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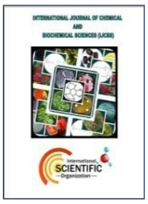

Quality evaluation of "Gấc" arils and peels according to the maturity and ripeness stages

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Abstract

Two parts (arils and peel) of "Gấc" fruit (*Momordica cochinchinensis* Spreng) were analyzed for their physicochemical properties from the stage when the fruit reached maturity to the next ripening stages. Understanding these characteristics can help identify maturity indicators and use them most effectively. Research results show that "Gấc" fruit reaches maturity at the 7th week (A1) after fruit set (WAFS). At this time, the diameter and weight of the fruit no longer increase. Subsequent changes represent a gradual color change from completely blue (A1) to completely red (A5) and dark red (A6), through three intermediate stages (from A2 to A4). "Gấc" peel synthesizes the highest lycopene content (131.72 µg/g) at stage A5 (11 WAFS) and the highest β-carotene content at both stages A4 and A5 (10 and 11 WAFS) compared to fruit at stage A1 (7 WAFS). Meanwhile, lycopene and β-carotene in arils reached the highest concentrations (1672.04±9.1 µg/g and 582.45±3.4 µg/g, respectively) at stage A5 (11 WAFS). The total polyphenol content (TPC) in "Gấc" fruit arils/peel and total chlorophyll in "Gấc" fruit peel gradually decrease through the ripening stages, the highest value was achieved when the fruit was mature (A1) and the lowest value in fully ripened fruit (A5). Although showing a decrease, "Gấc" fruit still maintained TPC content in arils and peels of 89% and 73%, respectively (stages A4 and A5). The antioxidant activity of both "Gấc" fruit arils and peel also showed similar activity. In addition, "Gấc" arils also contain the highest vitamin C content in the fully ripe fruit stage compared to other stages. Thus, harvesting "Gấc" fruit at stages A4 and A5 will have beneficial ingredients (lycopene, β-carotene, total polyphenol content and vitamin C) that are good for human health.

Keywords: "Gấc" fruit, Aril, Peel, Physico-chemical properties

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1. Introduction

"Gấc" (Vietnamese name) has the scientific name *Momordica cochinchinensis*. This is a plant in the melon and cucumber family *Cucurbitaceae*, which is native to countries throughout Southeast Asia and Queensland, Australia. "Gấc" fruit has many spines on the peel, the fruit is oval shaped. When young, "Gấc" fruit skin is very dark green. When ripe, the fruit skin turns orange and finally dark red. Inside the fruit there are many seeds (black) covered with a thick membrane (Gấc aril), this is an ingredient mainly used for food processing due to its benefits. The special feature of "Gấc" fruit is its beautiful and characteristic red-orange color, which represents the high content of the components β-carotene and lycopene. "Gấc" fruit has been widely used in Vietnam for a long time due to its nutritional and medicinal properties. "Gấc" is used in cooking sticky rice and served during "Tết" holidays, festivals and weddings [1, 2]. This fruit was also gradually spreading to Asian markets in the form of dietary supplements, becoming increasingly popular due to their high vitamin and antioxidant content. Recently, "Gấc" fruit is also attracting attention in European countries because scientists have announced high levels of several important phytonutrients, in addition to fiber and vitamins from chemical analysis. In terms of nutrition, scientific publications have shown that "Gấc" fruit contains high levels of carotenoids, of which the main ingredients are β-carotene, lycopene and lutein. Besides, α-tocopherol, essential fatty acids along with high content of polyphenols and flavonoids are also found in the seed shell and membrane [3, 4]. Because of these nutritional advantages, "Gấc" fruit is widely used in the food and pharmaceutical industries. In addition to the "Gấc" aril, the peels of "Gấc" fruit are also said to be rich sources of carotenoids (lycopene, β-carotene and lutein) [4]. In most food and pharmaceutical production, the pulp (the part below the fruit's skin) and peel which accounted for about 15-18% and 40-45%, respectively, relative to the total weight of the fruit, were usually discarded. Lycopene is one of the carotenoid compounds present in "Gấc" fruit, it gives plants their characteristic red color and has many health benefits. In addition, β-carotene in the carotenoid group, which is a group of natural pigments and a precursor of vitamin A, plays an essential role as an antioxidant to protect cells and tissues from peroxides [3, 4]. They are responsible for creating red, yellow and orange pigments in plants, which are antioxidants known to reduce the risk of cancer and cardiovascular diseases.

