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Review Article

Recent developments in cultivation and processing of sweet gourd (*Momordica cochinchinensis* Spreng.)

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Sweet gourd (*Momordica cochinchinensis* Spreng.), commonly found in Vietnam and parts of India is a nutritionally rich crop known for its high carotenoid content, particularly lycopene and β-carotene. These nutrients contribute to the fruit's antioxidant properties, anticancer activity, and provitamin A content, which can boost human immunity. The fruit is gaining attention due to its potential to enhance health and well-being, alongside its economic benefits for farmers. To improve the cultivation and propagation of sweet gourd, various techniques have been developed, including seed germination methods, propagation by cuttings, and agrobacterium-mediated leaf explant protocols. Additionally, micropropagation techniques have been employed to facilitate the mass production of grafted plants, addressing the fruit's historically poor horticultural potential. Furthermore, advancements in processing technologies are being utilized to maximize nutrient retention, extend shelf life, and enhance the efficacy of sweet gourd in food and beverage products. India has made significant strides in cultivating and processing sweet gourd, with successful cultivation across various states and the potential for high market returns. The promotion and widespread cultivation of this crop can meet the growing demand for nutritionally rich foods, offer farmers a new source of income, and contribute to improved health outcomes. Sweet gourd holds promise as a nutraceutical crop that can contribute to both health and economic well-being. By leveraging improved cultivation and processing methods, there is significant potential for its introduction and expansion in India, offering substantial benefits in terms of nutrition, agriculture, and market opportunities.

Keywords: *sweet gourd, gac fruit, Momordica cochinchinensis, dioecious, anticancer, carotenoids, provitamin A, trypsin inhibitors, Xoi gac*

Introduction

Sweet gourd (*Momordica cochinchinensis* Spreng.), a member of the Cucurbitaceae family, is identified as an underutilized species (Joseph & Bharathi, 2008). It is also, also known as 'the fruit from heaven' (Kuhnlein, 2004), and is hailed for its potential to extend lifespan by enhancing energy levels, vitality, strength, and vigor (Voung et al., 2006). It is also known as cochin gourd, prickly bitter cucumber, and sweet gourd. This plant is native to Vietnam and grows well in the hot climates of Southeast Asia (Krishnan, 2022). It is taxonomically native to the Indian subcontinent, specific localities being Assam, Nagaland, Tamil Nadu, Uttar Pradesh, and West Bengal (Do et al., 2019). The Gac fruit is a popular delicacy in Thailand because of its delicious taste and vibrant color. With very limited cultivation, it is primarily found in its natural wild state. These crops are known for their resistance to biotic and environmental stresses, making them suitable for drought-prone areas (Singh et al., 2020). A number of native fruit varieties from India have already been identified for large-scale cultivation. Still, it becomes clear that there are more fruit crops to be fully utilized in the future (Singh et al., 2020). Farming sweet gourd has the capability to boost incomes and supply health-conscious consumers with a high-value product. Thus, we need to design methods for cultivation that can be adjusted for both large and small-scale production. The sex ratio of seed-derived plants is not precisely known, and their growth will be slowed by the cold (Parks et al., 2013).

The review paper will focus on the development in Gac fruit cultivation and its potential in India. In this part, the composition of Gac fruit is named, including nutrition, nutritive value, and processing. We will also explore the potential of this exotic fruit in India.

