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Review:

Gac fruit: nutrient and phytochemical composition, and options for processing

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Momordica cochinchinensis Spreng or Gac fruits are rich in nutrients including carotenoids, fatty acids, vitamin E, polyphenol compounds and flavonoids. Medicinal compounds are also found in the seeds, but the benefits of traditional preparations from these need to be clarified. The plant has the potential to be a high value crop particularly as parts of the fruit can be processed into nutrient supplements and/or natural orange and yellow colorants. However, the plant remains underutilized. There is limited information on its requirements in production, and the processing of health products from the fruits is a relatively new area of endeavour. The versatility of the fruit is highlighted through processing options outlined for fruit aril, seeds, pulp and skin into powders and/or encapsulated oil products. These Gac fruit products will have the potential to be utilized in a range of foods such as pasteurized juice and milk beverages, glutinous rice, yoghurt, pasta and sauces.

Keywords: Gac fruit, carotenoids, fatty acid, antioxidant, oil extraction, encapsulation

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Introduction

The cucurbit *Momordica cochinchinensis* Spreng., called Gac in Vietnam, is a variable species and is widespread across South East Asia, Malesia and India.[(1)] English names for the fruit include baby jackfruit, sweet gourd and cochinchin gourd. Nutritionally, this fruit is special because the flesh around the seeds (aril) is rich in carotenoids, especially β-carotene and lycopene. Gac fruits also contain relatively high levels of α-tocopherol (vitamin E), polyunsaturated fatty acids[(2-4)] and polyphenol compounds and flavonoids.[(5)] A number of studies highlight the important role these products play in human health. Beyond its natural distribution, Gac aril products are gaining popularity as health-promoting foods. Gac fruit products also have market potential as alternatives to the artificial colourants, Tartrazine, Sunset yellow and Quinoline yellow which are associated with behavioral problems in children.[6]

In addition to the Gac aril having a very high nutritional content, the total carotenoid content (TCC) in the yellow pulp of the Gac fruit (mesocarp) is relatively high as compared to many plant foods.[2; 7] Furthermore, the yellow pulp represents approximately half of the weight of an entire fresh fruit and is the highest anatomical component.[7] However, while the aril is traditionally used for food preparation due to its attractive color and high nutrients, the pulp is often discarded. Similarly, Gac skin, which represents about 17% of the total weigh of the fruit, is not used. Importantly, the seeds containing high levels of fatty acids and other products are not usually used. Therefore, identifying means of utilizing of these components is necessary to reduce the environmental problem of waste and to enhance the economic value of the fruit

This review will focus on the traditional uses and production of Gac fruit, fruit nutrient and phytochemical composition, and the use of Gac products as nutrient supplements and natural food colorants. A potential processing scheme for Gac fruit is proposed to help facilitate greater use of this fruit.

Traditional uses

Gac fruit is a traditional Southeast Asian fruit. In Vietnam, ripe Gac fruit is most commonly prepared as “Xoi Gac” (the Gac aril cooked in glutinous rice) for Tet (Vietnamese New Year) and wedding celebrations. In India (Assam and Andamans), the fruits are harvested small and green with immature seeds to be consumed as a vegetable [8] The spiny skin is removed and the fruits are sliced and cooked sometimes with potato or bottle gourd and in some areas the tender leaves and shoots of the plant are also cooked.[9]

Gac fruit seeds are used in traditional Chinese medicine, known as *Mubiezhi*, to treat fluxes, liver and spleen disorders, wounds, hemorrhoids, bruises, boils, sores, scrofula, tinea, swelling and pus.[10; 11] Practically, many people in rural areas in Vietnam use ground Gac seeds mixed with alcohol or vinegar to cure furuncle, swelling, hemorrhoids and mumps. However, future research needs to clarify the benefits of these preparations.

