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Physicochemical Properties, Proximate Composition, and Carotenoid Content of *Momordica cochinchinensis* L. Spreng (Gac) Fruit

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ABSTRACT

The study aims to determine the physical and chemical properties of *Momordica cochinchinensis* L. Spreng (gac) fruits. Fruit size varied, weighing 359.17 to 588.33g, with lengths of 11.10 to 13.92 cm and circumferences of 27.43 to 30.67 cm. Components included pulp (34.06 to 41.58%), seeds (23.11 to 29.70%), peel (16.65 to 20.60%), and aril (15.64 to 18.64%). Skin and aril colour parameters (L*, a*, b*) indicated maturity and carotenoid content. Aril had higher acidity (pH 5.54±0.02, titratable acidity [TA] 0.03 to 0.05g/L), total soluble solids (TSS, 11.57%±0.52 °Brix), and carbohydrates (55.6 g/100 g) than pulp (pH 5.65±0.02, TA 0.01 to 0.02g/L, TSS 4.90%±0.33 °Brix, carbohydrates 30.9 g/100 g). Peel contained most protein (6.2 g/100 g) and dietary fibre (56.9 to 58.1 g/100 g). Glucose and fructose were found in both pulp and aril. Potassium levels were highest in peel (817.59 mg/100 g), followed by pulp (658.20 mg/100 g) and aril (228.79 mg/100 g). Lycopene dominated carotenoids, especially in aril (31.7 to 103.7 mg/g). β-carotene, lutein, astaxanthin,

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and zeaxanthin were also present. β-carotene (2.9 to 9.6 mg/g) was second to lycopene, followed by astaxanthin (1.54 to 4.91 mg/g), lutein (0.16 to 1.35 mg/g), and zeaxanthin (0.35 to 1.49 mg/g), absent in pulp. These findings have implications for the food industry, offering insights into gac fruit's nutritional potential. Malaysian gac exhibited superior nutritional content, with pulp and aril as notable sources of carbohydrates and minerals for consumption and aril as a promising source of healthy oils.

Keywords: Carotenoids, minerals, *Momordica cochinchinensis* L. Spreng, physicochemical, proximate, sugar profiles

INTRODUCTION

Momordica cochinchinensis L. Spreng, commonly referred to as 'gac', belongs to the *Momordica* genus, which encompasses other species such as *Momordica charantia*, *Momordica balsamina*, *Momordica dioica*, and *Momordica tuberosa*. Gac falls under the melon family (Cucurbitaceae), sharing its botanical lineage with cucumbers, squash, luffa, and bitter melon (Chomicki et al., 2020; Dujardin & Kitthawee, 2013; Parks et al., 2013). This tropical plant is native to Southeast Asia and enjoys extensive cultivation in countries like Thailand, Vietnam, Laos, China, Japan, India, Cambodia, the Philippines, Malaysia, and Bangladesh (Kubola et al., 2013; Mai et al., 2013; Mukherjee et al., 2022). Gac goes by various names in different regions, including spiny gourd, spiny bitter gourd, cochinchin gourd, sweet gourd (in English), Fak kao (in Thailand), gac (in Vietnam), Mak kao (in Laos), Moc Niet Tu (in China), Bhat kerala (in India), Kushika and Mokubetsushi (in Japan), Hakur, Kakrol, and Kakor (in Hindustan), and Teruah (in Malaysia) (Huynh & Nguyen, 2020; Kubola et al., 2013).

Gac has gained popularity in Vietnam due to its health benefits and its traditional role in cooking. It is frequently used in Vietnam as a natural colouring agent for making glutinous rice, known as *xoi Gac*, a dish commonly served during festive occasions (Le et al., 2018; Phan-thi & Waché, 2014). In Thailand, gac is often enjoyed as a vegetable, particularly in its immature stage. The fruit pulp has a flavour resembling papaya and is either cooked or boiled, typically served with chilli paste or included in various curry dishes (Kubola et al., 2013).

Gac fruits exhibit significant variation in size and weight, and this variability can impact the concentrations of bioactive compounds, especially carotenoids. Factors such as the specific plant variety, local climate, harvest season, level of maturity, geographical location, and the use of fertilisers all contribute to the diversity in fruit size (Bhumsaidon & Chamchong, 2016). Various attributes related to fruit quality, including size, weight, skin colour, firmness, thickness of the aril (the fleshy part surrounding the seeds), and colour, play a pivotal role in determining consumer acceptance and pricing. Traditionally, Vietnamese consumers prefer gac fruits weighing approximately 1.2–2 kg and possessing good firmness, red skin, and a thick, dark-red aril (Tran et al., 2016).

The gac fruit consists of two primary parts: the mesocarp and the endocarp. The mesocarp, which makes up nearly 50% of the fruit's weight, is thick, spongy, and has an orange colour. On the other hand, the endocarp is composed of red, soft, and sticky arils that are approximately 1–3 mm thick and envelop black seeds. These arils contain a high concentration of valuable carotenoids, notably β-carotene and lycopene (Kha et al., 2013). Previous studies have documented β-carotene concentrations ranging from 0.083–0.769 mg/g and lycopene concentrations ranging from 0.380-0.408 mg/g in Vietnamese gac varieties (Kubola et al., 2013). Compared to tomatoes, gac arils can contain approximately 3 mg/g of lycopene in terms of fresh weight, while tomatoes have around 40–50 µg/g in fresh weight (Mai et al., 2013). Gac fruits are also abundant in other carotenoids, earning them the status of a "super fruit" due to their substantial bioactive and nutritional potential, including essential fatty acids, vitamin E, and lutein.