Vitamin C content was detected in "Gấc" fruit at 42.57 mg/100 g under natural growing conditions in India [5]. Aoki *et al.* [6] reported that "Gấc" contains an astonishing amount of vitamin C, 60 times more than oranges. Vitamin C is potentially linked to the prevention of cancer and cardiovascular diseases. Vitamin C deficiency, or scurvy, is the main cause of severe vitamin C deficiency. Vitamin C deficiency manifests in humans as hair loss, loss of collagen, swollen or bleeding gums and skin lesions [7]. The high antioxidant activity of "Gấc" fruit and peel was determined, using the ability to scavenge diphenyl-picrylhydrazyl (DPPH) radical, iron-reducing antioxidant capacity (FRAP) and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS). "Gấc" arils have the highest FRAP value at the fully ripe stage [4], while "Gấc" peel has the highest antioxidant activity in the immature stage [3]. Because of the benefits that "Gấc" arils and peels bring, using "Gấc" arils and taking advantage of discarded "Gấc" peels to add to edible foods is a matter of concern. Changes in lycopene and β-carotene content in "Gấc" arils during storage were conducted by Nhung *et al.* [8]. The influence of maturity on the physicochemical properties of "Gấc" fruit has also been published by Tran *et al.* [9]. However, simultaneous evaluation of some physical and chemical characteristics of "Gấc" fruit (arils and peel) during ripening after the fruit reaches maturity is still limited in recent publications. The objective of this study is to determine some physicochemical properties and evaluate the antioxidant activity of the peel and arils of "Gấc" fruit grown in Vietnam, as a basis for further research.

2. Materials and methods

2.1 "Gấc" fruits preparation

"Gấc" fruits were harvested from the School of Agriculture, Can Tho University, at physiological maturity with maximum growth (diameter of fruit was measured) and dark green skin. The same fruits are also marked and harvested at subsequent ripening stages, including yellow-green, yellow, orange, red, and dark red (Table 1). The fruits were also free from pests and mechanical damage. Then, the fruits were washed and dried at ambient temperature. Next, the fruits were cut in half (Figure 1), taking the fruit's kernel inside (including the seeds surrounded by "Gấc" arils). The seeds were removed and the "Gấc" arils and peels (only the thin layer of peel on the fruit surface at the orange turning stages) (Figure 2) were obtained. All of them were contained in a PE zip bag (200 gr), wrapped tightly in aluminum foil and stored in the freezer (-18^{o}C). The samples were defrosted at the time of quality analysis.

Table 1: Six stages of maturity and ripening of "Gấc" fruit

	Color	WAFS	Appearance discription
A1	Green	7	Green peels, yellow spikes at the top of the fruit, white flesh, yellow or pink arils
A2	Green-yellow color	8	The fruit is 1/2 ripe, the outer skin begins to have yellow patches, the pulp is light yellow, the arils are orange.
A3	Beginning to ripen (yellow)	9	The fruit is more than 1/2 ripe, the skin has many yellow or orange patches, the fruit pulp is light yellow, the arils are red.
A4	Medium ripe (orange)	10	The fruit is just ripe, the skin is orange or red, the flesh is yellow, the arils are red.
A5	Fully ripe (red)	11	Fully ripe fruit, orange or red skin, yellow flesh, arils are red.
A6	Overripe (dark red)	12	The skin is completely red, the flesh is dark yellow, and the aril is dark red

WAFS: week after fruit setting

A1 **A2** **A3** **A4** **A5** **A6**

Figure 1: "Gấc" fruit at fully development (A1) and five ripening stages (A2 to A6)

A4 **A5** **A6**

Figure 2: The color of "Gấc" arils and peels at 3 stages of color changes

2.2 Analysis of physical and chemical properties

2.2.1 Physical properties

The diameter of "Gấc" fruits was measured using calipers. The fruit weight was recorded using an electronic scale. The color of "Gấc" arils and peel were measured using a colorimeter (CR-400, Minolta, Japan), CIE L*, a* and b* values were recorded. These values are then used to calculate the color angle H_o and chroma where 0° = red-violet, 90° = yellow, 180° = light green and 270° = blue [10].