Potential Health Benefits of Sweet gourd

Gac fruit is now recognized as a new and unique source of carotenoids such as lycopene and β-carotene. This fruit is known to contain many different types of carotenoids and other phytochemicals such as phenolics, and flavonoids. The trypsin inhibitors have also been found to possess valuable biological activities like antioxidant, anticancer, and provitamin A activity (Chuyen et al., 2015). Lycopene in the Sweet gourd appears to be exceptionally high, and its β-carotene is much higher than that of tomatoes. Antioxidants protect cells in your body from damage due to factors called free radicals Thefruit is a strong anti-cancer food that can eliminate free radicals as an antioxidant. In addition, beta-carotene can also be converted to Vitamin A by the human body and this fruit contains a rich source of vitamin C, making it an essential immune system boost that enhances total body immunity. Hence, this will help the body to fight against infections and diseases (Ariffin et al., 2021). The pulp, peel, and aril contained fairly high levels of lycopene and β-carotene. The aril showed the highest lycopene and β-carotene contents among parts of the fruit, with 579.3 µg/g DW (dry weight) and 621.0 µg/g DW, respectively. The peel and pulp had lower amounts of those compounds (Abdulqader et al., 2019). This is notably higher than other fruits and vegetables rich in lycopene, such as tomato (3.1 mg/100 g), watermelon (4.1 mg/100 g), and pink grapefruit (3.36 mg/100 g), as reported by Aoki et al. (2002). According to Aoki et al., (2002) he overall carotenoid concentration (lycopene and β-carotene) in aril contents was 48.1 mg/100 g fresh weight (FW). Additional investigations on the crop have shown diverse outcomes for total carotenoid content, with reported values including 294.5 mg/100 g FW (Ishida et al., 2004), 49.7 mg/100 g FW (Vuong et al., 2006), 410.7 mg/100 g FW (Nhung et al., 2010), 1502 mg/100 g (Kubola & Siriamornpun, 2011), and 78 mg/100 g FW (Tran et al., 2016). According to Aoki et al. (2002), the aril exhibited the highest carotenoid content, followed by the pulp and peel.

Alkhafaji et al. (2019) explored the antimicrobial properties of Sweet gourd seeds and seed aril extracts. The results showed that the seed aril extract had prominent antibacterial activity, especially against *Staphylococcus aureus*, with a minimum inhibitory concentration (MIC) of 0.78 mg/mL. Crude seed aril oil also showed moderate to strong bactericidal and larvicidal activities against a variety of bacteria, indicating its potential as an alternative antibacterial agent for pharmaceutical preparations. It is a good source of carotenoids (i.e. lycopene and β-carotene) which exert antioxidative and cancer-preventive effects by scavenging reactive oxygen species (ROS), thereby inhibiting the initiation/multiplication stages during carcinogenesis. The seeds contain triterpenoidal saponins that exert anti-inflammatory effects by decreasing nitric oxide production and interfering with inflammatory signal transduction (Yu *et* al., 2017). Both in vivo and in vitro studies show that Gac fruit extracts can induce apoptosis, inhibit cell growth, and prevent angiogenesis (Tien et al., 2005). Abdulqader et al. (2018) also reported nutraceutical applications with enhanced vision and immune function due to its high composition of phytonutrients. Additionally, Gac fruit extracts have significant potential in the cosmeceutical industry due to their antioxidant and melanogenesis inhibition effects, especially from its peel, which could be used as an anti-aging ingredient in skincare products (Reungpatthanaphong et al., 2019). This emphasizes its potential therapeutic utility in antimicrobial intervention against bacterial infections. Gac fruit contains various bioactive compounds and has potential health benefits. Gac fruit aril includes lutein (up to 718 µg/g FW) and other phenolic compounds such as gallic acid and p-hydroxybenzoic acid (Kubola & Siriamornpun, 2011). Moreover, the seeds of Sweet gourd contain high levels of oil rich in fatty acids, particularly stearic acid (60.5%) and linoleic acid (20%) (Ishida et al., 2004). With its high bioavailability of phytonutrients and pleasant taste, it is one of the best supplement candidates.

Conventional cultivation practices of Gac fruit

Seedling is the general reproduction method of Sweet gourd, while vine cuttings and root tubers (root corms) have also been used for propagation in traditional cultivation. Gac seed takes from 1-4 weeks to germinate. Seed dormancy has a great role in limiting the growth and productivity of crops. In other words, these are the several factors that need to be taken into consideration when planning for a successful harvest. In seedling production, identifying the sex of a plant can be challenging. This is because the sex of the plant can only be determined once the flowers have developed, as current DNA technology for sex identification of seeds is still in its early stages (Sarkar et al., 2017). Parks et al. (2013) noted this issue in their research. According to a study conducted by Ram et al. in 2002, using two to three-node cuttings from the *M. cochinchinensis* vine resulted in improved rooting, plant growth, and yield. When propagating plants through cuttings, selecting cuttings from robust mother plants during the initial flowering phase and before the emergence of axillary flower buds is crucial. This is to give the best chance of successful propagation.