Moreover, gac fruits boast high concentrations of nutrients like vitamin E and unsaturated and polyunsaturated fatty acids, which are known for their beneficial impacts on human health. Approximately 70% of the total fatty acids found in gac arils are unsaturated, with 50% being polyunsaturated. These arils contain significant amounts of oleic acid, palmitic acid, linoleic acid, vitamin E, and omega-3 fatty acids. The presence of fat in the gac aril aided the absorption of carotenoids, vitamin E, and other fat-soluble nutrients (Kha et al., 2013).

Despite gac fruit being widespread in Eastern Asia, its limited exposure in terms of food preparation and knowledge of its nutritional advantages has hindered its presence in the market. As a result, gac is viewed as an indigenous fruit in Malaysia. Furthermore, there is a noticeable absence of studies exploring the physicochemical traits, proximate composition, and nutritional advantages of gac fruits. Therefore, this study aims to investigate the physicochemical characteristics, proximate composition, and carotenoid content of the peel, pulp, and aril of *Momordica cochinchinensis* L. Spreng (gac) fruits cultivated in Malaysia.

MATERIALS AND METHODS

Sample Preparation

Seven mature gac fruits, distinguished by their uniform yellow-red skin as documented in the research conducted by Kha et al. (2013), were procured from the International Tropical Fruits Network (TFNet) located in Serdang, Selangor, Malaysia. Upon its arrival at the laboratory, the fruit underwent a thorough cleaning under tap water. Processing of the fruit was carried out on the same day. The peel, pulp (endocarp), red sticky arils (mesocarp), and seeds were manually separated from the fruit's cavity and then stored at -80°C. These components were then subjected to freeze-drying (lyophilisation) at a temperature of -45°C over 3 days, employing a Christ Beta 2-8 LD plus freeze dryer from GmbH (Germany). The various fruit parts were reduced and transformed into powdered using a Waring® stainless steel commercial blender to prepare the samples for analysis (Waring® Commercial, USA). The resulting powdered samples were securely sealed in opaque containers and maintained at -18°C until they were ready for further analysis.

Chemical and Reagents

The chemicals and reagents employed for the analysis of the proximate composition, as well as the carotenoid standards (β-carotene, lycopene, lutein, astaxanthin, and zeaxanthin), were procured from Sigma Chemical Co. (USA) and Fisher Scientific (USA), ensuring the highest available purity. For the high-performance liquid chromatography (HPLC) analysis, methanol, dichloromethane, and acetonitrile, which served as mobile phases, were obtained from Merck (Germany). Other solvents such as *n*-hexane, acetone, and ethanol were also sourced from Fisher Scientific (USA).

Determination of Physicochemical Properties of Gac Fruit

Determination of Weight, Length, and Circumference. The physical measurements of gac fruit, including weight, length, and circumference, were obtained using an analytical weigh balance, a Mitutoyo stainless steel calliper (0–6”, made in Japan), and a flexible measuring tape. Fruit length was defined as the distance from the apex to the stem along the polar axis, while fruit circumference was measured as the maximum width perpendicular to the polar axis.

Determination of Fruit Colour. The colour of various parts of the gac fruit, including the skin, pulp, and aril, was quantified using a HunterLab Ultrascan® PRO USP1092 spectrophotometer (USA). These measurements were conducted under the D65/10 illuminant, and the results were expressed in terms of darkness to lightness (L*), greenness to redness (a*), and blueness to yellowness (b*). The L* value ranges from 0 (representing black) to 100 (indicating white). Multiple measurements were taken at three distinct points on the fruit’s skin, pulp, and aril. The aril’s colour was determined using a glass cuvette following a standardised protocol.

Determination of Soluble Solids Concentration. The gac fruit pulp and aril’s total soluble solids (TSS) content was assessed using an Atago N1 Hand Refractometer (Japan). After separating the flesh and aril from the skin and seeds, 10 g of each tissue was homogenised with 40 ml of distilled water. Subsequently, the resultant mixture was filtered, and a small drop of the filtrate was carefully placed on the prism glass of the refractometer. The measurement of soluble solids concentration was conducted at a temperature of 27°C.

Determination of TA and pH. The remaining juice from the TSS determination was utilised to measure TA. It was accomplished by titrating it with a 0.1 mol/L sodium hydroxide (NaOH) solution, employing 1% phenolphthalein as an indicator. The outcomes were expressed as a percentage of citric acid, calculated using the formula [(ml NaOH × 0.1 mol/L/Weight of the titrated sample) × 0.064 × 100%], a method specified by Tran et al. (2016). Furthermore, the pH of the juice was gauged using a Crison Micro pH 2000 glass electrode pH meter. This pH meter was calibrated using pH 4.0 and 7.0 buffer solutions as references.

Determination of Proximate Composition

The assessment of the proximate composition of gac peel, pulp, and aril adhered to the Association of Official Analytical Chemists (AOAC) (2000) standard method, a well-established and widely acknowledged protocol within scientific research and food analysis. This method is commonly employed to determine nutritional components in food samples.

Moisture Content. The moisture content in the gac sample was ascertained by subjecting roughly 2 g of the sample to a drying process within pre-dried crucibles at 100°C for 24 hr. Following this, after allowing the crucibles to cool in a desiccator, their weights were re-measured. The weight of the dried sample was divided by the initial sample weight and then multiplied by 100% to compute the percentage of dry matter. Subsequently, the moisture content was determined by subtracting the percentage of dry matter from 100%.

