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Botanical Aspects, Nutritional Benefits and Cultivation of Elephant Foot Yam (*Amorphophallus paeoniifolius*)

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Abstract In recent years, there has been a significant shift toward exploring healthy foods and herbal medicines as people become more conscious of their health and well-being. *Amorphophallus paeoniifolius* is one of the potential plants in the genus that has high nutrient content, such as carbohydrates, protein, vitamins and minerals. This plant also possesses various health benefits including antibacterial, antioxidant, antitumor, analgesic and antidiarrhoeal due to the presence of phytochemicals. *Amorphophallus paeoniifolius* can be cultivated in various soil types and can thrive in adverse weather conditions, making it an excellent option for farmers to grow this plant as a crop in tropical and sub-tropical regions. This paper provides a comprehensive review of *A. paeoniifolius* from the updated literatures covering it's botanical aspects, nutritional benefits and cultivation. *Amorphophallus paeoniifolius* offers multiple advantages that align with the goals of sustainable development and global health. By understanding the methods for cultivation and utilization, people can improve their food supply, diversify diets, and enhance resilience to environmental and economic challenges.

Keywords: *Amorphophallus paeoniifolius*, cultivation, medicinal values, food sustainability.

Introduction

The elephant foot yam, scientifically known as *Amorphophallus paeoniifolius*, is a tropical plant that belongs to the Araceae family and is native to Southeast Asia. This plant is widely cultivated in various regions, including Southeast Asia, South Asia, Madagascar, New Guinea, and the Pacific islands, primarily for its edible tubers [1,2]. Elephant foot yam is an herbaceous, perennial plant with a diploid chromosome number of 2n = 26, 28. It thrives in a wide range of agroecological conditions, from low light intensities to altitudes up to 900 meters above sea level. The plant is commonly found in home gardens, mixed gardens, secondary forests, and agroforestry systems [2]. The corms and leaves of elephant foot yam are essential components of the local diet in many Asian regions. These parts are not only used as food but also hold medicinal value. The dietary fiber (glucomannan) extracted from the plant has a low glycemic index, making it beneficial for individuals with diabetes [2,3]. Additionally, the plant contains various enzymes and phytochemicals that have industrial applications [4]. Elephant foot yam is a valuable crop with high productivity potential. The corm production can reach 50-80 tons per hectare annually, making it a lucrative option for farmers. The plant growth and corm yield are influenced by factors such as the size of planting material, plant spacing, nutrient management, and water availability. Despite its popularity and productivity, there is still limited research on the production aspects of this crop, highlighting the need for further studies in this area [].

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Taxonomic Classification of *Amorphophallus paeoniifolius*

Amorphophallus paeoniifolius (Dennst.) Nicolson, is a C3 herbaceous perennial crop with a phallic-shaped inflorescence composed of a large fleshy spadix and a surrounding spathe. The name *Amorphophallus* derives from the Greek words "*amorpho*", meaning deformed, and "*phallus*," referring to the male anatomical member, while "*paeoniifolius*" refers to its peony-like foliage [5,6].

According to International Plants Name Index (IPNI) and Integrated Taxonomic Information System (ITIS), *A. paeoniifolius* is classified as part of the plant kingdom, specifically within the subkingdom Viridiplantae (green plants), infrakingdom Streptophyta (land plants), and superdivision Embryophyte. It is a member of the division Tracheophyte (vascular plants), subdivision Spermatophytina (seed plants), class Magnoliopsida, superorder Liliane (monocots), and order Alismatales. It belongs to Araceae, a diverse family of flowering plants with more than 170 species worldwide [7]. The common names for *A. paeoniifolius* include Elephant foot yam, White giant arum, Elephant bread, Suran, Sweet yam, and Jimikand, among others, from one region to another. For example, in Tamil Nadu, it is referred as Karak-kavanai, while in Japan, it is called Konjac, Konniaku, Konnyaku, and in China, it is known as Mo-yu [8]. In Malaysia this plant is known as ubi sarek, ubi kekek, loki, ubi lekir, teliga potato or hakai [5].

Morphology of *Amorphophallus paeoniifolius*

Corms

As per Shahbuddin's [5] and Hetterscheid and Peng [9] study, the corms of *A. paeoniifolius* as shown in Figure 1 exhibit distinct characteristics. They are typically large, ranging from round to spherical or elliptical in shape, and can attain weights of up to 10 kg with diameters spanning from 15 to 30 cm. The corms are described as globose or depressed-globose, with diameters reaching up to 25 cm and heights of up to 20 cm. These corms possess a dark brown outer layer and a light brown interior, and they feature multiple root-scars, an annulate structure, and may produce a varying number of offsets, which can be globose or shortly cylindrical. They are also accompanied by 2-5 mm thick roots. Moreover, the corms exhibit external wrinkles, and the skin texture can vary from rough to smooth [10]. The corm flesh's color ranges from pinkish yellow to orange.

Figure 1. The corm of *A. paeoniifolius* collected from Jerantut, Pahang, Malaysia

Corms undergo a dormancy period lasting 3-4 months, during which time leaves or inflorescences may emerge, although not simultaneously [11]. Ravi *et al*. [11] also observed that corms possess acrid properties before entering dormancy, which subsequently diminish after the dormancy period. It's worth noting that corms are a valuable food source that are rich in starch and as well as protein and have served as a staple food in several countries, including the Philippines, Indonesia, Malaysia, India, and China, as reported by Santosa and Sugiyama [12]. These corms are typically harvested after the dormancy period and are processed into flour, chips, or cooked as a vegetable.

Leaf and Petiole

The leaf of *A. paeoniifolius* as shown in Figure 2 is typically found in solitary or paired form, with a petiole that can reach heights ranging from 0.5-2.0 meters and a diameter of 2.5-10 centimeters [9]. As per observations by Edision *et al*. [10], Shahbuddin [5], and Hetterscheid and Peng [9], the base of the petiole displays variations in color, appearing as either pale green or dark green. It features numerous oval-elliptic spots with a whitish-green hue, and its surface is characterized by a scabrate-verrucate texture with elongated verrucae. The surface of the petiole may be either rough or smooth, and it may contain attractive paler green or white patches or blotches. Based on the surface texture of the petiole, *A. paeoniifolius* can be divided into two varieties which are *A. paeoniifolius* var. *hortensis* (smooth petiole) and *A.* paeoniifolius var. *sylvestris* (rough petiole) [13, 2, 14]. The size of the patches can range from small to large and may be distributed as spotty or contiguous patterns [10]. Emerging from an underground tuber, the petiole provides support for a single leaf that resembles an umbrella, giving the plant a tree-like appearance [5]. The rachis pattern of the petiole may adopt a V-type or Y-type configuration [9,10].

In accordance with the findings of Shahbuddin [5], Hetterscheid and Peng [9], and Madhurima *et al*. [15], the lamina of the leaf is highly divided and can reach diameters of up to 3 meters. The leaflets exhibit diverse shapes, including rounded, oval, ovate, obovate, elliptic, elliptic-oblong, elliptic-lanceolate, or lanceolate, with acuminate tips. These leaflets can range in length from 3-35 centimeters and in diameter from 2-12 centimeters. On the upper surface, the leaflets have a mid-green color, while the lower surface may vary from mid-green to pale green. The veins on the leaflets are impressed, and their color can be yellowish, pale green or light green [9,10].

Figure 2. The *Amorphophallus paeoniifolius* found in the Jerantut, Pahang, Malaysia

Inflorescence, Fruits and Seeds

The inflorescence of *A. paeoniifolius* as shown in Figure 3 consists of a spadix surrounded by a spathe, with the actual male and female flowers located at the base of the spadix. The inflorescence is solitary, has short peduncle and without foliage leaves [9]. The inflorescence is supported by a short peduncle attached to the tuber and is cylindrical with a surface that can be somewhat smooth to rough. The peduncle can range from 3-20 cm long, 1-8 cm in diameter and slightly less verrucate [9,15,16]. As stated by Handayani *et al*. [16], the peduncle's color is usually green, with a combination of large and small blotches in different shades of green, greyish white, greyish orange, orange-white, and yellow-green.

Another essential feature of the inflorescence of *A. paeoniifolius* is the presence of cataphylls, which protect the inflorescence bud until it opens completely. Cataphylls are modified leaves that lack a blade and resemble a petiole sheath. As noted by Handayani *et al*. [16], there are usually three to four cataphylls in this species, with the first being the smallest and outermost and subsequent ones increasing in size towards the inside. The cataphylls of *A. paeoniifolius* are elliptical with an acute tip and entire margin. The size of the second cataphyll ranges from 3 - 9.5 cm long and 3 - 9 cm wide, while the third one is 6 - 17 cm long and 5 - 10.5 cm wide. The cataphylls are yellow-green on the outside and white on the inside, with white blotches.

The spathe of *A. paeoniifolius* is campanulate, extremely broadly triangular, obtuse or acute, broader than long, and ranges from 10-40 cm in length and 15-60 cm in diameter, according to Shahbuddin [5], Madhurima *et al*. [15] and Hetterscheid' and Peng [9]. A shallow constriction separates the base and limb of the spathe, base strongly convolute and thick-walled while the limb horizontally spreading, collar-shaped, strongly undulates [9]. Furthermore, the background color of the spathe ranges from dark green or pale green to reddish brown, with few round dark spots. The lower inside of the spathe base is dark maroon, while the upper zone is white or pale pinkish [9,16]. The limb outside is similar to the base but with more prominent maroon flushes, especially near the margin, while the limb inside is glossy dark maroon [9,16].