According to Wimalasiri's research in 2015, it has been observed that a significant proportion of seed-grown plants, amounting to 40 per cent or more, exhibit male characteristics. The lack of a swollen structure, such as an ovary or immature fruit, at the base of the flowers is evidence of this. Using tubers or cuttings, a cultivator can exercise authority over the quantity and proportion of male and female plants. To optimize insect-mediated pollination, it is recommended to achieve a male-to-female plant ratio of approximately 1:10 (Parks et al., 2013). According to Parks et al. (2013), vine cuttings that measure 15 to 20 cm in length and 3 to 6 mm in width can be successfully rooted either in water or in a potting mix that is well-aerated and moist. Once rooted, these cuttings can then be transplanted to their final location. There are two approaches to increase the number of female plants: either take cuttings from the female plants or use the undesirable male plants as rootstock with female scions. Due to its robust climbing ability, the gac plant can extensively cover trees if given the opportunity. Therefore, it is recommended to provide sufficient space for the vines, such as a distance of 1.5m within and between rows, and to contemplate implementing pruning measures. To reduce the decomposition of the soft and ripe fruits, supporting the vines using a lattice or trellis that is 2 to 2.5 m in height is recommended. Upon the main stem's ascent to the apex of the trellis, the apical meristem may be excised, thereby allowing for the selection and cultivation of laterals in a preferred manner (ECHO community, 2017). Gac pollination is insect-mediated. However, due to low production, manual pollination is necessary to enhance fruit set (Growables, n.d.). Hand pollination can be necessary if insect pollination is inadequate, but it is not a complex process (ECHO community, 2017).

By dabbing the stigma with pollen from the stamen, putting fresh pollen to the stigma with a paintbrush, or applying dry, frozen pollen to the stigma with a paintbrush, male flower pollen can be manually transferred to female flowers. After pollination, fruit development can be monitored, and the fruit can be supported by the vine using a mesh bag (Growables, n.d.). Reduced pollination efficiency can impair specific physicochemical properties of Gac fruit, so it is crucial to ensure appropriate pollination (Tran et al., 2021). Gac pollen can be preserved for pollination in situations where male flowers or pollinators are limited. The pollen can be stored at low temperatures, specifically at 4°C or −20°C. Storage at these temperatures has been found to maintain some pollen viability for up to 84 days. However, the viability and subsequent fruit set were significantly better when using fresh pollen compared to stored pollen (Tran et al., 2021). Pollen is gently gathered with a brush or other equipment and kept in a cold, dry location (Tran & Parksa, 2022).

Recent innovations in the propagation of Sweet gourd

Like many other plants, the propagation of Gac fruit has historically relied on conventional methods such as seed sowing and grafting. This method, while effective, has limitations such as long germination periods and varied seed viability. The need for more efficient propagation techniques becomes evident as global interest in this cropSweet gourd grows, driven by its high nutrient content and potential health benefits

Seed Germination: Seed germination is best between 25 °C and 35 °C, with a maximum germination rate of 91% at 30 °C. However, increasing storage time from 6 to 18 months under laboratory conditions (21 ± 1°C and 60% relative humidity) reduces germination and seed weight loss, highlighting the need for storage guidelines, particularly for higher temperature and humidity conditions where Gac is grown (Tran & Parksa, 2022).