Ash Content. The ash content analysis of gac fruits followed the AOAC (2000) standard using the dried ashing method. Initially, 5 g of the sample was weighed and placed into crucibles. These crucibles underwent high-temperature ashing at 550°C for 24 hr. After cooling in a desiccator, the crucibles were reweighed to calculate the ash content as a percentage of the original sample weight.

Crude Protein Content. The protein content in gac fruit was determined via the Kjeldahl method. Initially, 1 g of the sample was weighed and placed into a digesting tube, along with Kjeltabs Cu 3.5 Catalyst tablets and concentrated sulfuric acid. Digestion continued until a green solution formed. After cooling, the solution was combined with a receiving solution containing boric acid and bromocresol indicator. NaOH was added, and distillation occurred using a Kjeltec™ Distillation Unit (Denmark). The resulting distillate underwent titration with 0.1 N hydrochloric acid (HCl) until a noticeable colour change was observed. The protein percentage was calculated using the formula:

$$\text{Protein (\%)} = [(T - B) \times N \times 14.007 \times 100\%] / \text{Weight of the sample (in mg)} \qquad \text{[Equation 1]}$$

Where, T = Volume of the sample titration; B = Volume of the blank titration; N = Normality of hydrochloric acid

Crude Fat Content. The fat content in gac fruit was determined using the Soxhlet method. Initially, 2 g of the sample were accurately weighed and then transferred to thimbles. These thimbles were subsequently placed within an extraction cup containing 70 ml of petroleum ether. After extraction, the cup containing the extracted fat was dried in an oven at 103°C for 2 hr. Following this, it was allowed to cool within a desiccator. The weight of the extraction cup was then recorded. The percentage of fat was calculated using the formula:

$$\text{Percentage of fat (\%)} = [(W3 - W2) \times 100\%] / W1 \quad \text{[Equation 2]}$$

Where, $W1$ = Weight of the initial sample; $W2$ = Weight of the extraction cup; $W3$ = Weight of the extraction cup along with the extracted fat

Total Available Carbohydrate Content. The total available carbohydrate content of the gac fruits was assessed using the Clegg-anthrone method, following the procedure outlined by Chin et al. (2023) as well as Ram and Shankar (2023). Initially, 2.5 g of the sample were mixed with 10 ml of water and agitated to disperse the sample evenly. Subsequently, 13 ml of 52% perchloric acid was added to the mixture, which was then stirred for 20 min before being diluted to a final volume of 100 ml. For the carbohydrate analysis, 10 ml of the extracted sample was diluted with 100 ml of water. Next, 1 ml of the diluted sample extract or a glucose standard solution was carefully transferred into a test tube, followed by adding 5 ml of anthrone reagent. The test tube was then placed in a boiling water bath for 12 min and cooled to room temperature. The absorbance of the resulting reaction mixture was measured at 630 nm against a blank. The formula $(25 \times b) / (a \times w)$ was then employed to compute the total available carbohydrate content, expressed as a percentage of glucose by weight, where ‘a’ represents the absorbance of the glucose standard solution, ‘b’ is the absorbance of the sample extract, and ‘w’ signifies the weight of the sample in grams.

Total Dietary Fibre Content. The total dietary fibre in gac fruit was analysed using the AOAC (2000) method. The sample (1 g) was mixed with 50 ml of pH 6.0 phosphate buffer, and α-amylase was added. After 15 min of boiling in a water bath with periodic agitation, the mixture was cooled, the pH was adjusted, and protease was introduced. Subsequently, it was incubated in a 60°C water bath. Amyloglucosidase was then added, followed by another incubation at 60°C. After cooling, ethanol was used to precipitate the fibre. The precipitate was filtered, washed, and transferred to crucibles with celite. These crucibles were washed, dried, and weighed. The residues were analysed using the dried ashing and Kjeldahl methods. Finally, the crucibles, including celite and ash, were weighed to determine the total dietary fibre content.

Sugar Profiles

Sugars in gac peel, pulp, and aril were extracted following the method outlined by Zheng et al. (2016). In summary, 2 g of powdered sample was homogenised with 5.0 ml of cold ethanol (80%). After incubation and centrifugation, the supernatants were combined and adjusted to a total volume of 25 ml, and a portion of the extract was dried for sugar analysis. Sugar analysis involved a chromatographic system with acetonitrile-water (80:20, v/v) as the mobile phase and an Agilent Hi-Plex H-cation exchange column (Agilent Technologies, USA). Detection was performed using a refractive index detector, and data analysis was conducted with a chromatography data system. Sugar concentrations were expressed as µg/g fresh weight (FW).

Mineral Analysis

Mineral concentrations in gac fruit parts (peel, pulp, and aril) were determined using atomic absorption spectrophotometry (AAS) with a PerkinElmer A Analyst 800 model (USA). Gac samples were ashed at 550°C for 5 hr, and the resulting ash was dissolved in concentrated hydrochloric acid (HCl). The diluted solution was then analysed using AAS under optimised conditions and calibrated using standard solutions.

Carotenoid Extraction Method

For carotenoid extraction from gac samples (peel, pulp, and aril), a modified method based on Auisakchaiyoung and Rojanakorn (2015) as well as Tran et al. (2016) was used. Approximately 2 g of gac powder were blended with 100 ml of a solvent mixture (n-hexane, acetone, and ethanol in a 50:25:25 ratio) and stirred for 30 min. Next, 15 ml of water was added, and the upper layer was filtered through a 0.45 µm filter paper. A 10 ml aliquot of the extract was evaporated using a rotary evaporator, repeated four times until the extract became colourless, and then used for total carotenoid measurement via high-performance *liquid chromatography* with diode-array detection (DAD-HPLC) analysis.