2.2.2 Chemical properties

β-carotene content was analyzed according to the method of Fikselová *et al.* [11]. Lycopene and total chlorophyll content were determined according to the method of Nagata and Yamashita [12]. Total polyphenol content (TPC) of "Gấc" arils and peels were determined using the Folin-Ciocalteu method [13]. Results are expressed in milligrams of gallic acid equivalent/g of sample. The vitamin C content was determined by the titration method [14]. Free radical scavenging capacity of 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical in sample extracts was evaluated based on the method proposed by Teixeira *et al.* [15]. The moisture content was determined by drying the sample at 105°C to a constant weight and calculated based on the weight of the original sample and the weight of the sample after drying [16].

3. Results and Discussions

3.1 Changes in some physical properties, arils and peel ratio compared to total weight of "Gấc" fruit at different levels of ripeness

Fruit quality can be evaluated by many parameters, such as organoleptic properties, nutritional value or various physical and chemical properties [17]. In this study, "Gấc" fruit reached maturity at 7 weeks after fruit setting (WAFS) and was completely ripe at 11 WAFS and overripe at 12 WAFS. From A4 to A6 stages, when arils have a deep red color, their structure becomes softer, more flexible and juicier than in previous stages. Research by Tran *et al.* [9] showed that "Gấc" fruit reached maturity in the 8^{th} week after pollination (WAP) and fully ripened at 16 WAP, fruit weight increased from 1040.42±294 g (8 WAP) (when the fruit was completely green) to 1729.74±227 g (16 WAP) (when the fruit was fully ripe), which was different from our study. Win *et al.* [18] announced that Thai Gac fruit is completely green at 5 weeks after fruit setting (WAS), yellow fruit (6 weeks), orange fruit (7 WAS) and red fruit (8 WAS) covered more than 2/3 of the entire fruit skin with red color.

The fruit diameter at the 5 ripening stages (A2 to A6) did not show any difference compared to the "Gấc" fruit when it reached maturity, and the fruit was still green (A1) (Table 2). The weight of "Gấc" fruit at the maximum development stage (A1) is about 998.67±10.26 g. This weight is quite stable or only slightly decreases in the next ripening stages (from A2 to A5) and only shows a clear decrease in stage A6, the dark red ripe fruit lost more weight (928.11±10.44 g) than the other samples (Table 2). These results are quite similar to the research results published by Nhung *et al.* [8], they showed a clear decrease in fruit weight from green to fully ripe, with no significant differences at the intermediate stage. Water loss from the fruit peel during ripening was also reported by Ishida *et al.* [19]. The fruit weight obtained from our study is also within the fruit weight range published by other groups of authors with "Gấc" fruit harvested in Thailand and Australia. Fruit weight ranged from 390.8 g to 1057.8 g [20] and 517 g to 2168 g [21], respectively.

The ratio between the weight of "Gấc" fruit peel and fruit was lowest in stage A1 (10.15%), then increased significantly in stages A2 (11.39%) to A5 (11.97%) and then decreased slightly in stage A6 (11.59%). On the contrary, the ratio between peel and fruit weight gradually decreased from the maturity stage A1 - which has the highest ratio (13.38%) - to the next ripening stages, sample A6 showed the lowest value (12.25%). The ratio of peel weight to whole fruit weight of samples in the ripening stage from A2 to A5 did not show a significant difference ($p>0.05$). Weight loss is a natural phenomenon during fruit ripening and is influenced by environmental factors such as relative humidity and temperature, as well as fruit ripeness. The fruit surface is surrounded by a biopolymer cuticle, which functions as the first barrier layer to limit the movement of water across the fruit's surfaces. In this study, as the fruit goes through the overripe stage (A6), the cuticle may be damaged, thus possibly increasing further water loss and facilitating the invasion of fungal pathogens [22].

Table 2: Diameter, weight of "Gấc" fruit and the ratio of "Gấc" arils/peel compared to total fruit weight during ripening

Maturity and ripening stages	Diameter (cm)	Weight (g)	Arils weight/Fruit weight (%)	Peel weight/Fruit weight (%)
A1	13.2^{a}±0.9	998.67^{f}±10.26	10.15^{a}±0.11	13.38^{d}±0.21
A2	13.3^{a}±0.4	983.67^{df}±7.23	11.39^{b}±0.39	12.94^{c}±0.18
A3	13.2^{a}±0.5	973.33^{cd}±10.4	11.88^{cd}±0.13	12.71^{bc}±0.15
A4	13.0^{a}±0.6	959.56^{bc}±9.29	11.93^{d}±0.14	12.58^{b}±0.09
A5	13.1^{a}±0.5	951.89^{b}±8.54	11.97^{d}±0.12	12.52^{b}±0.1
A6	13.0^{a}±0.4	928.11^{a}±10.44	11.59^{bc}±0.11	12.25^{a}±0.07

Mean±STD; The different superscript letters with means in the same column showed significantly different according to LSD test (p<0.05).