Propagation by cuttings: Cuttings taken from female plants are treated with indole-3-butyric rooting hormone, which is available in powder or gel form. The cuttings are then placed in several types of media, such as rock wool, potting mix, water, or closed media sachet, in order to cultivate robust plants (Parks *et al.*, 2012). Tran & Parksa (2022) have verified that the application of rooting hormones can enhance the viability of softwood cuttings from 53% to 77% when treated with indole-3-butyric acid (IBA) at a concentration of 3-5 g/L. However, semi-hardwood cuttings do not necessitate IBA treatment. Furthermore, the results showed that both splice and wedge grafting methods were successfully producing a growth unit with relatively high rates of survival (>53%) (Tran & Parksa, 2022). It also enhances above 85% while using the smallest rootstock (4 weeks and then 8 weeks) (Tran & Parksa, 2022). In a recent study by Hamidon et al. (2020), the effect of IBA and NAA at a dose of 1000 ppm on root initiation and regeneration was assessed in vine cuttings. Results indicated a significant positive effect on growth and development in cuttings treated with IBA and NAA. Specifically, root formation and sprouting were significantly higher than in untreated controls. These findings suggest that applying IBA and NAA at 1000 ppm can result in better growth promotion and microshoot development of vine cuttings.

Micropropagation of sweet gourd: In the micropropagation (Figure 1) of Sweet gourd (*Momordica cochinchinensis* Spreng.), Al-Amery et al. (2023) conducted research outlining an efficient protocol based on three main stages: shoot multiplication, rooting, and acclimatization. Results showed that the best shoot multiplication medium was MS (Murashige & Skoog) nutrient medium containing 2 mgL^{-1} Benzylaminopurine, with an average of 3.0 main branches, 23.2 secondary branches, and a shoot length of 7.3 mm. Additionally, the shoots produced 28.6 leaves that weighed on average 0.570 gm fresh weight and 0.054 gm dry weight. For rooting, explants of 10 mm treated with 1.5 mgL-1 IBA were the most effective, resulting in an average of 14.10 roots per shoot and a root length of 7.5 cm. The survival rate of the rooted plantlets reached 90% during the acclimatization stage in different growth media, particularly peat moss.

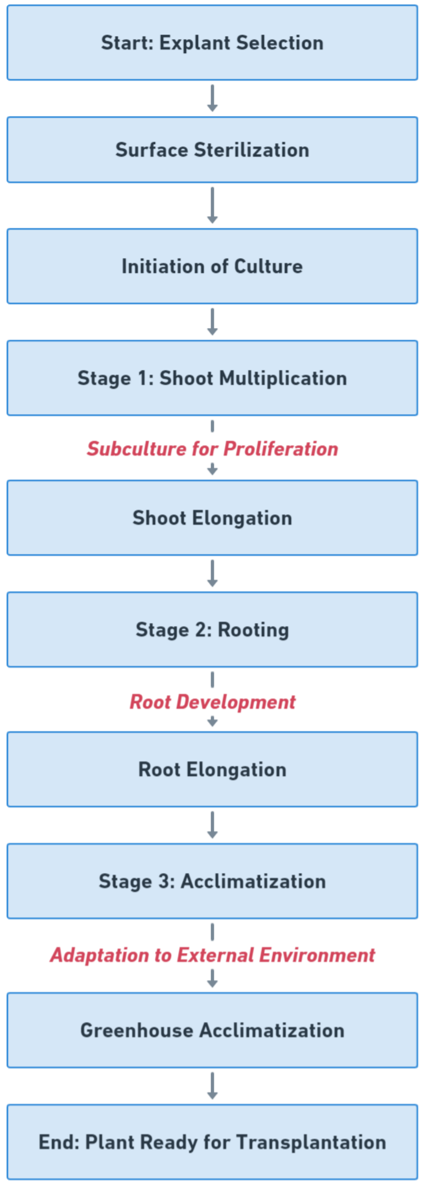

Figure 1. Schematic representation of the micropropagation process for Sweet Gourd

Harvest and yield

The ideal time to harvest Sweet gourd is when it has reached full maturity and developed a vibrant orange-red hue. It typically takes approximately nine weeks after the fruit is set to reach its whole ripe stage. The data suggests a gradual decrease in firmness after five weeks of fruit development, as evidenced by the single sigmoid curve observed in the changes in fresh weight and volume (Win et al., 2015). Additionally, it has been observed that the fruit displays an increase in ethylene levels throughout its growth and development process. Fruit harvested at various stages of maturity, including mature green, yellow, orange, and entirely red, were stored under typical room conditions of 25°C and 65-70% RH (Win et al., 2015). Fruit at the yellow stage tends to reach a normal ripe stage after a storage period of 12 days. It is observed that green fruit remains unripened while red fruit tends to become rotten during this period. The aril showed the highest amount of phenolics, particularly in the yellow stage at six days of storage. The peel and pulp also exhibited significant levels of phenolics, which reduced gradually in all parts of the fruit over time. It is recommended to consider harvesting the fruits during November and December as it tends to mature entirely and at its peak ripeness. Timing the fruit harvest is crucial for preserving optimal flavor and nutritive value (Win et al., 2015).