Determination of Carotenoid Content by HPLC. The extracted solution was diluted to 4 ml and filtered through a 0.45 µm membrane syringe filter into HPLC glass amber vials. Following Kubola et al. (2013), HPLC analysis used a 20 µl injection volume. Calibration curves for carotenoids (lutein, zeaxanthin, β-carotene, lycopene, and astaxanthin) were constructed with standard solutions. The analysis employed an Agilent 1100 Series HPLC system with a diode array detector (DAD, USA) and either an Alltech C-18 column (USA) or a YMC Carotenoids C-30 column (Japan). Columns were preconditioned with the mobile phase. The mobile phase consisted of methanol, acetonitrile, and dichloromethane in varying ratios, with a 1.0 to 1.2 ml/min flow rate. Column temperature was set at 30°C, and absorbance was monitored at specific wavelengths for each carotenoid. The mobile phase was filtered and degassed before HPLC analysis.

Statistical Analysis

The experiment was conducted in triplicate, and the results are reported as mean values with standard deviations (mean ± SD). One-way analysis of variance (ANOVA) was performed using SPSS software (version 17.0) to assess differences between means, with a significance level set at $p<0.05$.

RESULTS AND DISCUSSION

Physicochemical Properties of Gac Fruit

Weight, Length, and Circumference of Gac Fruit. Figure 1 illustrates the different shapes (oblong and round) of the gac fruit in (a) and (b), as well as various maturity levels of the fruit in (c), (d), and (e). The figure also provides a visual representation of the different parts of the fruit, including the opened cut before part separation in (f), the skin and pulp after removing seeds and aril in (g), the seeds coated with the sticky aril in (h) and (i), the aril after separation from the seeds in (j), the dried seeds with aril in (k), the dried peel in (l), and the size of the gac seed in (m) and (n). The pulp, also known as mesocarp, is a significant component of fruits and vegetables, but it is often underutilised, except for green gac, commonly used in Thai cuisine (Kubola et al., 2013). Given the limited available information on the physical properties of gac fruit, various measurements such as weight, length, circumference, pulp thickness, as well as the weight percentage of seeds, pulp, aril, and peel in relation to the fruit weight, have been compiled and are presented in Table 1.

The collected data on the size and characteristics of gac fruit are significant for the food industry as they provide insights into the potential commercial utilisation of different fruit parts with optimal nutritional content. It is worth noting that there was variability in fruit size, leading to larger standard deviations in Table 1. In line with Müller-Maatsch et al. (2017), the study identified two types of gac fruit: oblong and round. The oblong fruits weighed between 500 and 1,600 g, ranging from 6 to 10 cm and a maximum length of 13 cm. On the other hand, the round fruits measured approximately 4-6 cm in length. In this investigation, the oblong-shaped fruits exhibited larger dimensions compared to the round-shaped ones, with weights of 588.33 versus 359.17 g, lengths of 13.92 versus 11.10 cm, and circumferences of 30.67 versus 27.43 cm, respectively.

Tran et al. (2016) observed that the size, including length and diameter, as well as the weight of gac fruit, is influenced by its maturity stage. However, there was no significant difference in length for gac fruit cultivated in Malaysia between the two types. In Assam, India, Hamidon et al. (2020) reported that gac fruit typically ranges in weight from 1 to 3 kg. Similarly, Tran et al. (2016) found that gac fruit grown in Sydney, Australia, had weights ranging from 1.04 to 1.73 kg, lengths varying between 21.33 and 26.33 cm, and diameters ranging from 42.50 to 50.83 cm, depending on the maturity stage, which ranged from green and immature to fully ripened and mature.

Conversely, Bhumsaidon and Chamchong (2016) noted that the average weight of gac fruit in Vietnam is approximately 710 g, with the aril accounting for 125 g (18%). In contrast, in Thailand, the average weight is around 438

(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m) (n)

Figure 1. *Momordica cochinchinensis* L. Spreng (gac) fruit and its part as shown as follows: (a) oblong and round shape of gac fruit from freezer; (b) post-thawed; (c) fully ripe (red) gac fruit; (d) fully ripe (red); (e) medium ripe (yellow); (f) interior view; (g) skin and pulp after seed and aril removal; (h) seeds coated by sticky aril; (i) seeds coated by sticky aril; (j) aril after separation from the seeds; (k) dried seeds with arils; (l) dried gac skin; (m) gac seeds; and (n) size of seed

g, with a higher percentage of aril (21% or 110 g). These findings suggest that the gac fruit in Malaysia, as studied in this research, tended to be smaller in size compared to reports from other regions. As noted by Parks et al. (2013), fruit size can impact the thickness of the aril, which generally increases with larger fruit sizes.