3.2 Changes in "Gấc" fruit peel during ripening stages

3.2.1 Color

During fruit ripening and senescence, a lot of changes can occured, these include changes in respiratory rate, ethylene, flesh firmness, sugar, acidity, starch, pectin, enzymes, aroma volatiles... Color changes are also associated with these changes (Table 3). The color of "Gấc" fruit peel measured with a colorimeter showed a clear progression through five distinct stages (as described in Table 1). The skin color in A1 is dark green (the fruit reaches maturity), changing as the fruit matures to green with some yellow (A2), to yellow and orange (A3), to orange and red (A4), red (A5) and finally dark red (A6). Among the three color values of the L* a* b* color system, the a* value of the fruit peel shows the most obvious change according to the ripening stages after reaching maturity (Table 3). The a* value has gradually increased with the ripeness level of the fruit. At time A1 when the fruit was still green, the measured a* value was -13.82±1.27, then increased rapidly in the next four ripening stages of the fruit, the values changed from negative (green) to positive (red) and then decreased at stage A6. "Gấc" peel turns from yellow to red in one week and the peel's sharpness decreases (from A3 to A5), the decrease in peel hue value and chroma was very pronounced. The resulting color change is a decrease in chlorophyll and an increase in carotenoid synthesis reflecting the chloroplast-to-chromoplast transition [23]. López Camelo and Gómez [10] reported that this change is the result of chlorophyll breakdown and lycopene synthesis during fruit ripening.

The L* value (which indicates the lightness or darkness of fruit) represented that the brightness did not change significantly during the early stages of harvest when the fruit skin was still green. As more and more red pigments are synthesized, the L* value gradually decreased, showing that the red color becomes darker. However, Tran *et al.* [9] reported that the L* value remained stable at the five maturity stages. Although the b* value varies little with the harvest stage, it appears to increase in stages A1 to A3 (but the difference is not significant), then gradually decrease (from stages A4 to A6, in which stages A5 and A6 do not show significant differences). This is probably because the main pigments present are ζ-carotene (pale-yellow color), lycopene (red) and β-carotene (orange) [10]. Fruits in stage A1 (green) move to the ripening stage (yellow), the ζ-carotene content (pale-yellow color) increased, and the b* value increases. Meanwhile, from stage A4 (medium ripe with orange skin) to A6 (overripe with dark red skin), high lycopene (red) and β-carotene (orange) reduced the b* value. The change in a* and b* values simultaneously led to changes in chroma and H_o.

Table 3: Color of "Gấc" fruit peel during ripening

Maturity and ripening stages	L*	a*	b*	Chroma	H_o
A1	51.01^{d}±1.14	-13.82^{a}±1.27	46.02^{c}±1.29	48.91^{c}±0.89	-73.53^{a}±1.84
A2	49.14^{dc}±1.29	10.95^{b}±2.05	48.20^{c}±4.93	52.85^{d}±0.8	77.31^{e}±1.96
A3	48.32^{cb}±1.33	23.36^{c}±1.01	50.18^{c}±3.48	53.35^{d}±2.81	64.96^{d}±2.40
A4	47.57^{cb}±1.38	33.87^{d}±2.82	31.14^{b}±1.69	45.83^{b}±1.10	42.93^{c}±3.91
A5	46.32^{b}±1.23	41.64^{e}±1.25	21.52^{a}±1.61	46.89^{b}±0.45	27.32^{b}±1.94
A6	41.87^{a}±1.34	36.16^{d}±1.78	18.17^{a}±1.12	40.48^{a}±1.68	26.70^{b}±0.84

Mean±STD; The different superscript letters with means in the same column showed significantly different according to LSD test (p<0.05).

3.2.2 Moisture content and bioactive compounds in "Gấc" peel

Analysis results show that the moisture content of "Gấc" peel decreases through successive stages of ripening (Table 4). The highest moisture content (79.75%) was measured in the "Gấc" fruit harvested in its mature state (A1), then gradually decreased to sample A3 (75.02%). The moisture content of samples from A3 to A5 did not show a significant difference (p>0.05). The overripe sample (A6) had the lowest moisture content (69.80%). The values obtained from our research results are slightly lower than those of Tran *et al.* [9] and Chuyen *et al.* [24], who reported the moisture content of "Gấc" peel from 78.11% to 86.94% and 83.52%, respectively. Fruit color is an indicator of the stage of maturity, freshness and quality of the fruit and serves as an important parameter in their classification. As the fruit goes through different stages of maturity and ripening, changes in fruit color are often due to the biosynthesis and degradation of pigments during development. Changes in pigmentation are indicative of the developmental stage and physiological condition of the fruit, and are essential for optimal storage, post-harvest management, and utilization of the fruit [25].