The spadix of *A. paeoniifolius* is sessile, equaling or longer or sometimes shorter than the spathe and is supported directly without a peduncle [9]. It is 20-40 cm long and contains three distinct zones of flowers: female, male, and sterile male (appendix) [9]. The male and female flowers produce fruits after pollination, while the appendix releases a foul odor during the female anthesis [16]. The female zone is cylindrical and contains congested flowers congested or slightly remote; 4-12 cm long and 2-7 cm in diameter. The male zone is also cylindrical or strongly obconic, the upper part roofed against the broad base of the appendix, with congested flowers 3-8 cm long and 2-6 cm in diameter [9,16]. The appendix is irregularly globoseconic, up to 20 cm long, 20 cm wide at the base, obtuse on top, surface irregularly, shallowly or deeply folded, minutely verrucate, and pale or dark purplish brown in color [9].

The female flower has depressed or depressed-globose ovaries, circular in cross-section, with a white base and maroonish rest [16]. They are 4-5 mm in diameter and about 2.5 mm high with 2-3 locules, each containing one basal ovule. The style is long and slender, measuring 8-10 mm in length and 1.5 mm in diameter, with a maroon color. The stigma is large, capitate, and laterally compressed, about 4 x 2.5 mm in diameter and 3 mm high, with 2-3 (-4) lobes that are conic and obtuse. The surface of the stigma is pale yellowish-white and densely verrucate-scabrate. The male flowers consist of 4-6 stamens that are narrowly elongated, ivory white, and about 5 mm long and 1.5-2 mm in diameter. The filaments are extremely short, connate, and about 0.2-0.5 mm long. The anthers are narrowly elongated, with a truncated top and measuring about 4.5-5 mm in length. The pores are apical and elongate, while the pollen is orange with a smooth exine [9].

During female anthesis which usually lasts for two days, the spathe opens fully, leading to thermogenesis, where the spadix heats up and releases steam through an appendix [16,17]. This process results in the flower emitting a specific aromatic scent, described as a sickening gas, rotting flesh or decomposing organic material, such as carrion. Due to this smell the flower is also called 'corpse flower'. This odor is crucial in attracting pollinators such as carrion beetles and flies [16]. According to the gas chromatography-mass spectrometry analysis conducted by Shirasu et. al. [17], the odor of the inflorescence is contributed to by several compounds, primarily sulfides. The sulfides include dimethyl trisulfide, which lends a rotting, animal-like sulfury odour, and dimethyl disulfide, which smells of garlic. Other compounds, such as isovaleric acid, methylthiol acetate, and trimethylamine, have also been found to cause the foul odor of this inflorescence [17].

The reproductive system of *A. paeoniifolius* employs a dichogamous barrier that prevents self-pollination. The protogynous nature of the reproductive parts of the inflorescence makes self-pollination by the plant impossible [18]. During the first day of the anthesis upon full opening of the spathe, the stigmas of the female flowers are receptive for the pollens. On the second day of anthesis, pollen is released by the male flowers. However, the female flowers are no longer receptive to the pollen and this prevents self-pollination. The success of pollination requires interaction between insects and the mature male and female flowers from different individual plants [6]. The inflorescence of *A. paeoniifolius* attracts a range of insect pollinators, including beetles, bees, flies, ants, and cockroaches through its bad foul, to facilitate seed production [16]. The seeds of this plant are tiny, black, and shiny and are contained within a bright red fruit roughly the size of a grape. The berries are typically globose or elongate, and the seeds are usually globose, subglobose, ovate, elliptic, or saucer-shaped and have a distinct raphe [5]. The fruit of *A. paeoniifolius* is edible but commonly not consumed due to its strong odor and unpleasant taste [16]. Moreover, the shiny-red fruit pericarps were not enough to attract fruit or seed dispersers because the fruit pericarp may contain oxalate crystals [19]. Thus, in order for germination, the seeds need to be harvested from the fruits manually and sown fresh as the drying may cause the seeds to lose their viability. However, cultivation of *A. paeoniifolius* through seeds is not common due to dormancy of five to six months exhibited by the seeds and also unavailability of the seeds [11].

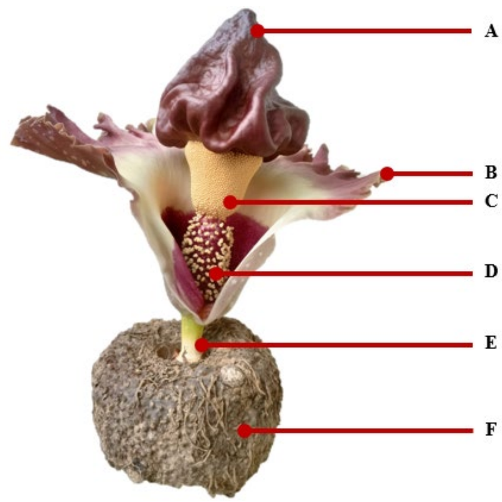

Figure 3. The inflorescence of *Amorphophallus paeoniifolius.* A: Spadix; B: Spathe; C: Male flowers; D: Female flowers; E: Peduncle; F: Corm

Habitat of *Amorphophallus paeoniifolius*

Amorphophallus paeoniifolius is a plant species that originates from tropical and subtropical regions in Asia and is highly adaptable to different habitats. It is widely distributed across various countries, including India, Sri Lanka, Indonesia, Malaysia, and Thailand, as noted by Dey *et al*. [20]. Santosa *et al*. [21] reported that the plant can thrive in low light environments due to its ability to store significant amounts of carbohydrates in its underground corms. The stored carbohydrates are utilized by the plant to produce energy, enabling it to survive in low light conditions. Additionally, Santosa *et al*. [12] found that *A. paeoniifolius* can withstand diverse soil and environmental conditions, enabling it to grow in areas with sandy, saline soils near the coast, as well as at higher elevations with cooler temperatures, with plants recorded to have grown up to 900 meters above sea level near the coastline.

This crop species can adapt to a variety of soil moisture conditions, which allows it to grow in both dry and damp environments [12]. The plant can grow in both waterlogged soils and dry, sandy soils, making it a versatile crop that can thrive in different environments. Due to its adaptability to varying lighting conditions and soil types, *A. paeoniifolius* is also common in many places, including beneath trees shading residential gardens, mixed gardens, secondary woods, agroforestry, and open fields [12, 21].

World Distribution of *Amorphophallus paeoniifolius*

Amorphophallus paeoniifolius is predominantly cultivated in Southeast Asian countries such as India, Philippines and Indonesia, and it has also gained popularity in Africa and the Pacific regions [11]. Due to the plant's strong production potential, market acceptance, and appealing economic returns in India, which ranges from 50-80 t/ha, it has been classified as a cash crop [22]. Yadav *et al*. [22] added that tuber crops, such as *A. paeoniifolius*, are planted for their variety of uses and are the third most significant food crop after cereals and legumes. *Amorphophallus paeoniifolius*, also known as the "king of tubers," has emerged as a viable crop for food security as it can grow in marginal soils, despite low annual rainfall and drought [23]. The plant is grown not only as a food security crop but also as a commercial crop due to its production capacity and attractiveness as a starchy vegetable with great nutritional and therapeutic properties [23].

According to Utomo and Ginting [24], the global production of *A. paeoniifolius* is approximately 5.5 million tons per year, providing a significant amount of food for over 400 million people in the tropics. India is the leading exporter of this crop, with Thailand and Myanmar following suit. Bangladesh, Saudi Arabia, and the United Arab Emirates are the largest importers of this crop. In India, *A. paeoniifolius* is produced on 26,000 hectares of land, with a production of 659,000 metric tons [25]. The crop offers potential for export since it is not commercially grown in other countries. According to Agricultural and Processed Food Products Export Development Authority (APEDA), India [26] reported that India produced 2.92 million metric tons of *A. paeoniifolius* in 2020-2021 and exported approximately 66,096.28 metric tons of corms during the same period. Overall, *A. paeoniifolius* is a valuable and versatile crop, with significant global production and economic benefits.

Life Cycle of *Amorphophallus paeoniifolius*

The life cycle of *A. paeoniifolius* includes the vegetative and the generative phases, with a dormant phase between them. During the vegetative phase in the rainy season, the plant produces vegetative organs through leaves. The generative phase, on the other hand, frequently follows the vegetative phase and is characterized by the development of flowers and the flowering phase [27,28]. One of the peculiar characteristics of this species is that each phase never manifests in a single individual at the same time; a plant that enters the leafy phase will never bear flowers, and vice versa [27,28]. This is due to the plant allocating its energy to either the generative or the vegetative growth phase at a given time. The time required for each phase varies greatly and is determined mainly by the size of the tubers [29]. An inflorescence bud (Figure 4 c) tends to develop three to four years after one-year-old corms are planted, indicating the start of the generative stage [21]. A dormant period in the dry season, where *Amorphophallus* corm undergo a resting state for about two or three months, separates the two phases [21,27].