Momordica cochinchinensis is a remarkable perennial vine climber that can produce up to 60 fruits weighing 1-3 kg, during a single season (Muchjajib & Muchjajib, 2013).

Advances in Sweet gourd processing

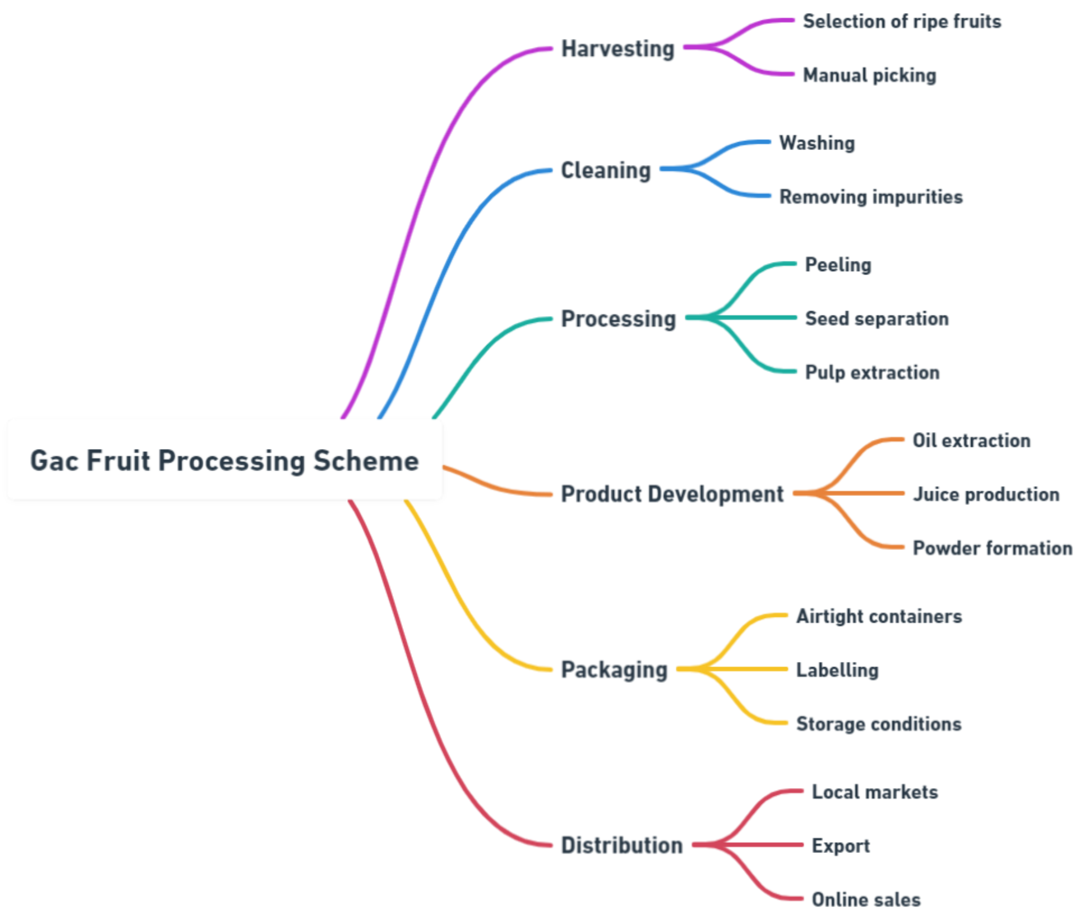

Figure 2. Overview of the Gac Fruit Processing Scheme, illustrating the sequential steps from harvesting and cleaning to processing, product development, packaging, and distribution.