Propagation and cultivation

Limited information is available on the requirements in production of the Gac plant for optimum yield and quality of the fruits. The Gac plant is not usually intensively cultivated but can be seen (in Vietnam) growing wild or in domestic settings with the vines growing on lattice in rural homes or in gardens. The plant can be cultivated from seeds or root tubers, and grows as dioecious vines (separate male and female plants). Rooted vine cuttings can also be used for propagation and are more reliable than production from seeds which can be affected by dormancy and a long lead time into production.[9] Further, several seedlings need to be planted in the one pit so that the male plants can be removed once they are identified as male at flowering, as only a few are needed for pollination.[9] Alternatively, it is possible to graft female scion material onto the main shoot of the unwanted male plant making it productive.[12]

Hybridization studies using several Mormordica species including Gac,[13] and studies on the effects of plant growth regulators on Gac[8; 14; 15] indicate that new varieties with bisexual flowers will be possible, overcoming some of the difficulties currently associated with Gac production.

Approximately two-three months after planting, flowering occurs. Pollination is chiefly carried out by insects rather than wind and hand pollination results in a higher fruit set than open pollination.[16] It takes approximately five months after flowering before the ripe fruits can be harvested. One plant can produce 30 to 60 fruits in one season,[17] although this may depend on factors such as climate and plant age, yet to be described.

Fruit morphology

The fleshy Gac fruit can be botanically described as a pepo. Gac fruits grown in Vietnam are typically round or ovoid in shape but one cultivar grown in India is recorded as oblong shaped.[18] The exterior skin of Gac is covered in short spines which can sparsely or densely cover the skin. Its green color becomes red or dark orange when ripe. Gac fruit (Figure 1)[19] comprises orange/yellow skin containing spines, yellow pulp and aril (red flesh surrounding the seeds). The highest anatomical component of a Gac fruit is yellow pulp (49%, by weight), whereas the aril, that contains the highest level of carotenoids, accounts for only 18%.[19] The aril weight has also been reported as 10% and 24.6%.[3; 7] Storage time and growth stage during which loss of water may contribute to this variation.[3]

Bioactive compounds of Gac fruit

Gac fruit is an exceptional fruit whose aril contains excellent sources of carotenoids, α-tocopherol (vitamin E), polyphenol compounds, flavonoids, and essential fatty acids.[2; 3; 5; 7; 10; 11; 20] Depending on the component, these phytochemicals are present in all parts of the fruit so there is the potential to utilize all parts in processed products. Future research will need to focus on the effect of growing, storage and processing conditions on the phytochemical qualities of fruits such that techniques and varieties are developed to protect and/or enhance the desired bioactive qualities.

Carotenoids

Carotenoids from plant-based foods play a crucial role in human health.[21; 22] For example, numerous studies have reported that lycopene-rich diets are linked with reduced risk of cardiovascular disease and cancers such as lung, breast, stomach and prostate.[23-25] β-Carotene is converted to vitamin A in the body[26)]

Evidence suggests that Gac has promise as a bioavailable source of carotenoids and it has been examined as a food supplement in a study with Vietnamese children. In the study, 185 Vietnamese preschoolers participated in a 30 day supplementation trial and were randomly divided into three groups, one group given Xoi Gac (sticky rice mixed with Gac fruit containing 3.5 mg β-carotene), one group given rice mixed with 5 mg synthetic β-carotene powder and a control group given rice without fortification. Results indicated that plasma levels of retinol and carotenoids (β-carotene, α-carotene, zeaxanthin and lycopene) after supplementation were significantly increased. Moreover, the increase in plasma β-carotene level after supplementation in the fruit group (1.86 μmol/L) was significantly higher than that in the powder group (1.48 μmol/L).[27] Therefore, using Gac fruit as a food-based intervention may be effective for reducing vitamin A deficiency.

The Gac aril, in particular, contains extraordinarily high levels of carotenoids, especially carotenes and lycopene (Table 1), in comparison to other fruits and vegetables. It is claimed that the lycopene concentration in Gac fruit is at least five times higher than in other well known fruits analyzed (grapefruit, tomato, papaya, guava and watermelon) (Figure 2).[2; 21] It is also shown that Gac aril has the highest known concentration of β-carotene of all fruits and vegetables.[4] For example, it is eight times higher than the level in carrots, which are recognized as being high in β-carotene (Figure 3).[27-29]