The life cycle of *A. paeoniifolius*, from seedbed to fruiting and lodging, takes 38–48 months, or four growth periods (GP) [28]. The first three growing periods are vegetative phases, lasting 5-6 months each, which produce elongated leaf buds (Figure 4 a, b), petioles, leaves, and tubers. The corms of *Amorphophallus* generally have one apical bud, which exists inside the cavity in the head part. During germination, the small bud emerged from the main region of the corm which was covered by the cataphylls. The cataphyll covers the first primordium that have been differentiated as they believed to protect the young leaves from soil impedance [11]. Besides, Ravi *et al*. [11] claimed that the subepidermal cells of the cataphylls contain needle-like crystals of calcium oxalate which act as defense mechanism for leaves against pest attack. The cataphyll will elongate with respect to leaf development. Eventually, the cataphyll will die back once the leaves emerge and become mature.

The fourth growing period (GP4) is a generative phase that lasts 8-9 months and is characterized by the flowering process of producing fruit and seeds. After the generative phase, the plant dies. The corms of *A. paeoniifolius* are usually harvested during the dry season when they reach a commercial size and enter a dormant period. This is due to the fact that corms become acrid when new leaves form, and the acridness goes away during the dormant stage [30]. The symptoms of acridity include an itchy, stinging, and burning sensation in the mouth and throat, which may be followed by swelling from an overabundance of calcium oxalate. This acridity may account for some of the limited uses of *A. paeoniifolius*, as well as low productivity and extended period needed until harvest [30,31,32,33].

Figure 4. The buds emerging from the corm. a: The bud from the main stem region; b: Elongated leaf bud enclosed in cataphyll; c: Inflorescence bud

Cultivation of *Amorphophallus paeoniifolius*

Soil Type and Climate Conditions

The cultivation of *A. paeoniifolius* is significantly influenced by soil type and climate conditions, which vary based on the region and climate. These requirements are essential for the successful growth of *A. paeoniifolius*. The plant typically thrives in well-drained, fertile soils rich in organic matter and essential trace elements. According to the Tamil Nadu Agricultural University (TNAU) [34], *A. paeoniifolius* flourishes in a rich red-loamy soil with a pH ranging from 5.5-7.0. Additionally, research by

Nedunchezhiyan *et al*. [32] and Ravi *et al*. [11] suggests that *A. paeoniifolius* also performs well in medium to light soils, such as sandy loam or black soil, provided they offer good drainage and sufficient organic matter. These soil types provide a well-aerated environment, a crucial factor for *A. paeoniifolius*. As indicated by Ravi *et al*. [4], the plant can also thrive in well-draining sandy loam or sandy clay loam soils with a pH ranging from 6.0-7.0.

Various authors recommend loamy soil with a slightly acidic to neutral pH for the growth of *A. paeoniifolius*. The preference for such soil conditions is attributed to several factors. Loamy soil, composed of 20% clay, 40% sand, and 40% silt, is rich in organic matter, providing essential nutrients, including nitrogen, phosphorus, and potassium, crucial for the growth of *A. paeoniifolius* [35]. This type of soil offers excellent aeration, nutrient retention capabilities, and efficient water retention while allowing excess water to drain away, making it ideal for the plant's needs. The pH range of 5.5-7.0 is considered optimal for the absorption of vital nutrients, such as phosphorus, potassium, sulphur, calcium, and magnesium [36]. Maintaining this pH level is crucial for plants like *A. paeoniifolius* to absorb necessary nutrients efficiently. Soil pH that is too high (pH>7) or too low (pH<5.5) can lead to stunted development or nutrient deficiencies, particularly regarding nitrogen, phosphorus, and potassium absorption which are crucial elements for the growth of *A. paeoniifolius* [36,37].

It's worth noting, as suggested by Ravi *et al*. [4], that *A. paeoniifolius* can be cultivated in laterite soil containing approximately 40-50% gravel, but it does not thrive in heavy clay soil due to poor drainage and aeration. Heavy clay soil's high clay content results in a dense and compact texture, impeding adequate air circulation and water drainage [35,38]. This can lead to waterlogging, potentially causing root rot and other soil-borne diseases that can hinder plant growth. Furthermore, the compact nature of clay soil can obstruct root development, making it challenging for the plant to access essential nutrients and water [39]. In contrast, laterite soil with about 40-50% gravel offers better drainage and aeration properties, thus supporting *A. paeoniifolius* growth effectively [40].

The climate and rainfall conditions are also pivotal for successful *A. paeoniifolius* cultivation. The plant thrives in a warm and humid climate during its vegetative phase and prefers a cooler and drier climate during corm development [41]. As noted by Hidayat [41], Ravi *et al*. [4], and Nedunchezhiyan *et al*. [34], it performs best within a temperature range of 25- 35°C during the day and 20- 25°C at night, with a humidity level of 80-90% relative humidity. A warm and moist climate is particularly critical during the early stages of *A. paeoniifolius* growth to ensure robust development, while a drier climate benefits tuber bulking in later stages. Adequate rainfall, typically in the range of 1000-1500 mm, supports the plant's growth and tuber yield [42,43].

Propagation and Planting

Propagation and planting are vital components of *A. paeoniifolius* cultivation. Traditionally, this plant is propagated using corms, cormels, or corm pieces. Growth and development of *A. paeoniifolius* were determined by corm weight, large seed corm produced larger leaves and fresh mass of daughter corms [43]. A preference exists for larger corms as planting materials due to their capacity to yield larger daughter corms, resulting in increased corm and seed corms yields [43]. Larger corms possess greater carbohydrate reserves to support shoot and root growth during the plant's early stages, leading to more robust growth and greater vegetative biomass [44]. Additionally, the plant develops leaves by using preserved carbohydrates in seed corms (planting material) and then daughter corms (new corms) enlarge by using assimilates synthesized by the leaves [11]. Pathak *et al*. [45] emphasize that larger corms are rich in food materials and water content, fostering higher plant vigor and early sprouting through increased translocation of photosynthates from corm to vegetative parts. Santosa *et al*. [22] noted that using small corms, cormels, or bulbils as planting materials requires 3-4 years to produce harvestable corms weighing about 1 kg or more, whereas using large seed corms or whole corms can yield large size corms that can be harvested within one year of planting. Given the difficulty of obtaining an adequate quantity of large seed corms, corms of small size or cut pieces having a part of apical meristem of large corms are often utilized instead [21]. Thus, a large portion (about 25%) of the harvested corms are used as planting material for next season [11]. The recommended seed corm size of *A. paeoniifolius* for planting falls in the range of 500 g to 1 kg, including a portion of the apical meristem [34,42]. Larger seed corms tend to produce larger plants, with a corm size of 500 g yielding the best results [45,46]. Nedunchezhiyan *et al*. [32,47] suggest that cut tubers can serve as planting materials, but using whole tubers is more advantageous since they provide a higher sprouting percentage and overall yield. It was found that leaves emerged earlier and canopy spread was greater when whole corm was used as planting material [4,43].

For optimal growth and yield of *A. paeoniifolius*, the careful selection of corm size and segment is essential. The uppercut portion is favoured for propagation due to its higher sprouting rate (98%)

compared to the lower portion [48]. The central bud of *A. paeoniifolius*, located at the apex of the corm, tends to sprout first due to its apical dominance. To achieve a higher germination percentage, retaining the central bud when vertically cutting the corm is crucial. The presence of intact apical buds is essential for the rapid initial growth, as they are responsible for producing the highest biomass, leaf area, and dry leaf weight. Damage to the buds can reduce leaf growth, potentially lowering the yield [21].

Corms should be air-dried for approximately 40-45 days before planting and then vertically cut into pieces containing an apical bud [49]. Air-drying reduces moisture content and inhibits pathogen growth on the corm surface. It also encourages bud and root development, essential for plant growth and survival. Vertical cutting of the corms with apical buds increases the number of planting materials and ensures that each piece contains a viable apical bud for new plant development. Additionally, vertical cuts help reduce the risk of disease transmission between planting materials and promote faster growth. Additionally, if the cut pieces of the corms are used as planting material, treating them with certain chemicals is shown to improve its propagation, growth and overall yield [11]. To prevent moisture evaporation from the cut surface, cut pieces are dipped in a cow dung solution [47]. Furthermore, these cut pieces can be dipped in a cow dung slurry mixed with mancozeb (0.2%) and monocrotophos (0.05%) for 10 minutes. Subsequently, they can be surface-dried in the shade for 24 hours before planting, minimizing decay from soil-borne pathogens. To enhance nutrient content and crop productivity, it is recommended to add biofertilizers and beneficial microorganisms to the cow dung slurry [32]. Biofertilizers consist of live microorganisms that colonize plant root systems and enhance nutrient uptake, resulting in increased crop yield. They achieve this by fixing atmospheric nitrogen, solubilizing phosphorus, and producing plant growth-promoting substances. Thus, the inclusion of biofertilizers in cow dung slurry can improve nutrient content and boost *A. paoeniifolius* productivity.

Proper land preparation is crucial for successful *A. paeoniifolius* cultivation, involving thorough plowing in different directions, weed twig and rock removal, and land leveling [34]. Kumar *et al*. [42] recommends ridges and furrows for planting corms because they provide better drainage and aeration, preventing waterlogging and disease incidence. Ridges and furrows also contribute to improved soil tilth and weed management, ultimately enhancing crop growth and yield. These formations are filled with topsoil and farmyard manure (FYM), and cut tubers are sown, followed by thorough irrigation. Furthermore, practices such as digging interspaces and light earthing up one month later, along with intercultural operations like de-weeding and earthing up [42] and Tamil Nadu Agricultural University [34], help conserve soil moisture, enhance soil aeration, manage weeds, and promote healthy crop growth, maximizing corm yield. To ensure proper growth, cut corm pieces should be planted with the sprouting region (the bud) positioned above the soil surface.