The processing of Sweet gourd (Figure 2) traditionally involves extracting the pulp and seeds from the fruits spiny outer rind. This pulp, rich in nutrients and antioxidants, is often used in culinary applications or as a natural colorant. Due to the fruits high nutrient content, particularly carotenoids, and their potential health benefits, there has been growing interest in developing more advanced processing techniques. For example, Kha (2010) stated that arils, seeds, pulp, and skins can be powdered to produce powders from the Gac fruit which could potentially be applied in several food items such as pasteurized juice, milk beverages, yogurt, and sauces due to their versatility. This study examined the physicochemical and antioxidant properties of Sweet gourd powder using pre-treatment and drying processes. For instance, a test study was conducted by Kha in 2010 to analyze how pre-treatments (blanching, ascorbic acid, and bisulfite) and drying techniques (air, vacuum, freeze, and spray drier) influence the properties of Sweet gourd powder. Freeze-dried fresh Gac aril without pre-treatments resulted in powder with high quality; it provided an important level of carotenoids and antioxidant properties. Another study by Kha et al. (2013) on extracting Gac oil utilizes a microwave-assisted method that increases β-carotene and lycopene yield as well. In this work, the process flow for co-producing Gac oil and 2% B-rich organic chelate extract with nutrients is proposed. This sequence involves pre-heating Gac aril using a microwave at rated power 630 W for 62 mins, followed by steaming for 22 mins. After being treated, the processed arils are hydraulically pressed under a pressure of 175 kg per cm^2 to release the oil. The new method shows that it could be more efficient and advanced in the quality of the extraction process to obtain Gac oil (Kha et al., 2013). The new technologies along with these approaches will allow for a better nutritional profile, shelf life extension, and improved utility of Gac fruit in different food applications. Other advances in Sweet gourd processing are as follows:

Foam drying: A study by Auisakchaiyoung & Rojanakorn (2015) was carried out with the objective of investigating the effects of foam-mat drying conditions on the quality of the aril. The ideal condition for foam formation was determined with 1.5% methylcellulose and a whip time of 25 minutes. More importantly, drying at 70°C for 60 minutes with the thickness of the aril foam at 1 mm resulted in the highest preservation of lycopene, β-carotene, total phenolic compounds, and antioxidant activity. Results show that foam-mat drying was effective in preserving important nutritional and antioxidant benefits of the aril.

Spray drying: Pinthong et al. (2019) studied the impact of different drying treatments on sweet gourd powder properties: physical attributes and carotenoid level. Their work also confirmed that both spray drying (Figure. 3), particularly with the aid of pectinase, contributed greatly to the retention of carotenoid concentration close to that found in fresh fruit. This method also affected the powder's moisture, color characteristics, water solubility, and holding capacity. Of all evaluated drying methods, spray pectinase treatment was the most advantageous in terms of retaining the fruit powder's nutritional and functional properties.