Table 1
Physical properties of gac fruits and seeds

Sample	Fruits												Seeds
	Weight (g)	Length (cm)	Circumference (cm)	Pulp thickness (mm)	Seed (g)	Seed % (g)	Pulp (g)	Pulp % (g)	Aril (g)	Aril % (g)	Peel (g)	Peel % (g)	Length (mm)
Oblong	588.33 ± 92.92	13.92 ± 0.92	30.67 ± 2.04	23.00 ± 2.00	135.97 ± 18.17	23.11 ± 19.56	244.65 ± 48.87	41.58 ± 52.59	109.65 ± 25.53	18.64 ± 27.47	97.93 ± 14.79	16.65 ± 15.92	20.50 ± 1.05
Round	359.17 ± 69.13	11.10 ± 0.85	27.43 ± 1.94	16.75 ± 1.89	106.67 ± 12.48	29.70 ± 18.06	122.33 ± 30.28	34.06 ± 43.81	56.17 ± 14.61	15.64 ± 21.13	74.00 ± 15.38	20.60 ± 22.24	16.17 ± 1.72

Note. Results are expressed as means ± standard deviations (n = 6)

Table 1 presents the relative weights of the four primary components of the gac fruit: peel, pulp, aril, and seeds, expressed as percentages of the total fruit weight. The findings reveal that the pulp constitutes the largest proportion of the fruit (34.06%–41.58%), followed by the seeds (23.11%–29.70%), peel (16.65%–20.60%), and the aril, which is of particular interest, makes up the smallest proportion (15.64%–18.64%) of the total fruit weight. The peel percentage in relation to the fruit weight in this study ranged from 16.65% to 20.60%. This finding is higher than that reported by Parks et al. (2013), who stated that the gac skin accounts for about 17% of the fruit weight. However, it is lower than the range of 13.89% to 15.16% reported by Tran et al. (2016) for fully ripe gac fruit.

In terms of pulp thickness, the study found it to be in the range of 16.75 to 23.00 mm (approximately 0.66 to 0.91”). It differs from the report by Chintan and Vijayakumar (2020), who stated that gac fruit grown in Vietnam has a pulp thickness of approximately half an inch (approximately 38.1 mm). The variation in pulp thickness could be attributed to the different fruit sizes in the respective studies. The pulp of the gac fruit in the study accounted for 34.06% to 41.58% of the fruit weight. This observation is lower than the values reported by Tran et al. (2016) (43.86% and 49% of fruit weight) and Parks et al. (2013) (52% to 75% of total fruit weight). The lower percentage of pulp weight in this study suggests that the gac fruit used was at a semi-ripe maturity stage, aligning with the findings of Tran et al. (2016), who reported a pulp weight of 36.20% at a similar stage.

Conversely, the aril contributed 15.64% to 18.64% of the fresh weight, which is significantly lower compared to the findings of Tran et al. (2016) (29.17% to 30.00%), who reported that the fruit flesh, encompassing the red soft and sticky aril, accounted for 25% of the fruit weight. Parks et al. (2013) also reported a range of 6 to 31% for the aril component of gac fruit. Additionally, other studies by Tran and Parks (2022) have reported aril percentages of 10%, 18%, and 24.6% of fruit weight, respectively.

The seeds of the gac fruit in this study accounted for 23.11 to 29.70% of the fresh weight, which is significantly higher compared to the findings of Tran and Parks (2022) (9.33% to 10.20%). This difference suggests that the quality of gac fruit grown in Malaysia may be lower due to its smaller size (less weight), a lower percentage of aril, and a higher percentage of seeds compared to other studies such as Parks et al. (2013) and Tran et al. (2016).

The size of the seeds in this study ranged from 16.17 to 20.50 mm in length. Chintan and Vijayakumar (2020) reported that each gac fruit has an average of 15 to 20 round, compressed, sculptured seeds. Parks et al. (2013) also stated that approximately 30 to 40 seeds per fruit, accounting for 18% to 30% of the fruit weight. According to Tran et al. (2016), the development of the seeds within the gac fruit is influenced by the harvest maturity stage, with a significant difference in the number of immature white seeds compared to fully mature black seeds at different stages of maturity.

The Colour of Gac Fruit. The skin colour of gac fruit is an important sensory attribute, as highlighted by Angkananon and Anantawat (2015), and it is influenced by factors such as maturity index, as discussed by Kubola et al. (2013). This study observed various skin colours of mature gac fruits (Figures 1a, b, c, d, and e). Figure 1c and d represent ripe (red) gac fruits, while Figure 1e depicts a mature (yellow) gac fruit. Kubola et al. (2013) categorised gac fruits into three maturity indices: immature (green), mature or medium ripe (yellow), and fully ripe (red). Immature gac fruits are typically green in colour with white pulp and very small transparent seeds, commonly consumed as a vegetable in Thailand. Medium-ripe fruits have yellow peels, light yellow pulp, and white seed coats and are aged between 120 to 130 days. Fully ripe fruits, aged between 140 and 150 days, have orange pulp, red arils (mesocarp), and black seed coats. According to Kha et al. (2013), mature gac fruits can be identified by their uniform yellow to red skin colour and size. Gac fruit is generally seasonal, maturing from August to February (Mai et al., 2013). Determining maturity standards is crucial for achieving higher yields of gac aril for carotenoid and gac oil extraction purposes.

The skin colour of gac fruit was analysed using the L*, a*, and b* values, representing lightness, redness/greenness, and yellowness/blueness, respectively, as presented in Table 2. The results indicate that the pulp exhibited a lighter colour compared to the arils, while the arils displayed a redder colour compared to the pulp. Skin colour provides insights into the maturity stages of gac fruit, with higher L* values suggesting lighter skin, positive a* values indicating more redness, and positive b* values indicating greater yellowness. In this study, the L*, a*, and b* values for skin colour were 40.69±0.82, 43.93±0.59, and 37.38±1.67, respectively.