Subsequently, the corms will sprout within 2-3 months [42]. The time of emergence (sprouting) of new shoots depends on the dormancy status of the planting material [11]. If the planting material has completed its dormancy before planting, then the new shoot sprout will emerge as soon as it is planted. The new daughter corm is formed at the region between the petiole and the seed corms when the buds emerge from the corm and enlarge gradually when the leaves expand fully [11]. The initial mother corm (planting material) will shrink as the dry mass and eventually decompose. Additionally, Ravi *et al*. [11], stated four rules for daughter corm growth rate (corm bulking rate) which are: 1. at identical plant spacing, corm bulking efficiency decreases with increases in planting material size in both cut pieces and whole corm; 2. at a given constant planting material size, corm bulking efficiency increases with increasing plant spacing; 3. Corm bulking efficiency is greater in the case of whole than cut corms used as a planting material; 4. Under rainfed conditions, using constant size of planting material, corms harvested shows gradient sizes.

Amorphophallus paeoniifolius planting density is not fixed and varies depending on the size of the planting material used. Researchers and authors have recommended various spacing for different sizes of corms, and even the fixed size of planting material has different spacing. According to Patel *et al*. [50], the most effective way to achieve higher corm yield is by planting seed corms of 500 g size at a spacing of 75 cm x 60 cm. The experiment was designed using a randomized complete block design with three replications (250, 500 and 750 g seed corm with 60 x 60 cm, 75 x 50 cm and 75 x 60 cm plant spacing). Patel *et al*. [50] noticed that seed corm with 500 g in 75 cm x 60 cm resulted in the highest plant height (89.22 cm), pseudostem girth (21.46 cm), canopy spread (102.25 cm), corm girth (72.94 cm), and corm yield (71.52 t/h). Pathak *et al*. [45] found that a corm sett size of 500 g of corm planted at a spacing of 50 x 50 cm resulted in the maximum height of primary pseudostem (75.5cm), basal girth (9.93cm) of primary pseudostem, corm weight (1196.25g), and yield of seed corms (478.50q/h) compared to other corm set of 100 g, 200 g, 300 g, and 400 g.

Salam *et al*. [51] found that the closest spacing of 40 x 40 cm with a larger corm size of 500 g resulted in the maximum pseudostem length (101.00 cm) and corm yield (46.29 t/h). However, maximum girth

(19.33 cm), canopy spread (112.86 cm), corm diameter (19.50 cm), and corm weight (1.92 kg) were observed in plants under the broadest spacing of 80 x 80 cm with 500 g planting material. The plant height was maximum at the closest plant spacing compared to the broadest plant spacing (80 x 80 cm) due to stiff competition for light and space. Under higher planting density, the basal girth, canopy spread, and yield attributes may be reduced due to increased plant competition and mutual shading. If *A. paeoniifolius* is to be commercially cultivated, a seed size of either 0.5 kg of whole corm or cut pieces is recommended, with a plant spacing of 75 cm [52]. However, a smaller seed size of 100 g and a tighter plant spacing of 50 cm is required for seed production. Jata *et al*. [53] and Nedunchezhiyan *et al*. [32] reported that field trials conducted in India using whole or cut pieces of *A. paeoniifolius* tubers weighing 500 g resulted in the highest yield per hectare when planted at a spacing of 90 x 90 cm. Misra *et al*. [54] found that to produce whole tubers of 400-500 g for commercial cultivation, cut tubers of approximately 50-100 g with a spacing of 60 x 60 cm between plants and rows were appropriate for growing the crop to produce planting material. Tamil Nadu Agricultural University [34] recommended a 500 g tuber planted in spacing 45 cm x 90 cm for commercial yield.

Spacing between *A. paeoniifolius* with intercropping also influences the growth and yield of the plant. Orchard crops, such as mango, sapota, guava, citrus, custard apple, coconut, areca nut, banana, papaya, and drumstick, are planted with wide spacing, ranging from 5 x 5m to 20 x 20m. *Amorphophallus paeoniifolius* can be grown in the space between these crops with a recommended spacing of 90 x 90cm. The number of *A. paeoniifolius* plants that can be planted per hectare varies between 5000-9000, depending on the canopy size of the fruit or orchard crops [53]. According to Tamil Nadu Agricultural University [34], it is recommended to intercrop *A. paeoniifolius* with coconut, areca nut, rubber, banana, and robusta coffee plantations at a spacing of 90 x 90 cm due to its potential profitability. Ghosh *et al*. [55] and Salam *et al*. [51] conducted an experiment on intercropping *A. paeoniifolius* with coconut trees. They found that the most effective combination for maximizing yield was a spacing of 40 x 40 cm with a planting material size of 500 g. This led to a higher nut yield per palm per year, with a yield of 8.71 compared to the monocrop yield of 5.58.

Fertilizer and Nutrient Requirements

Applying fertilizers plays a pivotal role in achieving optimal growth and yield of the *A. paeoniifolius* crop. Integrated nutrient management (INM) is a widely accepted agricultural strategy aimed at providing crops with balanced and sufficient nutrition. This approach combines various nutrient sources and management practices to ensure that *A. paeoniifolius* receives the necessary nutrients [56,57,58]. The INM incorporates organic and inorganic fertilizers, crop residues, green manures, biofertilizers, and other nutrient inputs to enhance soil fertility, maximize efficiency, minimize nutrient loss, and improve overall soil health and productivity. It is a crop-specific approach that considers local soil and climatic conditions.

According to Santosa *et al*. [59], the application of nitrogen (N) and potassium (K) fertilizers is essential for increasing corm yield in *Amorphophallus* species. Nitrogen is a critical nutrient for plant growth and development, as it plays a vital role in the formation of proteins, enzymes, and chlorophyll. It also promotes leaf growth and aids in the absorption of other essential nutrients, such as phosphorus (P). Potassium, on the other hand, regulates plant water balance, enhances photosynthesis, improves stress tolerance, and contributes to the synthesis of starch and proteins, ultimately leading to improved growth and yield. Additionally, Santosa *et al*. [59] notes that the application of Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizers significantly enhance various growth and yield parameters of *A. paeoniifolius*, including pseudostem height, leaf count, corm yield, and corm weight. The highest corm yield was achieved when using NPK fertilizer in a 100:60:80 kg/ha ratio. Similarly, Nedunchezhiyan *et al*. [32] recommend an optimal fertilizer dose of 100:80:100 kg N:P:K per hectare; however, the precise amount should be adjusted based on soil type and nutrient status. Tamil Nadu Agricultural University [34] recommends a dose of 80:60:100 kg NPK/ha for *A. paeoniifolius*, with an initial application of 40:60:50 kg NPK/ha 45 days after planting, followed by a top dressing of 40:50 N and K one month later, along with shallow intercultural operations. According to Navya *et al*. [58], using 100% of the recommended NPK dose (80:60:100 kg/ha) resulted in significantly higher corm yields compared to lower doses.

Navya *et al*. [58] suggests that the growth and yield of *A. paeoniifolius* can be enhanced by combining inorganic fertilizers with organic manure. For instance, Mondal *et al*. [60] recommend the application of 10 tons of manure per hectare during the planting of cut corms to cultivate high-quality *A. paeoniifolius* crops. Additionally, the addition of 10 tons of FYM along with 5 tons of ash, 5 kg of *Azospirillum*, and 5 kg of phosphorus-solubilizing bacteria per hectare can result in taller pseudostem, larger canopies, and substantial pseudostem girth at the collar region at three and five months after planting (MAP) [61]. Furthermore, it is recommended to incorporate well-decomposed cow dung or FYM at 15 kg per m^2 when growing *A. paeoniifolius* [57]. The addition of FYM serves to enhance soil organic matter content, improve nutrient availability, and stimulate microbial activity in the soil, ultimately leading to improved crop growth and yield. However, it's important to note that the optimal amount of fertilizer and organic manure required for a specific crop may depend on various factors, such as soil type, crop type, and local climate. Adhering to specific recommendations for each crop is essential to achieve the best results.

Sunlight Requirement

Sunlight is a crucial factor in the growth and yield of any crop, and *A. paeoniifolius* is no exception. A study conducted by Santosa *et al*. [21] revealed that light intensity has a significant impact on corm size. Specifically, reduced light intensity, achieved through shading, resulted in increased fresh biomass and larger corms. In fact, 75% shading produced the largest corms compared to 0%, 25%, and 50% shade. However, exposing the plant to full sunlight had adverse effects, including leaflet necrosis and curling, leading to a 25% crop loss, while no damage was observed in the 25, 50 and 75% of shading. Shading treatments also had noticeable effects on petiole and rachis length, with plants exhibiting the shortest petioles under full sunlight and the longest under 75% shading.

According to Hidayat [41], *A. paeoniifolius* thrives in locations that aren't directly exposed to intense sunlight but rather in areas shaded by surrounding vegetation, such as trees or shrubs. Due to its adaptability to low light intensity, the plant is well-suited for intercropping or multiple cropping systems. Intercropping involves cultivating two or more crops near each other simultaneously. Intercropping with short-duration pulses can be particularly advantageous because *A. paeoniifolius* takes approximately 50-60 days to establish ground cover [62]. Crops like ginger or turmeric can be used as intercrops to increase yield and economic returns [62,63]. *Amorphophallus paeoniifolius* is also cultivated as an intercrop along with turmeric and under coconut or banana [11]. Short-duration pulses like green gram (*Vigna radiata*) can also be intercropped with *A. paeoniifolius*. Intercropping has been shown to improve soil fertility through mechanisms like symbiotic nitrogen fixation and increased organic matter content through the incorporation of leaf litter into the soil [64].