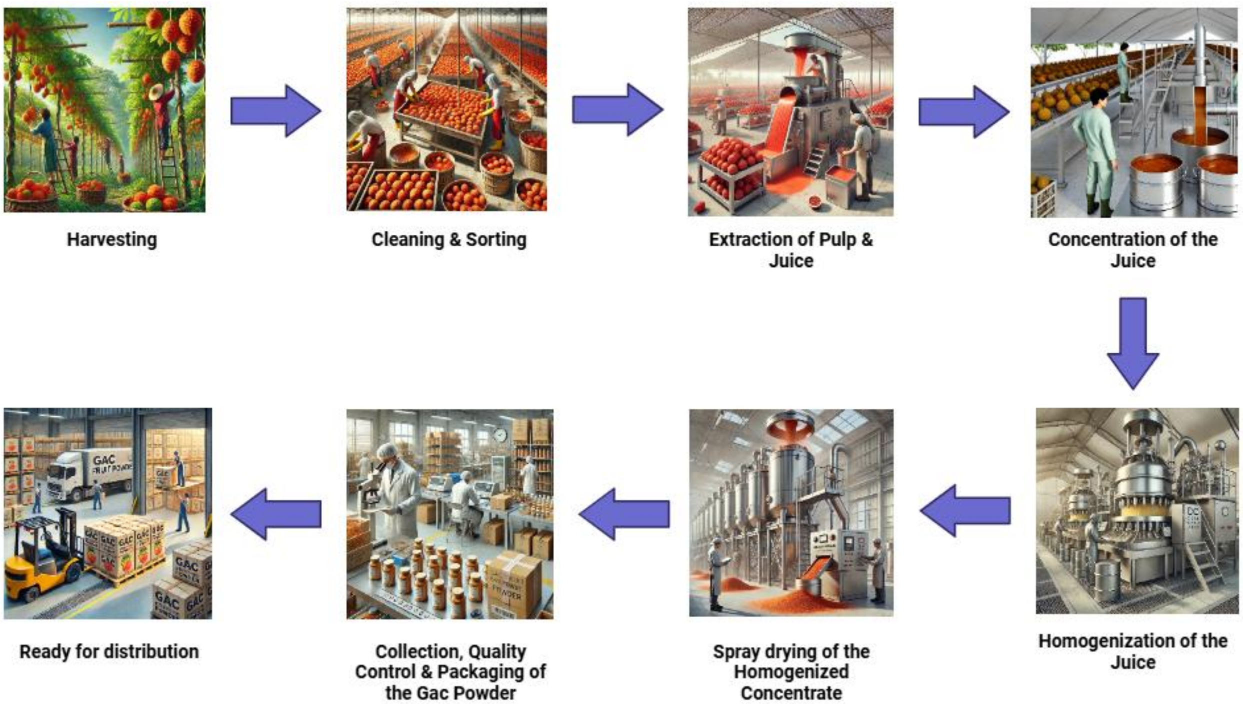

Figure 3. Process flow diagram showcasing the drying treatments involved in Gac Fruit processing

Sweet gourd products

Sweet gourd has been utilized in various and diverse ways across numerous cultures worldwide (Kha et al., 2013). The delectable flavor of the mature Gac aril makes it a commonly used coloring agent in the preparation of red glutinous rice or xoi Gac (Figure 4a) (Ishida et al., 2004). This dish is often served during celebrations such as weddings and the New Year in Vietnam (Zheng et al., 2015). Alternatively, the young green fruit can be used for cooking by boiling or cooking with chili paste. In Thailand, it is also utilized to prepare curry (Kubola & Siriamornpun, 2011). Adding aril has been reported to result in delectable stir-fried dishes and soups with a lustrous appearance and distinct flavor (Chuyen et al., 2015). In addition to the traditional utilization, commercial products like Gac powder (Figure 4b) and Gac oil (Figure 4c) have been manufactured as natural colorants and medicinal supplements. The utilization of Gac for nutritional supplementation is prevalent in the form of Gac extracts contained in soft capsules (Figure 4d). There has been a growing interest in the Gac aril, which has led to the development of various health products by international companies. Some of the most heavily advertised products are still beverages and capsules with Gac. Gac's natural carotenoids have been proposed as alternatives to synthetic coloring agents tartrazine, sunset yellow, and quinoline yellow. Some research suggests that these artificial coloring agents may be contributing to mental issues in children (Bateman et al., 2004).

The fresh ripe aril of Gac is used for juice and ice cream processing in Thailand (Kubola & Siriamornpun, 2011; Innun, 2013). It is also consumed as a blend of fresh Gac fruit with honey, lemon, and aril in Malaysia, Indonesia, and the Philippines. Different commercial Gac products have been marketed in countries like Vietnam, China, and Thailand, including aril puree, oil, dried aril powder, juice, fruit enzyme, skin balm, soap, and seed alcohol. For example, the high levels of lycopene and provitamin A (β-carotene) in Gac oil and dried powder have been exploited for marketing purposes. The oil element in Gac aril is necessary to absorb carotenes, vitamin E, and other vital fat-soluble nutrients needed by the human body (Chuyen et al., 2015).

Figure 4. Various Gac Fruit Products: (a) Traditional Gac rice dish (Xoi Gac), (b) Gac fruit powder, (c) Gac fruit oil with fresh fruit, and (d) Gac fruit antioxidant softgel capsules.