Total chlorophyll content in "Gấc" peel gradually decreased with each ripening stage, the highest content was found at A1 (150.8 µg/g) and the lowest at stage A6 (37.7 µg/g). With fully ripe and overripe fruits (stages A5 and A6), the decrease in total chlorophyll content was not significantly different ($p>0.05$).

The content of lycopene and β-carotene in "Gấc" peel increased from the mature stage (A1) to the highest peak at stage A5 (fully ripe red fruit). The lycopene content in the peel increased from 45.91±5.58 µg/g to 131.72±2.69 µg/g. Through the darker shell color stage (A6), the lycopene content in the shell decreased again (122.39±2.81 µg/g). Similarly, the β-carotene content in the fruit was lowest (58.44 µg/g) at stage A1, this value gradually increased and reached its peak (251.85±5.48 and 243.66±5.6 µg/g) at the stage where the fruit reached an orange and red color (stages A4 and A5). The β-carotene content in the fruit peel also shows a decreasing trend at the dark red fruit stage (A6), just 215.17 µg/g.

Table 4: Moisture and bioactive compounds content in "Gấc" peels during ripening

Maturity and ripening stages	Moisture content (%)	Total chlorophyll (µg/g)	Lycopene (µg/g)	β-carotene (µg/g)	Total polyphenol (mgGAE/g)	DPPH%
A1	$79.75^{e}±0.35$	$150.8^{e}±6.35$	$45.91^{a}±5.58$	$58.44^{a}±5.48$	$2.2^{c}±0.1$	$2.18^{c}±0.05$
A2	$77.42^{d}±0.43$	$109.25^{d}±8.12$	$68.66^{b}±6.84$	$146.28^{b}±6.32$	$1.8^{b}±0.1$	$1.85^{b}±0.1$
A3	$75.02^{c}±0.52$	$74.12^{c}±6.65$	$92.87^{c}±5.63$	$192.38^{c}±6.57$	$1.8^{b}±0.06$	$1.74^{ab}±0.1$
A4	$74.66^{bc}±0.25$	$54.54^{b}±8.05$	$113.11^{d}±4.37$	$251.85^{d}±5.48$	$1.6^{a}±0.08$	$1.54^{a}±0.05$
A5	$74.12^{b}±0.35$	$41.79^{a}±6.97$	$131.72^{f}±2.69$	$243.66^{d}±5.6$	$1.6^{a}±0.12$	$1.45^{a}±0.08$
A6	$69.8^{a}±0.48$	$37.70^{a}±8.19$	$122.39^{e}±2.81$	$215.17^{e}±7.87$	$1.5^{a}±0.07$	$1.45^{a}±0.1$

Mean±STD; The different superscript letters with means in the same column showed significantly different according to LSD test (p<0.05).

The color change of "Gấc" peel was almost similar to the change of tomatoes during ripening. Soytong *et al.* [26] reported that the pink color tomato expressed the highest β-carotene content while tomatoes with orange and yellow-orange colors had the lowest β-carotene content. They also presented that most orange-colored fruits show high lycopene content, while pink and red flesh shows high β-carotene content. The pink flesh tomatoes also contain high levels of both lycopene and β-carotene. However, tomatoes with red flesh show varying amounts of lycopene and β-carotene. So, consumption of "Gấc" for the purpose of providing dietary antioxidants lycopene and pro-vitamin A can be maximized when the fruit is harvested at the fully ripe stage. Other publications show little variation in lycopene and β-carotene content in fruit peels. Chuyen *et al.* [24] announced that the lycopene and β-carotene contents in ripe "Gấc" peel are 56 mg/100 g DW and 119.9 mg/100 g DW, respectively. Abdulqader *et al.* [4] reported lycopene and β-carotene contents in "Gấc" peel as 51 µg/g DW and 210 µg/g DW, respectively.