In addition to the aril, the yellow pulp and skin are good sources of carotenoids and should not be overlooked as carotenoid sources (Table 1). For example, lutein has a higher concentration in the skin than in the aril or the pulp.[5] Many studies have reported that lutein plays an important role in the prevention of age-related macular degradation (AMD).[22; 30-32] These components of Gac fruit are usually discarded when the aril is scooped out and used for processing purposes. Although high, the concentration of carotenoids content in Gac fruit are variable (Table 1). The factors responsible for this remain to be investigated but may include variety, genotype, season, geographic location, stage of maturity, growing conditions and storage conditions. For example, one single study investigated concentration changes in carotenoids (lycopene and β-carotene) in Gac fruit as affected by ambient storage conditions and stage of maturity. Fruit maturity was the most important factor with the content of carotenoids highest in the ripe fruits.[3] Ultimately, the factors that affect the concentration of carotenoids in Gac will need to be actively investigated to allow for production of fruits with a consistently high source of carotenoids.

α-Tocopherol (Vitamin E)

Vitamin E or α-tocopherol is an important fat-soluble antioxidative component in foods and the human body and potentially plays a key role in preventing cardiovascular disease,[33; 34] coronary heart disease[35-37] and delaying Alzheimer's disease.[38; 39] The concentration of vitamin E in Gac fruit, at 76 µg/ g of fresh weight, is high compared with other fruits.[20] Vitamin E, as a natural antioxidant, helps protect Gac aril oil from oxidation.[40] In foods, vitamin E could potentially preserve valuable phytonutrients rich in Gac fruit from oxidation.

Polyphenolics and flavonoids

Phenolic acids and flavonoids are found in Gac fruit, which potentially have beneficial effects on human health.[41-43] These compounds are in all fruit parts at concentrations between 1.5 to 4.3 mg/g of dry weight. The aril contains the highest concentrations of phenolic acids and flavonoids, 4.3 and 2.1 mg/g respectively.[5]

Fatty acids

Primarily, the benefit of Gac derived fatty acids would be in using these as an alternative to saturated fats in the diet. The benefits of essential fatty acids in human health are well known. The presence of fat in the Gac fruit aril plays an important role in the absorption of carotenes and other fat-soluble nutrients.[27, 44] Similarly, several studies also show that fat ingested with carotenoid compounds in plant foods significantly improves their absorption by the body.[45-47]

Gac fruit (aril and seeds) are rich in fatty acids, particularly monounsaturated and polyunsaturated acids. Unlike the aril, the seeds are usually discarded; therefore utilization of the seeds contributes to preventing waste disposal problems and maximizing available sources.

The Gac aril contains significant amounts of fatty acids at 102 mg/g of fresh weight (FW).[27] Seventy percent of total fatty acids in the aril are unsaturated, and 50% of these are polyunsaturated.[4] Unusual for fruits, Gac has a high concentration of linoleic acid and omega-3 fatty acids.[7] The fatty acid composition and total oil content of Gac aril are presented in Table 2.

The total fatty acid content in Gac seeds is between 15.7% and 36.6% of the total weight of the seed.[7] The fatty acid composition includes stearic acid (54.5% - 71.7% by weight), linoleic acid (11.2% - 25.0%) and α-linolenic acid (0.5% - 0.6%). Several other types of fatty acids are found in Gac seeds in smaller amounts.[7]

Gac aril oil contains a high concentration of oleic acid, 34 % of total fatty acids (see Table 2); hence it can be used in addition to other sources such as sunflower, palm and soya. However, research on the effects of oleic acid in Gac fruit is still needed to confirm its benefits. Gac aril and seeds also contain α-linolenic acid that is beneficial to human health. For example, α-linolenic acid has been seen in some studies to play important role in reducing the incidence of cardiovascular disease.[48-50]

Other components

Gac fruit seeds are used in traditional Chinese medicine and they are rich in beneficial chemical compounds such as oleanodic acid, diterpene columbin, chondrillasterol, *momordica* saponins momordins and pentacyclic triterpenoid ester.[10; 11] Some evidence supports the beneficial effect of Gac seed components. Ethanol extract from Gac seed was shown to significantly decrease blood glucose levels and increase insulin in diabetic rats. The presence of saponins, flavonoids and other compounds in seeds may synergistically or independently contribute to this beneficial effect.[51]