Tran et al. (2016) reported that fully ripened gac fruit in their study, characterised by orange or red skin, yellow pulp, and red arils, had L*, a*, and b* values of 42.17±3.83, 40.11±3.60, and 51.55±11.17, respectively. These results align with the findings here in terms of skin lightness and redness. However, there is a discrepancy in yellowness, as this study indicated less yellowness in gac skin. This difference can be explained by the colour-opponent

Table 2
Physicochemical characteristics of gac fruit

Fruit part	Colour			pH	Titratable acidity (g/L)	Total soluble solids
	L*	a*	b*			
Peel	40.69 ± 0.82	43.93 ± 0.59	37.38 ± 1.67	NA	NA	NA
Pulp	42.20 ± 1.99	24.68 ± 1.49	43.76 ± 4.33	5.65 ± 0.02	0.02 ± 0.01	4.90 ± 0.33
Aril	26.62 ± 1.10	36.35 ± 1.24	27.62 ± 2.63	5.54 ± 0.05	0.03 ± 0.02	11.57 ± 0.52

Note. Results are expressed as means ± standard deviations (n = 3); NA = Not applicable theory, which suggests that colours cannot simultaneously appear as red and green or yellow and blue.

The gac aril's dark-red colour indicates its high content of lycopene, β-carotene, and oils (Tran et al., 2016). In this study, the aril colour was characterised by L*, a*, and b* values of 26.62±1.10, 36.35±1.24, and 27.62±2.63, respectively. Comparing these values to the findings of Mai et al. (2013), their fresh gac aril had colour indices (L*, a*, b*) of 44.0±1.4, 20.7±3.6, and 9.0±1.6, respectively. The results suggest that the aril colour in this study was darker than that reported by Mai et al. (2013) but exhibited less redness and yellowness. This colour variation could indicate that the gac aril in this study may contain a lower concentration of carotenoids compared to the peel. The red colour of the aril is likely attributed to the presence of carotenoids, particularly β-carotene and lycopene, in the fruit composition.

pH, TA, and TSS of Gac Fruit. The pH values for the edible parts of the gac fruit (pulp and aril) were 5.65±0.02 and 5.54±0.02, respectively, indicating slightly acidic conditions. TA ranged from 0.01 to 0.02 g/L for the pulp and 0.03 to 0.05 g/L for the aril. The aril also had higher TSS compared to the pulp, with a value of 11.57%±0.52 °Brix for the aril and 4.90%±0.33 °Brix for the pulp. It indicates that the gac aril is more acidic than the pulp, with an inverse relationship between pH and TA. Additionally, an increase in TA and total soluble solids were observed.

In comparison to the findings of Tran et al. (2016), this study showed lower pH, TA, and TSS values for the gac aril. Tran et al. (2016) reported pH, TA, and TSS values of 6.73±0.13, 0.26±0.01, and 15.80±0.13 for gac aril juice. In this study, the gac aril had a lower acidity level and lower total soluble solids compared to the findings of Tran et al. (2016). According to Tran et al. (2016), there is a close relationship between harvest maturity and TSS of gac aril juice, with an increase in TSS as maturity increases, followed by a decline at the final maturity stage or when fully ripe. Therefore, the pH and TA remain stable as the TSS increases during maturation.

Proximate Composition of Gac Fruit

The proximate composition analysis of gac fruit revealed that the pulp had the highest moisture content (94.9 g/100 g), followed by the aril (90.7 g/100 g) and the peel (88.1 g/100 g) (Table 3). It indicates that gac fruit grown in Malaysia had significantly higher moisture content compared to gac fruit grown in Vietnam, as reported by Gunasekaran et al. (2014) (88.6% moisture). Mai et al. (2013) also reported a high water content of 76.8% in gac aril. The moisture content tends to increase with the maturity of the fruit. The high moisture content in gac pulp and aril makes them suitable for juice extraction. However, it poses challenges in terms of fruit preservation and finding cost-effective drying methods. The selection of a drying technique for processing and preserving gac fruit aril powder is crucial to maintain its quality and achieve a high

Table 3
Proximate composition of gac fruit

Fruit part	Proximate composition*					
	Moisture	Ash	Total available carbohydrate	Crude fat	Crude protein	Total dietary fibre
Peel	88.1±0.25^{bc}	14.0 ± 0.66^{ab}	19.3 ± 0.82^{c}	1.6 ± 0.07^{b}	6.2 ± 0.26^{a}	56.9 ± 1.15^{a}
Pulp	94.9±0.26^{a}	17.3 ± 0.71^{a}	30.9 ± 0.57^{b}	1.6 ± 0.13^{b}	4.6 ± 0.22^{b}	33.3 ± 3.76^{b}
Arils	90.7±0.12^{b}	6.3 ± 0.55^{c}	55.6 ± 0.91^{a}	22.3 ± 2.33^{a}	5.8 ± 0.32^{ab}	7.0 ± 4.37^{c}

Note. Results are expressed as means ± standard deviations (n = 3); * g/100g fresh sample; $^{a-c}$ = Values with different superscript alphabet (small letters) within a column are significantly different (p<0.05)

yield of lycopene and β-carotene, which are valuable natural compounds for the food and pharmaceutical industries (Angkananon & Anantawat, 2015). Drying temperature has been found to significantly affect the contents of lycopene, β-carotene, and total phenolics in dried gac aril (Auisakchaiyoung & Rojanakorn, 2015).

In this study, gac pulp was found to have a high ash content ranging from 17.3 to 23.5 g/100 g, compared to the peel (14.0 to 15.9 g/100 g) and aril (6.3 to 13.1 g/100 g). There are limited reports on gac fruit's ash and minerals content, but Angkananon and Anantawat (2015) reported ash content of 0.7 mg and 0.58% in gac arils, respectively. It suggests that gac fruit in this study had higher mineral content than Angkananon and Anantawat's reported values (2015).