Besides, phenolic compounds were also found in "Gấc" fruit. However, unlike lycopene and β-carotene, TPC in "Gấc" peel gradually decreased with the ripening of the fuit. TPC in fruit peel was highest (2.2 mgGAE/g) in green fruit (A1) and the lowest value was in dark red fruit at stage A5 and A6 (1.6 mgGAE/g). Phenolic compounds are powerful antioxidants, able to scavenge reactive oxygen species (ROS) and chelate transition metals that play an important role in initiating harmful free radical reactions [27]. The analytical value of TPC from this study is slightly lower than the results published by Kubola and Siriamornpun [3] with peel TPC of 2.8±0.23 mgGAE/g. However, our obtained result was higher than the published data by Tinrat *et al.* [28], who reported that TPC in "Gấc" peel was 55 µg/g FW. Perhaps environmental conditions have a great influence on polyphenol content. Climatic, agronomic and ripeness factors significantly influence polyphenols [29]. The antioxidant activity of the extract DPPH% decreased from green (A1) to the full ripe and overripe stages (A5 and A6), it might be caused by the decreases in the levels of phenolics during the development stage of fruit.

3.3 Changes in "Gấc" fruit arils during ripening stages

3.3.1 The color change

At the stage of fruit maturity (A1), arils are yellow or pink. When the ripening stage begins (A2), the arils had a beautiful orange color, but the membrane structure is still hard. From stage A3 to A6, a softer membrane (arils) with a beautiful red-orange color was present. It is because of these changes that the color values of the arils showed significantly differences (Table 5). The changes in the "Gấc" peel are more obvious for "Gấc" arils, the color expressed through chroma and H_o values on "Gấc" arils only showed differences in comparison to mature sample A1 (when the peel was completely green). From stage A2 to A5, this change was not clear.

Table 5: The color changes of "Gấc" arils during ripening

Maturity and ripening stages	L*	a*	b*	Choma	H_o
A1	$34.4^{d}±0.8$	$50.8^{a}±2.1$	$16.4^{d}±0.6$	$53.3^{a}±2.1$	$17.9^{d}±0.6$
A2	$26.8^{c}±1.1$	$55.9^{b}±1.5$	$9.2^{c}±0.99$	$56.8^{bc}±1.7$	$9.3^{c}±2.9$
A3	$26.7^{bc}±1.7$	$57.9^{bc}±1.7$	$5.4^{b}±0.7$	$58.1^{bc}±1.8$	$5.4^{b}±0.6$
A4	$25.1^{bc}±1.7$	$58.9^{bcd}±1.6$	$4.8^{b}±0.8$	$59.2^{c}±1.6$	$4.7^{b}±0.8$
A5	$24.6^{b}±0.9$	$58.6^{cd}±1.8$	$4.1^{b}±0.2$	$58.7^{c}±1.7$	$3.0^{b}±1.3$
A6	$18.2^{a}±0.2$	$55.4^{b}±1.1$	$-3.5^{a}±0.2$	$55.5^{ab}±1.2$	$-3.6^{a}±0.3$

Mean±STD; The different superscript letters with means in the same column showed significantly different according to LSD test (p<0.05).

The hue angle (H° value, which integrates both a* and b* values) decreased significantly between stage A3 (in the yellow range) to A5 (in the red range). The L* value of "Gấc" arils decreased with the ripeness level of the fruit, the highest value of 34.4 was shown in sample A1 and the lowest is 18.2 (A6 - the color of "Gấc" arils was much darker). Samples A2 to A4 did not show significant differences (p>0.05). Win *et al.* [30] also reported that peel L* values of red fruit decreased gradually during the storage time. The a* value of "Gấc" arils increased from sample A1 to A5, with no clear difference from sample A2 to A5. However, the a* value of sample A6 decreased, perhaps because the excessive darkening changed this value (as shown in Figure 1). The a* values greater than 50 indicated that all of them are orange-hued colors. The b* value on "Gấc" arils showed a decrease over successive ripening stages, the highest and lowest values were found in sample A1 (16.4) and A6 (-3.50), respectively. Samples A3 to A5 did not show a significant difference (p>0.05), it may be due to the color at this stage was relatively stable.