Other components in seeds, such as multiple trypsin inhibitors,[52] play an important role in the prevention of human cancer.[53; 54]

Processing of Gac fruit

If the fruit was to be used for all the applications indicated above and more then appropriate processing would be needed. However, little information is available on how the Gac fruit might be processed to make full use of its components and maintain its quality characteristics. It is envisaged that Gac fruit can be processed in several ways (Figure 4) including drying, extraction of oil, encapsulation and incorporation into foods.

Drying methods

Generally, fruit powders are often used in the food industry as they are convenient to store, handle and transport. This is particularly important for fruits such as Gac which are only available fresh for a short season. Powders are also favored when used as natural colorants. Gac fruit, available as a powder, will ensure its supply for use as colorings in food products, including juices and dairy products.

Gac aril

Studies show that the choice of pre-treatments and drying treatments plays an important role in effectively maintaining the highest content of carotenoids, color and antioxidant activity.
In comparing different drying methods, it is clear that freeze drying processes can substantially preserve the nutritional values of samples, in terms of TCC and total antioxidant activity (TAA). This has been confirmed for Gac powder,[19; 55] carrot slices [56] and paprika powder.[57] However, freeze drying is generally seen as a very expensive preservation method. For example, freeze drying costs are 4 to 8 times higher than that of air drying.[58]

Freeze drying may not always be the superior process since it did not show any advantage over convective air drying at below 70^{0}C in terms of carotenoid retention in carrots. The β-carotene and lycopene contents remained almost constant after the convection air-drying.[(56)] Similarly, in a comparison of freeze drying and oven drying (at 25-75^{0}C) of tomato pulp solids, the lycopene content was not significantly different.[(59)] Some research indicates a negative impact of freeze drying on the content of carotenoids. For example, the amounts of lycopene in two tomato varieties after freeze drying were reduced to 33%-48% of the levels in fresh fruits.[(60)] In contrast, the lycopene contents after air-drying increased by 152%-197% of levels in fresh fruits. In this case, the heating process breaks down the cell walls and the bonding force between lycopene and the tissue matrix. As a result, lycopene is more accessible and increases more *cis*-isomerization.[(60)]

For Gac, the TCC of samples pre-soaked in ascorbic solution or bisulfite prior to vacuum drying at low temperature of 40^{0}C was highly comparable with the freeze dried samples.[(19)] Also, a good quality Gac powder was obtained, in terms of color, total carotenoids and antioxidant activity when produced by spray drying at inlet temperature of 120^{0}C and adding maltodextrin concentration at 10%.[(61)] Based on these studies, a suitable drying technique has good potential for producing powder from Gac aril .

Gac skin and pulp

Gac skin and pulp may also be suitable for production as powders since they have a high nutritional value even when dried. For example, air-drying at a temperature of 60^{0}C was performed to produce powders from Gac skin and pulp.[(19)] This showed that skin powder is higher in TCC and TAA compared with the pulp powder, Additionally, the TCC of skin and pulp powders is high compared to other fruits and vegetables, including cherry tomatoes, pumpkin, carrot[(62)] and several tomato cultivars.[(63)] This confirms skin and pulp powders as desirable sources of carotenoids and may encourage greater utilization of these by air drying.

Oil extraction methods

Oil rich in essential fatty acids can be extracted from Gac aril and seeds but optimization of Gac oil extraction is needed. Traditional extraction using potentially harmful organic solvents has been abandoned due to health concerns, environmental problems and quality degradation and it is important to find an alternative extraction method using non-solvent or food grade solvent. Many reports show that plant oil can be extracted by other methods such as supercritical carbon dioxide (SC-CO_2) extraction, aqueous enzymatic extraction, microwave-assisted extraction and ultrasound assisted extraction. These methods are environmental friendly and solvent free. The advantages and drawbacks of ultrasound-assisted pressing extraction[(64-66)] and microwave-assisted pressing extraction[(67-69)] in food extraction have been reviewed.