Intercropping not only contributes to soil fertility but can also act as effective mulching material using crop haulms (stalks), as observed by Jata *et al*. [64]. Moreover, intercropping with crops like ginger has demonstrated significant benefits, including higher corm equivalent, gross and net returns, and a better benefit-cost ratio compared to other intercropping systems like turmeric or sole cropping [62]. According to Nedunchezhiyan *et al*. [32], leafy vegetables, black gram, cowpea, and cucumber are suitable intercrop options during the initial 2-3 months after planting. In conclusion, *A. paeoniifolius* is adaptable to low light conditions, but the level of shading significantly influences crop yield and quality, making it suitable for intercropping or multiple cropping systems.

Water Requirement

Amorphophallus paeoniifolius is predominantly a rainfed crop, but irrigation becomes essential during dry seasons. In areas where irrigation is available, it necessitates weekly watering, as advised by Tamil Nadu Agricultural University [34]. Research by Ravi *et al*. [65] and Santosa *et al*. [66] suggests that *A. paeoniifolius* is well-suited for cultivation in arid regions with limited water resources, displaying impressive drought tolerance. However, it's worth noting that a consistent water supply significantly enhances the plant's growth. Although water is not essential for the development of the buds, further development of new shoots depends on the adequate watering [11]. Santosa *et al*. [66] found that daily watering provides the most significant benefits for *A. paeoniifolius* growth. This practice leads to improved growth parameters, including increased leaf count, longer vine length, and higher fresh weight of aerial parts when compared to less frequent watering. Daily watering also helps prevent leaf curling, a symptom of water stress, especially during dry spells.

An annual rainfall between 1000 and 1500 mm, ideally distributed over ten months, significantly benefits the crop [4,65,66]. However, when the rainy season is shorter than four months, many plants enter dormancy earlier than usual, requiring additional irrigation for a good yield under these conditions. Soil moisture plays a crucial role in *A. paeoniifolius* growth and yield. Adequate soil moisture is necessary for new shoots to continue developing and affect dry matter usage and the transport of photoassimilates into daughter corms [65]. When the water supply is sufficient, *A. paeoniifolius* produces huge corms and yields more. Ravi *et al*. [4] reported that the crop can endure brief flooding but not anaerobic waterlogging, which results in corm rot.

Research by Ravi *et al*. [65] investigated the impact of water deficit stress (WDS) at various growth stages on *A. paeoniifolius*. The study revealed that the 4-5 months after planting period was most sensitive to WDS, resulting in the most significant negative impact on corm yield, underscoring the importance of proper irrigation during this time. These critical growth periods, identified as the first six months, necessitate adequate soil moisture to achieve optimal growth and higher corm yield. Santosa *et al*. [66] conducted a study on the effects of watering frequency on *A. paeoniifolius*. Frequent watering, such as daily or at three to five-day intervals, proved beneficial, leading to more leaves, larger corms, and extended leaf lifespan. Infrequent watering, with intervals of seven days or 15 days, negatively impacted various growth parameters, reducing yield, and inducing dormancy.

In summary, while *A. paeoniifolius* exhibits drought tolerance regarding plant survival, adequate watering is vital for achieving high yields. Drip irrigation, combined with mulching and fertigation, has proven to be an effective method to enhance growth, yield, and water use efficiency for this crop, making it a valuable option, particularly in water-scarce regions [67]. Research by Venkatesan *et al*. [68] also highlights the benefits of drip irrigation and fertigation in improving plant height, leaf count, corm weight, and overall yield. Nedunchezhiyan *et al*. [69] noted that drip irrigation and fertigation notably enhanced *A. paeoniifolius* growth, dry matter production, and nutrient uptake, stressing the importance of avoiding drought conditions to achieve high yields.

Harvesting and Storage

Harvesting and storage are critical stages in the cultivation of *A. paeoniifolius*. The correct timing of harvesting and suitable storage conditions is essential to prolong the shelf life of corms. Harvesting of *A. paeoniifolius* corms should be undertaken approximately 8-9 months after planting, typically during the dry season when the leaves and stalks have turned yellow or withered [52]. During harvesting, care should be taken to prevent injury to the corms, which can render them more susceptible to infections during storage [47,70]. After harvesting, the corms should be meticulously cleaned, and any damaged or infected ones should be promptly separated and discarded [70]. Surface cleaning without the use of water is advisable before long-term storage and marketing, as water can increase the risk of tuber sprouting, microbial infections, and growth under ambient humid storage conditions [70].

Corms can be stored safely for 3 - 4 months if they remain unsprouted during storage [48]. Adequate ventilation and cool temperatures are essential in storage facilities, which should also be protected from rain [71]. Corms can be stored either in three layers with dried river sand or without sand; this method allows the corms to be stored in viable conditions for up to three months [47]. According to More *et al*. [48], spreading *A. paeoniifolius* corms in single layers with the apical portion facing upwards and covering them with coarse dry sand contributes to an extended shelf life. Post-harvest shelf life of *A. paeoniifolius* corms can be extended by periodically inspecting and removing any decayed portions and treating the cut areas with a fungicide like mancozeb, as recommended by Nedunchezhiyan [47] and Ray [70]. An alternative method to retain corm shelf life up to four months is to store them separately on rocks [70].

Typically, after 2-3 months of storage, *A. paeoniifolius* corms commence sprouting. Panja *et al*. [72] noted that corms may undergo up to a 25% weight loss during the first month of storage but can be successfully stored for several months at a temperature of 10°C. Farmers usually store harvested corms in dry conditions or under a bed during the dry season, replanting them once the rainy season commences. In Indonesia, some farmers plant the corms upside down, believing it promotes corm enlargement, though this practice lacks scientific validation [33]. On occasion, farmers may opt not to harvest corms, leaving them in the ground with suitable irrigation, to be dug up as needed. At the end of the dormancy period, new leaves emerge from the corms. Farmers often wait until the stem diameter reaches 10 cm or more before harvesting the corms, as there is a direct correlation between stem diameter and corm size [52]. With favorable growing conditions, corm weights can reach up to 5 kg after three years of planting and, under ideal circumstances, increase further to as much as 25 kg. Thus, harvesting and storage practices play a crucial role in the successful cultivation of *A. paeoniifolius*.

Pests and Diseases in *Amorphophallus paeoniifolius*

Diseases

Like other crops, *A. paeoniifolius* is also vulnerable to various pests and diseases that can significantly reduce crop yield. One of the primary diseases affecting the plant is collar rot, caused by soil-borne fungi *Sclerotium rolfsii* and *Rhizoctonia solani* [73,74]. According to Pravi *et al*. [73], the fungus has the ability to persist in the soil for many years and can infect plants through natural openings or wounds. It spreads gradually, eventually infecting the entire tuber and resulting in complete loss of the crop. Collar rot is most prevalent in two to three-month-old plants and slowly infects the entire tuber, resulting in total crop loss. The disease can be identified by the presence of symptoms such as plant death, stunted growth, wilting, and yellowing of leaves. Furthermore, the disease is identified by the formation of a lesion at the base of the stem where it meets the roots, which gradually develops into a collar. Collar rot is often caused by poor drainage, waterlogging, or mechanical injury at the collar region. When the disease becomes severe, it can result in brownish lesions appearing on the collar region of the plant, spreading to the whole pseudostem. This can lead to complete yellowing of the plant and even result in plant death, as reported by Byju *et al*. [75]. Besides, *S. rolfsii* is the most common storage disease in *A. paeoniifolius* corms [74]. Collar rot can be controlled by implementing various management practices such as using disease-free planting material, removing infected plants, improving soil drainage, and applying neem cake in the soil. In addition, bio-control agents like *Trichoderma* can be used, and soil drenching with 0.2% cap tan or 0.1% Brassicol twice a month can also help prevent the spread of the disease [74]. Additionally, developing a rapid and sensitive species-specific PCR assay by Thangam *et al*. [74] can be a valuable tool for the early and accurate diagnosis of collar rot disease in *A. paeoniifolius*, reducing economic losses.

Dasheen mosaic virus (DsMV) is a member of the Potyviridae family that causes mosaic disease in *A. paeoniifolius*, resulting in damage to the crop [76,77]. The main modes of transmission for the virus are infected planting material or insect vectors, specifically aphids *Myzus persicae* and *Aphis gossypii* [77]. The symptoms of DsMV infection include mosaic pattern, puckering, filamentous or shoestring-like symptoms on leaves, stunted plant growth, and reduced corm yield [76]. Studies have shown that DsMV can cause a mosaic incidence of 24-88% with a maximum yield loss of up to 38% in *A. paeoniifolius* growing areas in India [77]. To control the spread of the virus, it is recommended to use virus-free planting material, regularly monitor crops for symptoms, and use insecticides to control aphid populations. Kamala *et al*. [77] suggested that the spread of the virus can be minimized by employing sanitation practices such as the removal of infected plant material.

