freundii*) bacteria that exhibited potential antagonistic activities [85].

9. Product formulations using *Amorphophallus paeoniifolius* (Dennst.) Nicolson

The utilization of *A. paeoniifolius* represents a significant opportunity as an edible tropical tuber crop, characterized by its substantial starch and protein content, along with a variety of other nutrients. However, its cultivation remains limited, and the preservation of fresh yam poses challenges due to the rapid onset of deterioration. As it grows naturally in forests that have not much commercially explored. Based on the findings of studies conducted by Sundaramoorthy et al., (2015), it has been demonstrated that the combination of drying techniques and the blanching process has considerably enhanced the feasibility and viability of the option in food compositions. It is for this reason that the preservation of *A. paeoniifolius* would be an essential step in the process of discovering the nutraceutical potential of *A. paeoniifolius*. *A. paeoniifolius* flour is presently being used in conjunction with wheat flour to create cookies that are currently on the market [86]. This decision was made in light of the prospective applications of *A. paeoniifolius*. The incorporation of *A. paeoniifolius* flour resulted in a decrease in the amount of gluten present in the wheat flour, which has the potential to be an advantageous component in the formulation of these cookies that are going to be included. For the most part, the physicochemical properties of *A. paeoniifolius* flour are comparable to those of wheat flour. Additionally, yam does not include gluten or gluten derivatives. *A. paeoniifolius* has garnered the least amount of attention when it comes to the creation of cookies. The result of this is that a novel cookie has been developed with a combination of functional ingredients [48]. This cookie will not only lessen the prevalence of lifestyle-related disorders, but it will also satisfy the need for functional foods to a greater extent and at a price that is more accessible. This cookie formulation not only has the potential to enhance the overall nutritional value of yogurt but also its biological functionality, attributed to its high fibre content and low glycaemic index [87]. Furthermore, it possesses the capability to improve the texture quality of yogurt, resulting in a more consistent texture. It is crucial to consider the amount of flour added, as the tasters often show a preference for maintaining the familiar sensory qualities of yogurt.

For ready-to-eat elephant foot yam, the osmotic dehydration process was optimized by comparing raw and optimized samples' quality. The optimized and raw samples revealed major protein concentration changes, but fat, ash, and phenolic content remained the same. Compared to raw samples, the optimized sample had decreased hardness, water activity, and oxalate content and increased crude fibre. Optimized osmo-dried samples had less micro-structural change than non-osmotically dried samples. It was found that the optimized product tastes excellent and has the same nutritional value as raw elephant foot yam samples, allowing for its regular use for therapeutic and nutritional purposes [88].

10. Challenges and Opportunities

Tuber of EFY is associated with acridity (itchy sensations in the mouth and throat) upon oral consumption. Because of crystals of calcium oxalate due to which consumers experiences with itching and hence irritating. This tuber crop requires fairly long growing season and rainfall during the growing period (April to July). A well-drained soil of medium texture is suited for growing the crop. EFY is traditionally cultivated in Indian states such as Andhra Pradesh, Tamil Nadu, Kerala, and West Bengal; however, literature lacks statistics on the area of cultivation, production, and yield of this crop, as well as data on farm income measures and resource-use efficiency of the corm. Moreover, for commercial cultivation, it needs rationalization in use of fertilizers. Proper agro-technology must be developed alongside the reorganization of farm resources to maximize returns on EFY farms across various production systems in India. EFY has a shelf-life of about two weeks at room temperature. Under the cold storage condition, it can last for up to a month. Therefore, individually wrapped and packed in ventilated, corrugated cardboard boxes lined with food-grade plastic to maintain freshness during transit. Henceforth, genetically improved, high humid resistance, low fertilizer input variety may play a vital role for commercial propagation. EFY, a Southeast Asian origin and generally wild-growing habitat, is a highly potential tropical tuber crop. It's become a very popular vegetable in certain regions because of its source of carbohydrates, minerals, and vitamins A & B. Due to its potentiality as supplementary food, it offers excellent export potential from tropical regions like India. Though the plant is not generally cultivated commercially, due to its shade tolerance, high productivity, fewer incidences of pests and diseases, and growing demands with reasonably good market value, it exhibits tremendous potentiality for commercialization.

Due to rising consumer demands, EFY may emerge as a lucrative and lucrative stem tuber crop. After thorough cooking, tender stems and tubers are primarily used as vegetables. It provides heart-healthy nutrients like potassium and fibre. While potassium helps to maintain healthy blood pressure levels, fibre is known for its capacity to lower cholesterol levels. The tuber's omega-3 fatty acids can improve cardiovascular health overall and reduce the risk of heart disease. An important part of the Ayurvedic medical system is the tuber. This plant's tuber is used as food and has important therapeutic qualities. EFY tubers are an important component of many traditional Ayurvedic and Unani medicinal formulations. In addition to being used medicinally to treat ailments like piles, asthma, dysentery, and other abdominal disorders, the tubers are known for their possible blood-purifying qualities. Local cultivars that grow naturally are usually used in the northern and eastern states of India to make pickles, vegetables, and traditional Ayurvedic treatments for a variety of illnesses.