Among the existing methods, SC-CO_2 extraction has been considered as a most promising alternative to traditional solvent extraction and mechanical pressing. It offers a number of advantages including non-solvent residues, shorter extraction times, higher extraction yields and better retention of nutritional and valuable bioactive compounds.[(70)] In recent years, SC-CO_2 extraction technique has been employed to extract essential oils,[(71-73)] fatty acids,[(74; 75)] carotenoids[(76-78)] and vitamin E[(78; 79)] from fruits and vegetables. However, the SC-CO_2 extraction of fatty acids, carotenoids and α-tocopherol from Gac aril has not yet been reported.

Encapsulation process

Encapsulation is the process by which bioactive components (core material) such as food oils are enveloped within a wall. This process is used for protection, stabilization and slow release of food ingredients. Recently, increased attention has been given to the application of encapsulation of bioactive compounds, particularly unsaturated fatty acids. The degradation of these compounds can be prevented by applying encapsulation techniques. The encapsulation of fatty acids has been successfully reported in numerous studies.[(80-82)] The process requires agents to protect the oils and emulsifiers to achieve good encapsulation in the spray drying technique commonly used in the food industry. However, the study of Gac oil encapsulation has not yet been reported.

There are various encapsulating agents (wall materials) effective for encapsulating food oils in providing good protection against heat, light and oxidation. The agents are classified as carbohydrates, cellulose, gum, lipids and protein which are reviewed elsewhere.[83-86] The wall materials have different physical and chemical characteristics, and their properties including viscosity, solubility, stabilization, reactivity, protective capacity and cost have been reviewed by several authors.[84; 86] Cyclodextrins are an example of an agent widely used in spray drying encapsulation of food oil. The monomers of cyclodextrins are connected to each other, giving a ring structure that is relatively rigid and has a hollow cavity with the ability to encapsulate other molecules.[84] Its suitability as an encapsulation agent for Gac fruit is unknown.

The encapsulation process requires an emulsifier, particularly for stabilizing the emulsion used in spray drying encapsulation. Generally, the choice of emulsifier is determined by its hydrophile-lipophile balance (HLB) value. According to Davis,[87] a high HLB value (8 - 13), indicates a more hydrophilic surfactant, and is suitable for facilitating oil in water emulsion formation and enhancing its stabiblity. Earlier, Griffin[88] claimed that this range should be about 8 - 18 for oil in water emulsifier. The HLB values of some common emulsifiers can be found elsewhere.[85] Other parameters needing consideration for emulsificaiton include total solids concentration, viscosity, droplet size and emulsification method.[84]

Among various encapsulation techniques reported,[83; 86] spray drying encapsulation is the most widely used in the food industry.[89; 90] This process can potentially offer many benefits such as economics, flexibility and good quality of encapsulated materials[91] and may be suitable for Gac fruits. However, to achieve good encapsulation efficiency for Gac, the conditions for wall materials, emusifiers and spray drying conditions all need optimizing. The key parameters for spray drying include feed temperature, air inlet and outlet temperatures,[84; 92] atomization type and conditions, drying air flow rate and humidity, and powder particle size.[84]

Utilization of Gac products

Finally, utilization of Gac powder or encapsulated Gac oil can be achieved by incorporating it into foods as a natural colorant and/or nutrient supplements. Natural carotenoid extracts are used as food colorants in many processed products including oily products (margarines, oils, fats and shortenings), fruit juice, beverages, dry soups, canned soups, dairy products, milk substitutes, coffee whiteners, dessert mixes, preserves, syrups, confectionery, salad dressings, meat products, pasta, egg products, baked goods and others [93; 94; 95]

Gac aril powders produced by different drying methods such as freeze-drying, vacuum-drying and spray-drying are easily incorporated into the Vietnamese dish "Xoi Gac", pasteurized Gac juice, pasteurized Gac milk beverages, yoghurt, fettuccine pasta, and creamy sauce.[19; 96] Also, the color, TCC and TAA of the juice and the milk beverages are maintained after storage for 30 days under refrigeration.[19] Considering these studies and given that Gac aril and Gac oil can be effective natural source of highly bioavailable lycopene and β-carotenes when cooked[97], there is great potential to produce high quality products from processed Gac fruits.