3.3.2 Changes in moisture content and bioactive compounds in "Gấc" arils

Analytical results showed that the moisture content of "Gấc" arils changed according to the ripeness of the fruit (Table 6). The moisture of "Gấc" arils in ripe red fruits (A4 and A5) were the highest (82.97±0.95 to 84.42±1.35%), the lowest value shown in A1 (67.8±1.35%). Intermediate moisture content was shown in samples A2, A3 and A6. The results obtained from this study are higher than those published by Tran *et al.* [9], they announced that the "Gấc" arils in the fruit was completely ripe, the skin was red, the flesh was dark yellow, and the red arils had a moisture content of 72.51%. However, our obtained results are quite similar to the published results of Bharathi *et al.* [31], the moisture content of some *Momordica* species ranges from 76.27-92.47%, but it is lower than that published specifically for *M. cochinchinensis* with a moisture content of 92.47%.

Table 6: Moisture content and bioactive compounds content in "Gấc" arils during ripening

Stages	Moisture content (%)	Lycopene (μg/g)	β-carotene (μg/g)	Vitamin C (mg/100 g)	Polyphenol (mgGAE/g)	DPPH%
A1	67.8^{a}±1.35	556.72^{a}±6.18	368.77^{a}±3.54	261.25^{a}±5.82	4.33^{d}±0.06	3.96^{c}±0.15
A2	73.11^{b}±1.02	789.4^{b}±4.3	424.95^{b}±3,12	268.36^{ab}±3.78	4.12^{c}±0.05	3.67^{b}±0.1
A3	78.21^{c}±1.96	894.56^{c}±4.36	499.03^{c}±2.35	275.25^{bc}±8.65	3.96^{c}±0.07	3.65^{b}±0.06
A4	82.97^{d}±0.95	1238.48^{d}±2.77	545.6^{d}±2.68	294.65^{c}±4.25	3.89^{c}±0.03	3.51^{a}±0.04
A5	84.42^{d}±1.35	1672.04^{e}±9.1	582.45^{e}±3,4	315.45^{d}±5.64	3.86^{b}±0.04	3.52^{a}±0.12
A6	77.96^{c}±1.23	1423.01^{f}±4.98	528.51^{f}±4.09	326.36^{d}±7.68	3.7^{a}±0.06	3.51^{a}±0.05

Mean±STD; The different superscript letters with means in the same column showed significantly different according to LSD test (p<0.05).

The content of lycopene and β-carotene in "Gấc" arils increased during ripening. At the stage A1, the lowest lycopene and β-carotene contents analyzed were 556.72 μg/g fresh weight (FW) and 368.77 μg/g. FW During fruit ripening and changing color, from the yellow (A2) to orange (A4) fruit stage, the lycopene content increased from 789.4±4.3 μg/g FW to 1238.48±2.77 μg/g FW, then increased to a maximum of 1672.04±9.1 μg/g FW at the ripe red fruit stage (A5) before decreasing to the dark red fruit stage (A6) which was 1423.01±4.98 μg/g FW. Similarly, the lowest β-carotene content is at stage A1 (368.77±3.54 μg/g FW), gradually increasing at the yellow-green to yellow and orange fruit stage, highest at stage A5 (582.45±3.4 μg/g FW) but decreased at stage A6 (528.51±4.09 μg/g FW). From these obtained results, it was shown that the quality of "Gấc" arils is mainly affected by the ripeness of "Gấc" fruit when harvesting, the content of lycopene and β-carotene in the arils increased as the fruit ripened. "Gấc" fruit harvested at full ripen was shown to contain higher lycopene and β-carotene content in the "Gấc" aril compared to yellow-green and just-ripe fruit [3, 9]. Aoki *et al.* [6] reported that the carotenoid content of some fruits increases during ripening. The degree of ripeness is believed to be a factor influencing the differences in carotenoid content found in "Gấc" arils. Nhung *et al.* [8] published much higher lycopene and lower β-carotene data than our study, they suggested that the lycopene content in "Gấc" arils ranged from 2378 mg/g FW in green fruits to 3728 mg/g FW in fully ripe. The amount of β-carotene in aril ranges from 257 μg/g FW in green fruits to 379 μg/g FW in fully ripe "Gấc" fruit. Vuong *et al.* [32] announced the lycopene and β-carotene contents in ripe red "Gấc" arils to be 802 μg/g and 175 μg/g, respectively (lower than our research results), while Ishida *et al.* [19] reported much higher results, lycopene and β-carotene contents were 2227 μg/g and 718 μg/g. "Gấc" varieties grown in different localities may vary in quality, due to climate, soil and farming conditions, but most studies showed that they contained two components with high bioactive value, lycopene and β-carotene, which plays an important role in human health. In addition, some studies have also announced that "Gấc" fruit contains 10 times more β-carotene than carrots or sweet potatoes [32], 70 times higher than tomatoes [33]. Other studies also show that some chemical components of "Gấc" have broad pharmacological effects, such as anti-cancer, anti-oxidant and anti-inflammatory [34].