Anthracnose is a fungal disease that can significantly affect the yield of *A. paeoniifolius* caused by *Colletotrichum siamense* [79]. The disease manifests as circular to irregular brown lesions on leaves, stems, and corms that can lead to the rotting of the entire plant. Infection can spread through contaminated planting material, soil, or water. Disease-resistant cultivars should be used, good field sanitation practices should be followed, and chemical control measures can be implemented to prevent anthracnose.

Phytophthora colocasiae can cause leaf blight disease in *A. paeoniifolius* [80]. The disease is characterized by the appearance of water-soaked lesions that become brown and necrotic on leaves and can infect the corm, leading to plant death. The fungus can also infect the corm and cause soft rot, resulting in the death of the plant. To manage the disease, the authors recommend using an integrated approach that includes removing and destroying infected plant debris, applying fungicides such as mancozeb, and adopting cultural practices like crop rotation and disease-free planting material. By implementing these strategies, leaf blight disease can be prevented, thereby ensuring better crop yields.

Pests

Mealybug infestation is the common pest in *A. paeoniifolius* which causes significant damage to the plant's corms both in storage and in the field. Mealybugs, a soft-bodied insect known as *Rhizoecus amorphophalli*, are a significant pest infesting the corms in storage and the field [80]. These pests appear as white, cottony masses on the undersides of leaves, petioles, and tubers, which can cause yellowing or wilting of affected leaves. In the absence of moisture, mealybugs can penetrate through openings created in the soil when the pseudostem dries, leading to the infestation of corms. This problem can become severe if the corms are not removed from the soil for an extended period. According to Sreerag *et al*. [81], the tubers of *A. paeoniifolius* are at risk of damage from the insect *R. amorphophalli*, which feeds on their cell sap. Infested tubers may become deformed and unsuitable for sale or cooking. The high temperature and humidity of over 30 °C favour the multiplication and growth of mealybugs. The study by Sreerag *et al*. [81] found that mealy bug-infested tubers exhibited delayed sprouting and slower growth, resulting in lower yields at harvest. However, these infested tubers were free from mealy bug infestation at harvest and could be used as seed material without uninfested ones. Nedunchezhiyan *et al*. [80] recommend combining neem oil and insecticides as the most effective way of controlling mealybug populations. Additionally, cultural practices such as removing weeds and pruning affected plant parts can help reduce mealybug infestations.

Amorphophallus paeoniifolius is susceptible to damage from two main nematode pests: *Meloidogyne incognita* and *Pratylenchus* spp. [70]. Root-knot nematodes cause galls on the roots that lead to wart-like projections on corms, and severe infestations can result in significant yield reductions. The nematodes can continue to feed and multiply even after harvest, leading to weight loss and rotting during transportation and storage. *Pratylenchus* spp. causes lesions on roots, cormels, and corms, and as the nematodes multiply, the lesions spread over the entire surface, and cracks appear on the tuber surface. The author suggested several preventive measures to manage root-knot nematode infestation, including crop rotation with non-host plants, using organic amendments such as neem cake and farmyard manure, soil solarization, deep summer plowing, and treating planting materials with hot water before planting.

Weeds are another significant problem in the production of tuber crops as they can adversely affect the yield and quality of the produce by competing with the roots for resources and penetrating the underground storage organs [82]. *Amorphophallus paeoniifolius* had a significant yield reduction ranging from 29.1% to 54.5% due to weed competition [82]. This reduction in yield was dependent on the density and species of the weeds present. Additionally, weeds also reduce the size and weight of the corms, which can significantly impact the profitability of the crop. Weeds can compete with *A. paeoniifolius* for nutrients, moisture, and light, which can result in stunted growth and reduced quality of the corms. Based on the study by Kumar *et al*. [82], the results showed that herbicides effectively controlled weeds and increased the yield of *A. paeoniifolius*. Other weed control methods like manual weeding, mulching, and crop rotation can also be employed depending on the situation and the farmer's preference.

Nutritional Content of *Amorphophallus paeoniifolius*

Amorphophallus paeoniifolius provides a rich source of minerals, carbohydrates, protein, and fibre. According to Yuzammi and Handayani [83], the *A. paeoniifolius* corms have the largest percentages of carbohydrate and protein (82.42% and 6.51%, respectively). The tubers had the least amount of fat (0.18%), and they were highly concentrated in phosphorus and calcium (113.96 mg/100g and 302.69 mg/100g, respectively) [77]. Additionally, the leaves of *A. paeoniifolius* are rich in vitamin A and are used as a vegetable by local tribes in India [84]. According to Kumar *et al*. [31], the tuber's dry matter composition ranges from 17.50- 24%, its starch content from 13.93- 21.53%, its sugar content from 0.55-1.77%, its protein content from 0.84 to 2.60%, and its fat content from 0.07- 0.37%. *Amorphophallus paeoniifolius* tubers are also abundant in trace elements including selenium, zinc, and copper as well as calcium (50 mg/g), phosphorus (34 mg/g), vitamin A (260 IU/g), and vitamin B6 [11,86]. *Amorphophallus paeoniifolius* tuber includes potassium (327.83 mg/100 g), phosphorus (166.91 mg/100 g), calcium (161.08 mg/100 g), and iron (3.43 mg/100 g) [85]. According to Rahman *et al*. [86], the *A. paeoniifolius* tuber had a moisture content of 10.03 g per 100 g of powder and 89.97 g of dry matter. Also abundant in potassium (263.74 mg), phosphorus (155.2 mg), zinc (0.92 mg/100g), iron (3.13 mg), and calcium (143.6 mg/100g), the tuber was a good source of these minerals. The *A. paeoniifolius* tuber showed a protein solubility of 86.90% and was high in vitamin C (5.57 mg). Total carotenoids and free fatty acids were 0.26 mg and 0.09 mg, respectively. According to Nedunchezhiyan *et al*. [47], the fresh tuber of *A. paeoniifolius* includes the following nutrients: moisture (79.0), protein (1.2), fat (0.1), carbs (18.4), minerals (0.8), calcium (0.05), phosphorus (0.34), iron (0.06), vitamin A (260 IU), thiamine (0.0006), niacin (0.07), and riboflavin (0.07).

The tuber of *A. paeoniifolius* is a rich source of nutrients; however, it also contains anti-nutritional factors such as oxalates, tannins, hydrogen cyanide, and phytates that can decrease the bioavailability of nutrients [83]. The acridity caused by oxalate levels in *A. paeoniifolius* generates irritative feelings in the mouth and throat and even swelling, with needle-like raphides of calcium oxalate causing severe harm if more than 2 g is consumed [31]. Oxalates chelate with essential minerals such as iron, calcium, zinc, and magnesium, rendering them unavailable to the body and leading to mineral deficiency [85]. A high intake of oxalate in foods causes hypocalcemia and contributes to renal stones and renal failure [86]. In *A. paeoniifolius*, the ranges of oxalate concentrations were determined to be: calcium oxalate 0.63-9.38 mg/100g, water-soluble oxalate 8.11-22.93 mg/100g, and total oxalate 10.86-31.04 mg/10g during storage,[86]. Yuzammi and Handayania [83] reported that the calcium oxalate was lower in the *A. paeoniifolius* flour (0.01%) rather than in fresh tuber (0.21%), meaning that processed tubers of *A. paeoniifolius* were safe to consume. Oxalates (318.51±3.2 mg kgG1), tannins (0.46±0.04%), cyanide (35878±0.402 ppm), and phytates (0.165±0.015%) were all detected by anti-nutrient analysis [85]. These findings demonstrate that *A. paeoniifolius* is acceptable for food or feed due to its high mineral content and low antinutrient content. According to Singh and Wadhwa [84], the mean soluble oxalate level (13.53 mg/100 g) was safe from the standpoint of kidney stones developing from urinary oxalate buildup. Yuzammi and Handayania [83] suggested the concentration of oxalates can be reduced by cooking it for long hours or by burying the tuber in charcoal husks, soaking it in saline water, or slicing it in running water. For example, soaking and cooking the tuber reduces oxalate concentration by 23.5% and 56.7%, respectively. In conclusion, *A. paeoniifolius* is a highly nutritious plant, rich in fibre, minerals, and vitamins. It is a suitable addition to the diet for individuals seeking to improve their nutritional status and prevent chronic diseases.

Medical Benefits of *Amorphophallus paeoniifolius*

Amorphophallus paeoniifolius is not only used as food, but it also has numerous medical benefits. *Amorphophallus paeoniifolius* has been studied for its potential medical uses, which include gastroprotective ability, analgesic activity, anticonvulsant activity, antihelmintic activity, antidiarrhoeal activity, anti-inflammatory activity, antibacterial activity, antioxidant activity, anti-tumour activity, CNS depressant activity, hepatoprotective activity, and immunomodulatory activity [84,87]. These findings were reported by Singh and Wadhwa [84] and Dey *et al*. [87] due to the presence of various phytochemicals. Table 1 summarizes various phytochemicals extracted from *A. paeoniifolius* using various extraction methods. Phytochemical refers to the medicinally active substances found in plants. It shows that *Amorphophallus paeoniifolius* contains phytochemicals such as alkaloids, tannins, phenol, proteins, sterols and terpenoids in various parts of the plants such as the corms, leaves and the inflorescence that contribute to the medical property. Table 2 summarizes the pharmaceuticals benefits of these phytochemicals.