The extraction of natural colorants from Gac would need to follow approved methods, such as those used for extracting lycopene from tomatoes.[98] Unfortunately, gaining approval to use natural colorants as food additives is a complicated task, because it takes time to meet the requirements of governments and organizations.[93] Only 13 natural colorants are approved in the EU and 26 natural colorants certificated in the USA.[99] However, in the EU , the "*Southampton Six"* colors, being Alurra Red (also called Red 40), Ponceau 4R (E124); Tartrazine (Yellow 5) (E102); Sunset Yellow FCF/Orange Yellow S (Yellow6) (E110); Quinoline Yellow (E104); and Carmoisine (E102)) now must have a specific warning label on food packaging. This increases the demand for natural colorants such as those from Gac fruit.

Drawbacks of developing new colorants are the high costs for manufacturers.[95] Development of Gac products as a natural food colorant needs to consider the many factors affecting its application in a particular food product. These factors include for example its solubility and stability in processing, packaging and storage. It is very important to optimize the factors allowing the stability of natural carotenoids in the final product. For example, the hue of carotenoids is affected by pH.[100]

Conclusions

Gac fruit contains extraordinarily high levels of carotenoids (particularly lycopene and β-carotene), α-tocopherol and fatty acids in its parts (aril, seeds, yellow pulp and skin). Other bioactive compounds such as polyphenol compounds and flavonoids are also found in Gac fruit. The seeds are high in fatty acids and are also used as traditional Chinese medicines. Many studies confirm that the valuable compounds in Gac fruit play a crucial role in human health. The proposed processing scheme of all the parts of Gac fruit including drying, oil extraction and oil encapsulation highlights how the utilization of air-dried powder from the pulp and skins prevents environmental pollution from waste disposal problem and enhances the overall value of Gac fruit.

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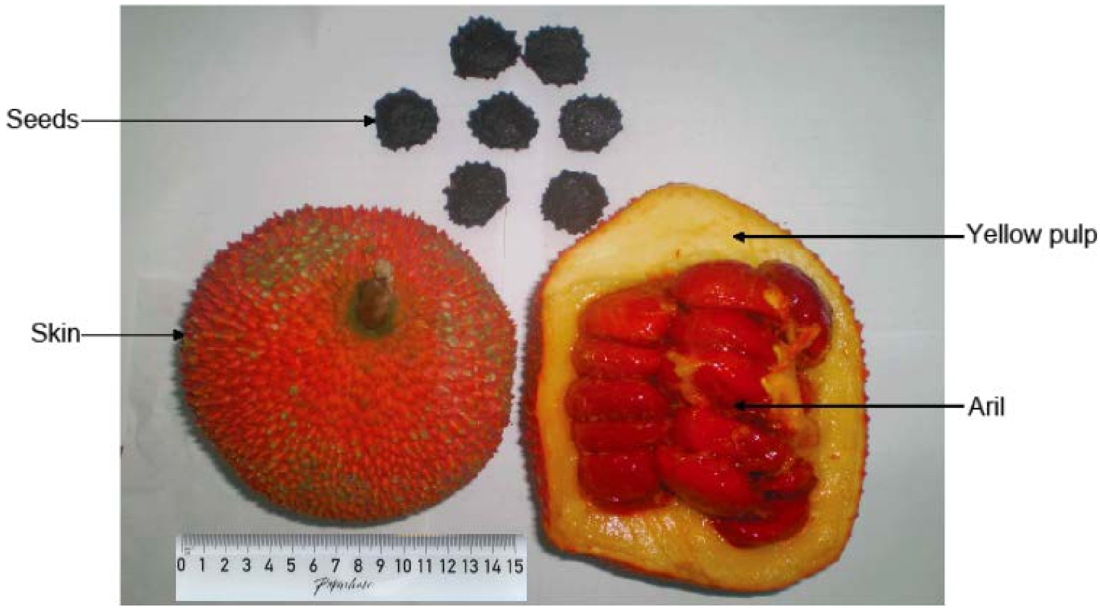