From the results obtained, it was observed that the lycopene and β-carotene content in "Gấc" peel contrasted with the lycopene and β-carotene content in "Gấc" arils. At the fully ripe stage (A5), "Gấc" peel contains lycopene (131.72 μg/g) lower than β-carotene (243.66 μg/g), while "Gấc" arils contains lycopene (1672.04 μg/g) about 2.9 times higher compared to β-carotene (582.45 μg/g). Thus, using both peels and arils will potentially provide many benefits to human health when these compounds are recovered by different methods. The vitamin C content of arils shows an increasing trend with stages of ripening after the fruit is fully developed. This content is lowest in arils (221.25±1.82 mg/100 g) when analyzing fruit at stage A1 and tends to gradually increase at stages A2 and A3, but it is not very clear. At stages A4 and A5, vitamin C synthesis was clearly higher (294.65±4.25 and 315.45±5.64 mg/100 g, respectively), and stabilized at stage A6 (Table 5). Thus, "Gấc" fruit continues to synthesize vitamin C from the stage of full development on the tree (green) until fully ripe (red and dark red). The obtained results are quite similar to the report of Ntagkas *et al.* [35]. They announced that the vitamin C content in overripe tomatoes contains much higher levels of vitamin C than in other stages of development. Lee and Kader [36] also reported that light intensity and availability during development have a strong impact on the amount of ascorbic acid synthesized. Our obtained data are slightly different from other authors' groups, the rather low value published by Sarmah *et al.* [5], the vitamin C content in "Gấc" fruit is only 42.57 mg/100 g, while Aoki *et al.* [6] announced that the vitamin C content in Gac is 60 times higher than orange juice. The vitamin C value in "Gấc" arils in this study was measured within the range of published values. It has been shown that fruit ripening is characterized by fruit softening and a significant increase in carotenoid and vitamin C content.

Phenolic compounds are widely distributed in plants and are components that affect antioxidant activity and free radical scavenging ability, bringing health benefits to humans [37]. The determined TPC in arils shows the highest value at stage A1 (4.33±0.06 mgGAE/g) and the lowest at stage A6 (3.7±0.06 mgGAE/g). These values were almost two times higher than the peel. Abdulqader et al. [4] reported that the TPC content in ripe "Gấc" arils was very low (0.31 mg/g DW), but Kubola and Siriamornpun [3] showed a higher TPC value (4.29 mgGAE/g), this value is quite similar to our research results. Environmental factors such as climate and agronomic conditions have a great influence on the polyphenol content of plants. The degree of ripeness significantly affects the concentration and ratio of different polyphenols [29]. Our obtained results also showed a positive correlation between TPC and DPPH% content in the peel and arils of "Gấc" fruit. Some studies have also shown a good correlation between total phenolic content and the DPPH free radical scavenging activity of plant extracts [38]. As analyzed, "Gấc" fruit contains a large amount of natural antioxidants and vitamins (carotenoids, vitamin C, total polyphenols, folic acid), a diet rich in antioxidants helps reduce the risk of cancer, cognitive decline, heart disease and depression [39, 40].

4. Conclusions

The results obtained from the study have determined the physical and chemical composition of "Gac" fruit arils and peels at the ripening stage after reaching maturity. In this study, both the aril and peel appeared to possess high contents of β-carotene and lycopene, vitamin C and TPC. Important components that create the color of "Gấc" fruit peel such as lycopene and β-carotene have reached high values at ripening stages A4 and A5, while these components show the highest values in arils at stage A5. Thus, A4 and A5 can be considered the best time to harvest "Gấc" fruit to extract bioactive compounds for functional foods/medicines or food processing. The content of TPC (in the peel) and chlorophyll (in the peel) was highest in the maturity stage (A1). The TPC content in arils and peels decreased by about 11% and 27% at ripening stages A5, respectively. The total chlorophyll content decreased clearly (about 75%) from green fruit (A1) to fully ripe fruit (A5), giving the best color of the skin and arils at this stage. "Gấc" arils and peels also maintain high humidity. Furthermore, from the results obtained, the lycopene and β-carotene content in "Gấc" fruit aril contrasts with the lycopene and β-carotene content in "Gấc" peel. Thus, the combined use of bioactive compounds from peels and arils has the potential to bring many benefits to human health when they are recovered and applied in useful food processing.

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