Table 1. Phytochemicals extracted from various parts of the Amorphophallus paeoniifolius using different extraction methods

No	Part used	Solvent used for Extraction Method	Phytochemicals Present	Sources
1	Corm	Petroleum ether	Alkaloids, steroids, fats and fixed oil	[88]
		Chloroform	Alkaloids	
		Methanol	Alkaloids, steroids, flavonoids and carbohydrates	
		Aqueous	Flavonoids, tannins, proteins and carbohydrates	
2	Corm	Petroleum ether	Tannins, sterol and terpenoids, carbohydrates and fat and fixed oil.	[89]
		Chloroform	Alkaloids, tannins, phenol, proteins, sterols, terpenoids, carbohydrates and fat.	
		Methanol	Tannins, phenol, flavonoids, sterols and terpenoids, carbohydrates and fat	
		Aqueous	Alkaloids, phenol, tannins, flavonoids, proteins and amino acids, carbohydrates and fat.	
3	Corm	Hexane	Glycosides, saponins	[90]
		Chloroform	Alkaloids, carbohydrates, saponins, flavonoids, tannins, terpenoids	
		Ethyl Acetate	Alkaloids, saponins, phenolics	
		Ethanol	Alkaloids, carbohydrates, saponins, phenolics, flavonoids, gum and mucilages	
		Water	Alkaloids, glycosides, saponins, phenolics, flavonoids, gum and mucilages	
4	Corm	Ethanol	Carbohydrates, reducing sugars, hexose sugar (glucose and fructose), steroids/terpenoids, protein, alkaloids, amino acids, flavonoids, glycosides (coumarin and anthraquinone), saponins	[91]
5	Corm	Methanol	Alkaloids, flavonoids, tannins, phenol and glycosides	[92]
		Aqueous		
		Crude powder	Alkaloids, saponins, flavonoids, carbohydrates and glycosides	
6	Corm	Methanol	Saponins, polysterols, phenols, flavonoids (tannins, terpenoids, steroids, gum and mucilage), carbohydrate	[93]
		Aqueous		
		Ethanol	Polysterols, phenols, flavonoids (tannins, terpenoids, steroids, gum and mucilage), carbohydrate	
		Ethyl acetate		
7	Corm	Ethanol	Phenol (gallic acid, resveratrol, quercetin), flavonoids, alkaloids	[94]
8	Corm	Methanol	Carbohydrates, Alkaloids, Flavonoids, Steroids and Terpenoids	[95]
9	Corm	Methanol	Steroids (β-sitosterol and betulinic acid)	[96,97]
10	Inflorescence	Methanol	Flavonoids (Vitexin, Orientin, Isovitexin, Schaftoside, Vicenin-2, Quercetin 3-O-glucoside, Kaempferol 3-O-glucoside)	[98]
11	Corm	Methanol	Flavonoids (Quercetin)	[99]
12	Corm	Methanol	Phenol (Betulinic acid)	[100,101]

Table 2. Pharmaceutical benefits of Amorphophallus paeoniifolius (Adopted and updated from Islam *et al*. [102]

Study	Subject	Solvent used for Extraction Method	Findings	Sources
Antioxidant	Adult male Wistar rats (200-250 g)	Petroleum ether	The presence of polyphenols such as gallic acid, resveratrol, and quercetin in the extract (1-50(µg/ mL) showed antioxidant activity *in vitro*. The extract showed maximum (68.6%) of 1,1-diphenyl-2-picrylhydrazyl-2-radical (DPPH) scavenging activity and maximum inhibition of 74% and 67.2% of 2,2-azinobis-(-3-ethyl) benzo-thiozoline-6-sulfonate ($ABTS^+$) and H_2O_2 respectively.	[94]
	-	Petroleum ether, chloroform, methanol, and water	The reducing capacity of a compound in the extract shows potential antioxidant activity. The presence reducers in the methanol extract causes the conversion of the Fe3+/ ferricyanide complex to the ferrous form. The extract with concentration of 100 µg/ml showed DPPH radical scavenging activity with maximum inhibition of 49.3% while reducing power activity with maximum absorbance of 0.85 nm compared to ascorbic acid.	[103]
	-	Ethanol, acetone and water	Acetone extracts consist of tannic acid, gallic acid, quercetin, p-coumaric acid and catechin shows antioxidant activity. The extract showed highest antioxidant activity towards Ferric reducing antioxidant power (0.541 O.D), 1, 1-diphenyl-2-picrylhydrazyl (74.52%), hydroxyl radical scavenging activity (64.29%) and nitric oxide radical scavenging activity (59.11%).	[104]
Analgesic activity	Male Swiss Albino mice (20-25 g)	Methanol	The intraperitoneal administration of extract (250, 500 mg/kg) induced a significant analgesic activity in a dose-dependent manner. The presence of flavonoids, alkaloids and steroids in the extract inhibit cyclooxygenase enzyme for reducing analgesia peripherally or act on central opioid receptors (µ receptors) for reducing analgesia centrally.	[105]
CNS	Male Swiss Albino mice	Petroleum ether	The extract doses of 100, 300 and 1000 mg/kg showed significant central nervous system activity in mice by interfering with the function of the cortex. The extract decreases locomotor activity (73.36% with dose of 1000 mg/kg) and activity in grip test (70.78% with dose of 1000 mg/kg)	[106]
	Male Swiss albino mice (20–25 g)	Petroleum ether	The presence of steroids, fats, and fixed oil in the extract was found to have CNS depressant activity with percentage of inhibition was 73.36% when a dose level 1000 mg/kg administered. The extract shows CNS depressant effect by acting on the $GABA_A$ receptor. The phytochemicals present in the extract may bind with the α subunit and facilitate the GABA mediated Cl^- channel opening, thus hyperpolarizing the cell and show CNS depressant action. Besides, the petroleum ether extract showed synergistic effect with diazepam.	[107]
	Swiss Albino male mice (18-25 g)	Petroleum ether	The extract was found to contain steroids, fats and fixed oils that may act as a potent anxiolytic agent in mice.	[108]
Anti-inflammatory	Male Wister rats (125–175 g)	Methanol	The presence of alkaloids and flavonoid in the extract shows anti-inflammatory activities and antihistaminic activity. A dose of 200 and 400 mg/kg significantly inhibits paw edema induced by carrageenan in the first phase, so the extract may inhibit the release of histamine or serotonins.	[87]

Study	Subject	Solvent used for Extraction Method	Findings	Sources
Anticonvulsant	Male albino mice (25-30 g) induced with Isoniazid	Petroleum ether	Presence of steroidal compounds in the extracts shows anticonvulsant activity. The steroid increases the synthesis and release GABA which afford allosteric receptor facilitation or reduce inactivation.	[109]
Antibacterial activity	*Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Bacillus subtilis and Streptococcus mutans*	Ethanol	Tuber extract of the plant shown inhibitory effect on four bacterial species such as *Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli* and *Streptococcus mutans* with an inhibition zone between 6-18 mm. Peel extract showed inhibitory effect two bacterial species such as *Staphylococcus aureus* and *Pseudomonas aeruginosa* with inhibition zone ranging from 7-16 mm.	[110]
	Two Gram-positive and four Gram-negative bacteria	-	The presence of phytochemicals act as a reducing and stabilizing agent responsible for the reduction of metal ions into metal nanoparticles and further colloidal stabilization. This allows the synthesis of AuNPs and AgNPs. AgNPs showed good inhibitory effect against both Gram-positive and Gram-negative bacteria	[111]
	Human bacterial pathogen: *Bacillus subtillis* – MTCC 121, *Klebsiella pneumoniae* – MTCC 109, *Pseudomonas auruginosa* – MTCC 424, *Staphylococcus aureus* – MTCC 727	Ethyl acetate, ethanol, methanol and aqueous	Ethyl acetate extract showed maximum activity for *Bacillus subtilis* - MTCC 121, *Staphylococcus aureus* - MTCC 737 (7.5 and 7 mm of zone of inhibition respectively). Aqueous extract showed maximum inhibition for *Klebsiella pneumoniae* - MTCC 109 (2.75 mm). Ethanolic extracts showed the zone of inhibition of 3.75 mm for *Staphylococcus aureus* - MTCC 737 and methanolic extract showed 4 mm of inhibition for *Pseudomonas aeruginosa* - MTCC 424. Phytochemicals like flavonoids, phenolic compounds, tannins, ascorbic acid, saponins and alkaloids have antibacterial activity.	[93]
	E. coli, K. pneumoniae, S. aureus, B. subtilis	Water	The extract showed moderate activity against *S. aureus* having 9 mm as a zone of inhibition.	[112]
Hepatoprotective activity	Male albino-Wistar rats (150-180 g) and mice (25-30 g) induced with paracetamol toxicity	Methanol and aqueous	Presence of flavonoids and steroids are responsible for hepatoprotective effect upon paracetamol-induced hepatic damage in rats. Methanol extract showed more significant results as compared to aqueous extract.	[113]
Antihelmintic activity	*Pheretima posthuma* (earthworms) and *Tubifex tubifex* (aquarium worms)	Methanol	The presence of steroids, flavonoids, and alkaloids in the extract shows significant anti-helmintic activity at the highest concentration of 100 mg/ml. The extracts were found not only to paralyze (Vermifuge) but also to kill the earthworms (Vermicidal).	[114]
Gastrokinetic activity	Adult male Wistar rats (220-250 g)	Methanol	It has gastrokinetic activity and has moderately increased the number of stools, feces volume, fecal matter water content, peristalsis, gastric emptying, and intestinal transportation. The extracts have an influence on gastric motility or contractile function of the stomach/intestine. The spasmogenic and stimulatory effect on the synthesis of prostaglandins was detected due to betulinic acid and glucomannan in the extract.	[101]