Figure 1. Fresh Gac fruit components (from Kha[19])

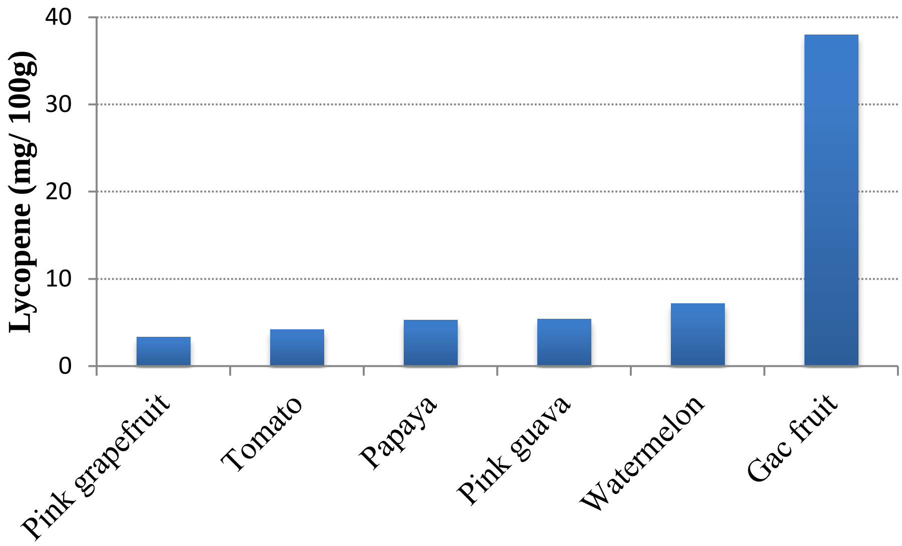

Figure 2. Lycopene content of fruit and vegetables (adapted from Aoki et al.[2]; Rao & Rao[21])

101.

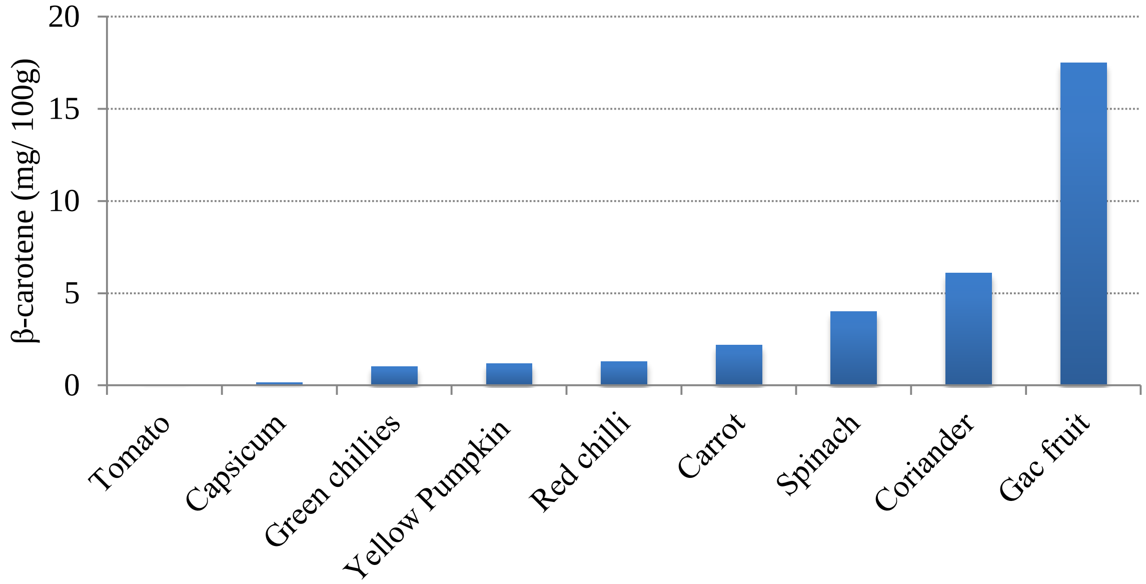

Figure 3. β-carotene content of fruit and vegetables (adapted from Kandlakunta et al.[28]; Singh et al.[29]; Vuong et al.[27])