11. Contribution to SDGs, Zero-waste potential and future Aspects

A. paeoniifolius contributes to the United Nations-SDGs through its nutritional, environmental, and socioeconomic potential. Its high levels of carbohydrates, fibre, and micronutrients help to achieve SDG 2 by improving food security and dietary diversity, especially in rural and undernourished areas. Yam cultivation directly supports SDG 1 and SDG 8 by creating jobs for small and marginal farmers and supporting the growth of value-added food and nutraceutical industries. Its bioactive ingredients, which have antidiabetic and antioxidant properties, help achieve SDG 3 by encouraging preventive healthcare. As a resilient crop that can withstand drought, it advances SDG 13 by promoting climate-resilient agriculture and advances SDG 15 by preserving biodiversity and soil fertility. Utilising yam processing waste to make compost, bioplastic, or animal feed supports SDG 12, which encourages a circular bioeconomy. Research on yam-based nutraceuticals and biodegradable packaging highlights yam's holistic contribution to sustainable food systems and rural development, while promoting women's involvement in cultivation and processing advances SDG 5.

In the arena of food preparation, making use of all the components of the plant reduces food waste and promotes the establishment of a circular economy. More crop diversity, conservation of genetic resources, and reduced dependence on monoculture all arise from the cultivation of this crop. Agricultural forestry initiatives using this plant can be capable of improving the soil microbiome and strengthen the ecosystem. Therefore, this work establishes how *A. paeoniifolius* can play a role towards a circular economy whereby resource utilization is optimized and waste generation along supply chains is minimized. The tuber can be processed into flour, chips or dietary fiber supplements and the leftovers of leaves and other parts added to animal feed to increase its nutritional content. The plant's fibers contain multiple uses, including the ability to create both compost and biodegradable packaging, that also helps improve soil health.

To clarify the processes behind *A. paeoniifolius's* bioactive and therapeutic qualities, future studies should concentrate on thorough molecular and biochemical characterisation. Key functional compounds and their biosynthesis pathways can be identified with the help of advanced omics-based techniques like proteomics, transcriptomics, and metabolomics. To improve yield, nutritional quality, and consumer acceptability, research on postharvest handling, processing technologies, and agronomic practice optimisation is also crucial. In order to guarantee the safety and effectiveness of nutraceutical formulations, toxicological and clinical assessments ought to be given top priority. Additionally, creating green extraction and biorefinery methods can reduce waste production and encourage sustainable use. Studies on life-cycle assessments and socioeconomic factors would also shed important light on its function in sustainable food systems. *A. paeoniifolius* will become a model crop for food security and nutraceutical innovation in a circular bioeconomy framework more quickly if these multidisciplinary efforts are integrated.

12. Conclusions

A. paeoniifolius, a tropical tuber that isn't used much, has a lot of potential for making sure that people have enough food and nutrients because it has a lot of nutrients and bioactive compounds. It is a crop that will be sustainable in agri-food systems of the future due to its adaptability to marginal soils, low input requirements, and resilience to harsh weather conditions. In addition to its high fibre and carbohydrate content, the tuber contains valuable phytochemicals like alkaloids, flavonoids, and phenolics that have strong anti-inflammatory, antidiabetic, and antioxidant effects. Its potential as a sustainable nutraceutical ingredient is indicated by these qualities, which also increase its functional food value. Scientific developments in processing technologies, like enzymatic treatment, fermentation, and biorefinery techniques, can effectively lower antinutritional factors and increase the bioavailability of important metabolites. Additionally, its incorporation into value-added formulations such as functional snacks, nutraceutical powders, and fortified flours promotes waste valorisation and the circular bioeconomy. More multidisciplinary studies on molecular characterisation, bioactivity verification, and scalable processing techniques are necessary to realise its full potential. In the context of future-ready nutraceutical innovations, *A. paeoniifolius* is an underutilised but promising crop that has the potential to bridge the gap between global food security, health promotion, and sustainable agriculture.

Author Contributions:
Conceptualization, S.M, Y.K.M.; software, S.R.; validation and analysis, R.T., A.S., S.R, Y.K.M. and B.M.; resources, Y.K.M.; writing—original draft preparation, J.P., A.N., B.M., R.T., A.S., P.C.N.; writing—review and editing, S.K.A, S.R., P.C.N. and Y.K.M; supervision, S.M., Y.K.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No

Acknowledgments: The authors are highly indebted and extend their sincere thanks to respective institution to provide amenities to develop this manuscript. JP and AN gratefully acknowledge the financial support provided by the DST-ANRF, Government of India, under Grant No. (ANRF/IRG/2024/000596/LS). This support was instrumental in facilitating the research and development activities presented in this work.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Clinical trial number: Not applicable.

Consent to Publish declaration: Not Applicable

Consent to Participate declaration: Not applicable.

Ethics declaration: Not applicable.

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