The gac aril in this study was found to have significantly higher available carbohydrate content (55.6 g/100 g) compared to the pulp (30.9 g/100 g) and peel (19.3 g/100 g). Angkananon and Anantawat (2015), as well as Gunasekaran et al. (2014), reported average carbohydrate content in gac fruit and gac fruit aril powders with maltodextrin addition of 7.6 and 73.25%, respectively.

The peel contained the highest protein content (6.2 g/100 g), followed by the aril (5.8 g/100 g) and pulp (4.6 g/100 g). These values were significantly higher compared to the reported values by Angkananon and Anantawat (2015) (0.31%), Chintan and Vijayakumar (2020) (0.6 g for fruit and 2.1 g for aril) as well as Gunasekaran et al. (2014) (1.5%). However, the gac aril in this study contained a significant fat content (22.3 g/100 g), while the peel and pulp had lower percentages (1.6 g/100 g). These values were significantly higher compared to the reported values by Angkananon and Anantawat (2015) (5.93%) as well as Gunasekaran et al. (2014) (0.1%).

The peel had the highest amount of total dietary fibre (56.9 to 58.1 g/100 g), followed by the pulp (33.3 to 37.1 g/100 g) and arils (7.0 to 11.4/100 g). These values were significantly higher compared to the reported values by Angkananon and Anantawat (2015) (15.16%) as well as Gunasekaran et al. (2014) (1.1%). The total energy contribution of gac fruit peel, pulp, and arils in this study was 116.4, 156.4, and 446.3 kcal/100 g, respectively. These values were significantly higher compared to the reported values by Gunasekaran et al. (2014) (37 kcal/100 g).

Sugar Profile Analysis of Gac Fruit

In this study, glucose was the main type of sugar in gac pulp and aril, with significant amounts of 6.66 and 7.55 g/100 g, respectively. Fructose was also detected in gac pulp and aril, with 5.84 and 6.45 g/100 g, respectively. No sucrose, maltose, or lactose was detected in either part of the gac fruit. There are no previous reports on the sugar profile of gac fruit from other researchers. The presence of glucose and fructose, monosaccharides, in gac pulp and aril corresponds to the carbohydrate content found in the total available carbohydrate analysis (Table 3). This finding indicates that gac aril contains significantly higher amounts of glucose and fructose compared to the pulp.

Mineral Composition of Gac Fruit

Mineral elements are essential for various physiological processes in the body. They are classified into macrominerals, required in larger quantities, and microminerals or trace elements, required in smaller quantities. Table 4 presents the mineral composition of gac peel, pulp, and aril. The pulp exhibited the highest ash content and significantly higher levels of most studied mineral elements, except for potassium and sodium, which were significantly higher in the peel. These findings are consistent with a study by Niyi et al. (2019) on the mineral composition of cucumber fruits, which found that potassium was highest in the peel, followed by the pulp and seeds. In the gac fruit, potassium was the most abundant mineral in the peel (817.59 mg/100g), followed by the pulp (658.20 mg/100g) and aril (228.79 mg/100g). As far as available information indicates, there are no published reports on the mineral composition of gac fruit. Potassium is a vital intracellular cation, calcium is important for bone and teeth

Table 4
Mineral composition of gac fruit

Minerals$^{\$}$	Peel	Pulp	Aril
Macronutrients			
Potassium	817.59±3.77^{a}	658.20±16.96^{b}	228.79±6.00^{c}
Phosphorus	38.37±1.68^{b}	53.97±0.88^{a}	20.89±2.84^{c}
Sodium	34.52±0.18^{a}	5.75±0.10^{b}	1.89±0.06^{c}
Sulphur	18.27±0.28^{ab}	20.07±1.22^{a}	11.47±1.22^{c}
Calcium	15.37±0.38^{b}	17.58±6.63^{a}	15.96±2.76^{b}
Magnesium	14.95±0.35^{a}	15.41±0.23^{a}	11.34±0.66^{b}
Micronutrients			
Aluminium	9.57±0.33^{a}	0.63±0.01^{b}	0.11±0.06^{b}
Iron/Ferum	1.98±0.05^{a}	0.71±0.13^{b}	1.72±0.12^{ab}
Zinc	1.77±2.11^{a}	0.26±0.02^{bc}	0.43±0.15^{b}
Boron	0.23±0.04^{ab}	0.27±0.00^{a}	0.12±0.01^{c}
Copper	0.21±0.01^{a}	0.14±0.00^{b}	0.09±0.01^{c}
Manganese	0.13±0.00^{a}	0.05±0.00^{b}	0.09±0.01^{ab}

Note. Results are expressed as means ± standard deviations (n = 2); $^{\$}$ mg/100g fresh sample; $^{a-c}$ = Values with different superscript alphabet (small letters) within a row are significantly different (p<0.05) health, and sodium plays a crucial role in regulating osmotic pressure in the body. Therefore, consuming gac pulp can provide a good source of minerals to support daily nutritional requirements.

Gac pulp was found to have the highest content of phosphorus, sulphur, calcium, and magnesium compared to the gac peel. The values for these minerals in gac pulp were 53.97, 20.07, 17.58, and 15.41 mg/100 g, respectively. Although gac aril contains lower amounts of minerals than the peel and pulp, it still had significant potassium, phosphorus, calcium, and magnesium levels at 228.79, 20.89, 15.96, and 11.34 mg/100 g, respectively. Additionally, all parts of the gac fruit (peel, pulp, and aril) were found to be good sources of phosphorus, with values of 38.37, 53.97, and 20.89 mg/100 g, respectively.