In the work of Marnpae et al. (2022), it was found that *Lactobacillus paracasei* could ferment processed sweet gourd juice to produce a probiotic beverage. This novel method lowered the pH from 4.45-4.85 to 3.60-3.71, and the sugar content of these samples fell in the range of 7.76-8.52 g/100 ml to 6.60-7.50 g/100 ml. The β-carotene content in the fermented juice significantly increased, from 6.80-14.52 mg/100 ml to 9.10-19.24 mg/100 ml. The drink also showed improved antioxidant activity and the potential to reduce cholesterol levels, which could offer a point of difference compared with existing non-dairy probiotic beverages.

Scope for Sweet Gourd cultivation in India

The potential for Sweet gourd cultivation in India is substantial, leveraging the insights from Do et al. (2019), who note its presence in states like Assam, Nagaland, Tamil Nadu, Uttar Pradesh, and West Bengal. The success stories of Indian farmers such as Jojo Punnackal from Ernakulam, Kerala, who has been cultivating Sweet gourd for four years with significant earnings from seed sales alone, are inspiring (Krishnan, 2022). Punnackal's experience is a testament to the viability and profitability of Sweet gourd farming in India, as he earns around Rs 2 lakh annually just by selling the seeds. It can grow in the Kerala states of southern India, in specific areas like Kottarakkara, Thodupuzha, and Perumbavoor (Krishnan, 2022). This shows that sweet gourd plants are adaptable to the diverse climates across India. Besides being rich in antioxidants such as carotenoids, beta-carotene, and lycopene, Sweet gourd is beneficial for health. The fruit's numerous health benefits for the skin, eyes, immunity, and heart were highlighted by Jojo Punnackal (Krishnan, 2022). There are also good economic prospects for Sweet gourd cultivation. Punnackal's annual earnings from seed sales and the high market price for thefruit (Rs 900 to Rs 1,200 per kg) suggest a lucrative opportunity (Krishnan, 2022). Additionally, the fruit's anti-aging properties make it suitable for use in other products, such as face creams, enhancing its commercial potential beyond fresh consumption (Krishnan, 2022). There are many prospects for sweet gourd farming in India. It not only caters to the increasing need for food with a high nutritional value but supplies an extra source of income to farmers and it has potential in many sectors such as health supplements or cosmetics. It is a versatile health food and can become a good supplement to the varied agriculture in our country if farmers like Jojo Punnackal are supported.

Conclusion

The review highlights significant advancements in the cultivation and processing of sweet gourd (*Momordica cochinchinensis*), focusing on its potential as a nutritionally dense and economically valuable crop. With its high levels of carotenoids, particularly lycopene and β-carotene, the fruit is well-positioned to make substantial contributions to the health and nutraceutical sectors. Recent innovations in propagation and processing have improved cultivation efficiency and nutrient preservation, making Sweet Gourd increasingly viable for large-scale production, particularly in India. These developments point to its potential in enhancing public health and contributing to economic growth.

Author contributions

Ambethgar Anbu Sezhian (First Author): Led the conceptualization and design of the review article, conducted comprehensive literature searches, and synthesized findings. Drafted the majority of the manuscript and integrated contributions from co-authors. Provided critical revisions and approved the final version. Sri Harini Ramalingam (Second Author): Assisted in the literature review, contributed to the writing and organization of the manuscript, and performed data analysis. Participated in revising and refining the manuscript based on feedback from all authors. Iyadurai Arumuka Pravin (Third Author): Contributed to the identification and evaluation of relevant literature, wrote specific sections of the manuscript, and ensured the accuracy and integrity of the information presented. Reviewed and edited the manuscript for coherence and academic rigor. Sundaresan Srivignesh (Corresponding Author): Provided expertise on key topics, contributed to the conceptual framework of the review, and assisted in drafting and revising critical sections. Coordinated the communication among co-authors, reviewed the manuscript for technical accuracy and clarity, and ensured the final version was of high quality. Corresponded with the journal and handled revisions.

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Conflict of interest

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Ethics approval

Not applicable

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