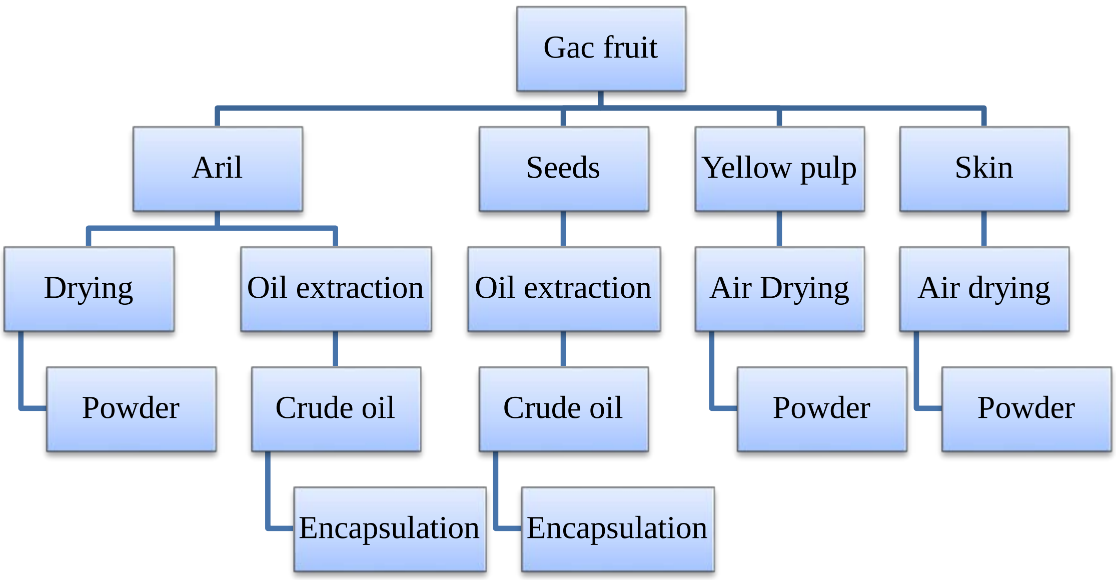

Figure 4. A potential processing scheme of Gac fruit

Table 1. Carotenoid content of fresh Gac fruit (mg/100g)

Carotenoids	**Skin**	**Pulp**	**Aril**
β-carotene	38.4 - 141.6[5]	24.0 - 43.2[5]	160.0[5]
		2.2[2]	63.6 - 83.6[7]
			10.1[2]

			8.3[20]
Lycopene	38.4 - 81.6[5]	14.4 - 49.6[5]	154.6 - 305.4[7]
		0.1[2]	140.0[5]
			38.0[2]
			40.8[20]
Lutein	189.6 - 1248[5]	16.0 - 144.8[5]	na
Zeaxanthin	na	0.2[2]	0.9[2]
β-cryptoxanthin	na	0.4[2]	0.2[2]

Note. na: not available; [5]: data converted from dry weight to fresh weight using the moisture content of skin, pulp and aril of 76%, 92% and 80%, respectively

Table 2. Fatty acid composition and total oil content of Gac aril[27]

Fatty acids	Abbreviation	Concentration (mg/g, FW)	% of total fatty acids
Myristic	14:0	0.89	0.87
Palmitic	16:0	22.48	22.04
Palmitoleic	16: 1 Δ^{9}	0.27	0.26
Stearic	18:0	7.20	7.06
Oleic	18:1 Δ^{9}	34.76	34.08
cis-vaccenic	18:1 Δ^{11}	1.15	1.13
Linoleic	18:2 $\Delta^{9,12}$	32.06	31.43
α-linolenic	18:3 $\Delta^{9,12,15}$	2.18	2.14

Arachidic	20:0	0.40	0.39
Gadoleic	20:1 Δ^9	0.15	0.15
Arachidonic	20:4	0.10	0.10
Behenic	22:0	0.19	0.19
Lignoceric	24:0	0.14	0.14
Total		101.98	