Study	Subject	Solvent used for Extraction Method	Findings	Sources
	Adult Wistar rats (220-250 g)	Methanol and aqueous	Betulinic acid and glucomannan exhibited beneficial effect on loperamide-induced constipation in rats. Betulinic acid showed spamsogenic effect by partial agonistic action in the serotonergic (5HT) receptors on rat fundus preparation. This improves the intestinal transit, showed laxative effects indicated by significant inhibition of increase in stool number and weight. Glucomannan was also reported to have influence on 5-HT in gastrointestinal tract and results in contraction It is fermented and degraded by colonic bacteria to short chain fatty acids which cause increase in serotonin levels leading to enhanced colonic motility	[97]
	Acetic acid induced ulcerative colitis in Adult male Wistar rats (220-250 g)	Methanol	β-sitosterol, betulinic acid and glucomannan in the extract shows anticolitic effect which can be used as alternative treatment for inflammatory bowel diseases. Betulinic acid demonstrated anticolitic effect through its inhibitory influence on inflammatory mediators and antioxidant activity while β-sitosterol through anti-inflammatory action.	[96]
Anticancer and antitumor effect	MCF-7, MDA-MB-231, HEK293, and MEF cell lines	Ethanol	The extract induced cytotoxicity to both MCF-7, an estrogen receptor-positive and MDA-MB231, a triple-negative breast cancer cell line. The extract reduced migration in both cell lines while inhibition of adhesion and invasion was higher in MDA-MB-231 cells. Besides, the extract induced apoptosis in the cells by inhibition of antiapoptotic Bcl-2 and increase of pro-apoptotic Bax, Caspase-7 expression and cleavage of PARP.	[115]
	MCF-7 cell lines	Petroleum ether, chloroform, methanol, and water	Methanolic extract showed cytotoxic activity in which 50% reduction in MCF-7 cell line at a dose of 51.07 µg/ml.	[103]
Anti-diabetic	Male Wistar rats (140-160 g) induced with streptozotocin	Hexane, chloroform, ethyl acetate, acetone and methanol	The acetone extract containing phenol and flavonoids showed anti-diabetic properties. Fasting blood sugar reduced to 23% and 37% when dose of 0.1% and 0.25% administered. The glomerular filtration rate showed 28% and 41% reduction when dose of 0.1% and 0.25% administered.	[116]
	Male Long Evan rats (98-168 g) induced with alloxan	Methanol	Antidiabetogenic phytochemicals like betulinic acid, stigmasterol, and β-sitosterol inhibit α-glucosidase and α-amylase, anthraquinone sensitizes insulin receptors, alkaloids and tannin prevent β-cell destruction and enhance glucose uptake. Fasting blood glucose (FBG) level was reduced remarkably ($p<0.05$) in diabetic rats after 1st week and was highly significant ($p\leq0.001$) after 3rd weeks of experimental feeding.	[86]

In addition, Dey *et al*. [87] stated that *A. paeoniifolius* has been traditionally used in Ayurvedic medicine to treat digestive disorders such as piles, abdominal pain, dysentery, and diarrhea, as well as respiratory conditions, tumors, and wounds. Dey *et al*. [87] also noted the traditional use of the plant's tuber to correct gastrointestinal abnormalities. In addition to traditional use, Swain *et al*. [117] found that different parts of the *A. paeoniifolius* plant, such as the leaf, corm, and petiole, were traditionally used to treat various diseases.

Furthermore, the corms of *A. paeoniifolius* consist of a valuable component called glucomannan (GM) or konjac glucomannan (KGM). Shahbuddin [5] in her study concluded that the highest percentage of GM was found in mature *A. paeoniifolius* corms (50.22%) than young *A. paeniifolius* corms (14.90%). Glucomannan offers potential health benefits and various applications in the food and pharmaceutical industries. One of glucomannan's key health advantages is its capacity to absorb water and transform into a gel-like material in the digestive tract. This process can increase feelings of satiety, lower caloric intake, and support weight management [118]. Additionally, glucomannan has been shown to improve cholesterol levels and blood sugar control, making it a promising dietary supplement for individuals with metabolic disorders [119]. The ability of GM to bind to bile acids in the gut, blocking their absorption and requiring the liver to use more cholesterol to create new bile acids, decreases blood cholesterol levels. The GM lowers blood sugar as it is able to slow down the absorption of glucose in the gut. In their clinical investigation, Walsh *et al*. [120] looked at the effects of glucomannan on 20 obese patients. The results of the study showed that using glucomannan supplements for more than eight weeks caused participants' lipid profiles to improve, resulting in significant weight loss (2.50 kg) and significant reductions in blood cholesterol and low-density lipoprotein cholesterol (21.7 and 15.0 mg/dl, respectively). Sood *et al*. [121] came to the same conclusion in another trial, finding that glucomannan use significantly reduced total cholesterol, LDL cholesterol, triglycerides, body weight, and fasting blood glucose. However, glucomannan did not appear to significantly alter HDL cholesterol or blood pressure. Thus, glucomannan is useful in promoting weight loss and lowering blood cholesterol.

In the biomedical and pharmaceutical industry, glucomannan plays an important role. In the pharmaceutical sector, GM is employed as a binder, thickening, gelling agent, film forming, coating ingredient for tablets, emulsifier, and stabilizer, according to Aanisah *et al*. [122]. Additionally, KGM is a bio-based material that can be utilized for wound dressing, according to Zhou *et al*. [123], because of its strong cell compatibility and gel characteristics. Hydrogels, xerogel, microspheres, films, and fibers are a few KGM-based wound barrier products. Mashudi *et al*. [124] supported this and stated that KGM-based wound dressing had good water retention, biocompatibility, and controlled-release properties. The dressing also showed promising results in promoting wound healing in an in vitro study. Another study by Genevro *et al*. [125] focused on the development of novel wound dressings using glucomannan asymmetric membranes. The study found that the glucomannan membranes exhibited good mechanical strength and flexibility, as well as high water uptake capacity and porosity, which are desirable properties for an effective wound dressing. The membranes also showed biocompatibility with human skin cells, promoting cell proliferation and attachment. Besides, Bahlawan *et al*. [126] mentioned that glucomannan is utilized in medicine delivery systems due to its ability to form a good gel.

The unusual colloidal properties of KGM, which increase viscosity and have the capacity to gel, have led to its widespread use in the food sector as a thickening and gelation agent. Besides, it is also used as a stabilizer, emulsifier and suspended ingredients in foods and beverages [126]. Moreover, KGM aids in generating luscious textures without boosting food's caloric, lipid, or carbohydrate content [127]. The impact of konjac glucomannan and konjac flours on the textural, rheological, and microstructural characteristics of low-fat processed cheese was examined in a study by Silva *et al*. [128]. The results showed that the cheese's texture was greatly improved by the addition of konjac glucomannan and konjac flours, making it more elastic and firmer. The rheological properties of the cheese were also improved with the addition of konjac glucomannan and konjac flours, leading to a better spread ability and reduced tendency to syneresis (separation of whey and milk solids). According to Fang *et al*. [129], KGM is a food additive that significantly enhances the flavor and taste of food while also extending its shelf life. Ice cream, sauces, baked goods including biscuits and cakes, noodles, meatballs and sausages, pastries and fudge, as well as alcoholic and carbonated beverages are typical foods that include KGM [127].

Conclusions

Amorphophallus paeoniifolius has several promising avenues for commercialization, particularly through the cultivation of the corms for food and health products. This species also can be effective intercrop plants, by improving soil health through their organic matters and nutrient cycling. *Amorphophallus paeoniifolius* could make a significant contribution to an economically sustainable crop production system. Based on the promising findings in this paper, further comprehensive investigation on its agricultural practices, health benefits, genetic improvement, and ecological roles are required to enhance its economic viability and sustainable use. *Amorphophallus paeoniifolius* holds considerable potential for commercialization due to its adaptability to diverse soil types and inherent drought resistance, making it a resilient crop that can significantly contribute to food security. This aligns well with the United Nations Sustainable Development Goal (SDG) 2: Zero Hunger. The corm of *A. paeoniifolius* is a rich source of nutrients, including vitamins, carbohydrates, fiber, and protein, positioning it as a viable alternative to traditional staples such as rice and grains. One of the most valuable components in the corm is glucomannan, a water-soluble dietary fiber that is currently in high demand for use in food, dietary supplements, and pharmaceutical products. In addition, *A. paeoniifolius* has been found to contain several bioactive phytochemicals, including flavonoids, phenolics, and alkaloids, which exhibit promising pharmacological properties such as antioxidant, anticancer, antidiabetic, and antihelminthic activities. However, these findings are largely based on laboratory research, and further clinical trials are necessary to validate their efficacy and safety in humans. Despite its many advantages, consumer acceptance of *A. paeoniifolius* remains limited, likely due to the presence of calcium oxalate crystals, which can cause irritation when consumed. Another challenge is the relatively long maturation period, with the crop typically requiring nine months before harvest, which may deter farmers from cultivating it. To address these limitations, future research could focus on plant breeding or genetic improvement strategies aimed at reducing calcium oxalate content and shortening the crop's growth cycle, thereby enhancing its appeal to both consumers and producers.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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