Carotenoids Composition of Gac Fruit

The carotenoid content of gac fruit, including lycopene, β-carotene, lutein, astaxanthin, and zeaxanthin, was analysed and is presented in Table 5. Lycopene was the most abundant carotenoid in gac fruit, particularly in the aril, with an average range of 31.7 to 103.7 mg/g of dry sample. β-carotene was the second most abundant carotenoid, with levels ranging from 2.9 to 9.6 mg/g of sample. Astaxanthin ranged from 1.54 to 4.91 mg/g, lutein from 0.16 to 1.35 mg/g, and zeaxanthin from 0.35 to 1.49 mg/g. Interestingly, zeaxanthin was not detected in the pulp.

When analysing the carotenoid composition, it was observed that the gac aril had the highest levels of lycopene, ranging from 31.7 to 103.7 mg/g, followed by the gac peel with a range of 6.3 to 15.5 mg/g, and the gac pulp with a range of 3.6 to 13.3 mg/g. The gac aril also contained significant amounts of β-carotene, ranging from 2.9 to 6.5 mg/g, while the gac peel had a slightly higher β-carotene content of 3.6 to 9.6 mg/g. Lutein content was higher in the gac aril compared to the peel, with a range of 0.2 to 1.4 mg/g. Astaxanthin content ranged from 1.5 to 3.6 mg/g in the gac pulp and 1.7 to 3.8 mg/g in the gac peel. Zeaxanthin was detected in the gac aril at levels ranging from 0.5 to 1.5 mg/g but was not detected in the gac pulp.

Comparing these findings to the study by Kubola and Siriamornpun (2011), results

Table 5
Carotenoids composition of gac fruit

Fruit part	Carotenoids composition (mg/g, dry material)				
	β-carotene	Lycopene	Lutein	Astaxanthin	Zeaxanthin
Peel	3.58±0.05 – 9.64±0.46	6.25±0.05 – 15.5±0.21	0.26±0.07 – 0.67±0.00	1.72±0.01 – 3.80±0.05	0.35±0.02 – 0.38±0.04
Pulp	3.04±0.00 – 6.10± 0.04	3.58±0.01 – 13.3±0.60	0.16±0.12 – 0.38±0.00	1.54±0.15 – 3.59±0.02	n.d$^{\$}$
Aril	2.89±0.01 – 6.45±0.01	31.69±0.12 – 103.7±0.15	0.20±0.03 – 1.35±0.00	3.23±0.44 – 4.91±0.04	0.52±0.02 – 1.49±0.03

Note. Results are expressed as means ± standard deviations (n = 3); $^{\$}$ n.d = Non detected showed higher levels of β-carotene and lycopene in both the gac peel and pulp. For instance, 1 g of gac peel contained 3.6–9.6 mg of β-carotene and 6.3–15.5 mg of lycopene, while Kubola and Siriamornpun (2011) reported lower values of 1.6–5.9 mg of β-carotene and 1.6–3.4 mg of lycopene. Similarly, 1 g of gac pulp contained 3.0–6.1 mg of β-carotene and 3.6–13.3 mg of lycopene, whereas Kubola and Siriamornpun (2011) reported lower values of 3.0–5.4 mg of β-carotene and 1.8–6.2 mg of lycopene. However, findings for lutein content were within a similar range to that reported by Kubola and Siriamornpun (2011), with values ranging from 0.2 to 1.4 mg/g in the gac aril. Additionally, results showed higher levels of lycopene and β-carotene in the gac aril compared to the findings of Angkananon and Anantawat (2015).

It is important to note that carotenoid content in gac fruit can vary due to variety, maturity stage, growing conditions, and storage conditions. Harvesting gac fruit at full maturity has resulted in the highest concentration of carotenoids, particularly lycopene and β-carotene, in the aril. Geographical and climate differences, as well as other environmental factors, can also influence the nutritional content of gac fruit samples. In comparison to the findings of Tran et al. (2016), the gac aril in this study from Malaysia contained less β-carotene but higher lycopene content, which may be attributed to variations in growing conditions and genetic factors. These factors should be considered when assessing the carotenoid content of gac fruit.

CONCLUSION

The study successfully met its objectives by investigating Malaysian gac fruits' physicochemical characteristics, proximate composition, and carotenoid content. These fruits distinguish themselves as "super fruits" due to their notably high carotenoid content. Malaysian gac fruits exhibit distinctions in size and proximate composition compared to other varieties. They offer essential nutritional qualities, particularly in the pulp and aril, and are abundant in carbohydrates, minerals, and potentially edible oils. This research underscores the potential of gac fruit as a valuable dietary addition and highlights the necessity for further exploration of its applications within the food and pharmaceutical industries. The study unveiled the variability in gac fruit components influenced by factors like maturity, location, and growth conditions. These factors encompass the content of the peel, the thickness of the pulp, the size of the seeds, and the colour of the skin, all serving as indicators of maturity. Gac pulp is well-suited for juice extraction, the peel contains a high ash content, and the aril excels in carbohydrates and fat. Gac pulp could serve as a source of minerals, particularly potassium. Carotenoid analysis identifies lycopene as the primary carotenoid, followed by β-carotene, lutein, astaxanthin, and zeaxanthin. These findings emphasise the importance of considering these factors to optimise the utilisation of gac fruit, particularly its valuable carotenoid content. Further research into preservation and utilisation methods has the potential to unlock the full capabilities of gac fruit within the food and pharmaceutical sectors, aligning with the study's goals.

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