EFFECTS OF ENCAPSULATION SUBSTANCES ON DRYING OF GAC FRUIT: PHYSICOCHEMICAL PROPERTIES AND STORAGE STABILITY

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ABSTRACT

This research aimed to identify suitable encapsulation materials for producing Gac fruit powder using the tray drying technique and to assess changes during storage at different temperatures. The encapsulating substances investigated included 20% Maltodextrin, 1% Tween80, a combination of 20% Maltodextrin and 1% Tween80, and a mixture of 2% Gelatin and 1% Carboxymethyl cellulose (w/w). Drying was performed at 60°C until the moisture content reached 10%. The encapsulated Gac fruit powder was analyzed for moisture content, water activity, encapsulation yield, color values (L*, a*, b*), bulk density, solubility, β-carotene, lycopene contents, and structural characteristics using scanning electron microscopy (SEM). The combination of 20% Maltodextrin and 1% Tween80 demonstrated superior characteristics in terms of overall powder yield and solubility, suggesting its effectiveness as a primary encapsulation matrix. Conversely, when assessing the preservation of bioactive compounds, 1% Tween80 and a complex mixture of 2% Gelatin combined with 1% Carboxymethyl cellulose showed notable efficacy. Storage tests in vacuum aluminum foil bags at 4°C, 30°C, and 40°C revealed that the encapsulated Gac fruit powder could be stored for over 8 weeks under all conditions. However, significant changes were observed over time, including an increase in color difference (ΔE) and a decrease in lycopene and β-carotene contents with higher temperatures and extended storage time. Thus, storing Gac fruit powder in vacuum-sealed packaging at low temperatures is recommended to minimize the loss of these nutrients and gradual physical changes.

Keywords: Gac fruit, Drying, Encapsulation, Physicochemical properties, Storage stability

Introduction

Gac fruit (*Momordica cochinchinensis* Spreng), referred to as Fak-Khao in Thai, is indigenous to Southern Asia, encompassing regions such as Vietnam, India, Bangladesh, China, Myanmar, Malaysia, Laos, and Thailand. In Thailand, Gac fruit is traditionally consumed in its raw form. Upon ripening, the fruit's dark red seed aril is utilized in the preparation of beverages, food items, desserts, and cosmetics. Renowned for its health benefits, Gac fruit is a staple in the production of nutritionally rich foods. It is particularly noted for its high concentrations of ß-carotene and lycopene, surpassing those found in many other fruits and vegetables. Extensive research indicates that these compounds can mitigate disease risks and promote overall health (Tinrat et al., 2014; Abdulqader et al., 2019; Wimalasiri et al., 2020; Darapong et al., 2023; Munsuk et al., 2024). Moreover, Gac fruit is abundant in essential fatty acids, which facilitate the absorption of lycopene and ß-carotene. The concentration of these beneficial substances peaks when the fruit reaches full maturity, with the seed aril transitioning from red-orange to dark red. However, post-harvest, the levels of these compounds diminish, and fresh Gac fruit exhibits a short shelf life (Bhumsaidon & Chamchong, 2016). To prolong shelf life and add value to agricultural products like Gac fruit, processing is imperative. The choice of processing technique is dictated by the nature of the raw materials and the intended final product.

Drying is a prevalent method in food processing, enhancing both the physical and biological stability of products by reducing moisture content. This reduction facilitates easier storage and integration as an ingredient in other food products. Various drying methods, such as hot air drying, spray drying, and freeze drying, each present unique advantages and limitations (Baeza & Chirife, 2021). Mai et al. (2013) demonstrated that optimal drying temperatures (50°C to 60°C) preserve color, carotenoid content, and antioxidant activity, maintaining a moisture content of 15% to 18%, which promotes quality and extends refrigerated storage life. This study adopts the hot air-drying technique due to its straightforwardness, convenience, and cost-effectiveness, presenting an opportunity to incorporate Gac fruit into the food industry as a natural alternative to synthetic food coloring while enhancing nutritional and therapeutic benefits. However, the high instability, poor water solubility, and sensitivity of ß-carotene and lycopene to light, temperature, and humidity pose challenges in processing and storing Gac fruit powder. Encapsulation technology offers a viable solution, enhancing the stability, solubility, and protection of various important substances in food applications, it also improves efficiency during the drying process. Maltodextrin, although limited in emulsifying properties, serves as a common encapsulating agent, improving texture and water solubility. Carboxymethyl cellulose, a cellulose-derived hydrocolloid, acts as a thickener, stabilizer, and emulsifier, while Tween80 facilitates stable emulsions. Combined, these agents prevent clumping in powdered foods

(Vuong & King, 2003). This research aims to investigate the encapsulation of key substances in Gac fruit through hot air drying at 60°C. This study focuses on the types and ratios of four encapsulating agents: maltodextrin, CMC, gelatin, and Tween80, and analyzes the physicochemical properties and changes in Gac fruit powder during storage.

Materials and Methods

1. Materials

Gac fruit (*Momordica cochinchinensis*) was purchased from Uncle Choey's farm in Chachoengsao province, Thailand. The gac fruit cultivated in Thailand does not have a clearly defined cultivar name. Based on studies, it is a hybrid between a Vietnamese cultivar and a local Thai variety. Maltodextrin with a Dextose equivalence value of 10-15, Tween80, gelatin, and carboxymethyl cellulose (CMC) were purchased from Adinop Company Ltd, Thailand. In this work, all chemical uses are food grade.

2. Preparation of Gac fruit

Mature fresh Gac fruit was chopped into two parts. In our experiments, we used only seed membrane by separating of seed aril from the Gac fruit, it was then added with 20 ml of water and blended in the kitchen aid (Artisan model, Hobart Company, USA) for 6 min to separate the seed from the aril by sieve. The homogenized seedless aril was placed in a plastic box and kept at -20°C for further studies and drying. Proximate analysis, Lycopene and β-carotene contents and L*, a*, b* of fresh Gac fruit were studied.

3. Drying of Gac fruit

Encapsulation is a technique that aids in drying agricultural produce by removing moisture, which is crucial for preserving quality and extending shelf life. This method involves applying protective coatings to create a barrier that minimizes the loss of essential nutrients and compounds during drying. Maltodextrin of 20%, Tween80 of 1%, a mixture of Maltodextrin of 20% and Tween80 of 1% and a mixture of Gelatin of 2% and Carboxymethyl cellulose of 1%, (w/w) were prepared and denoted as MD, T80, MD:T80, and GL:CMC, respectively. The Gac fruit was mixed with the carriers using a KitchenAid mixer on speed level 6 for 5 min. Then, pour the mixture into an aluminum tray lined with a plastic sheet, using 300 g per tray. Place the tray in the tray dryer (Kluay Nam Thai Co,Ltd.,Thailand) at a temperature of 60°C until the moisture content decreases to less than 10%. The moisture content does not exceed the standard criteria for dry food products, which is 15% or less, according to the Notification of the Ministry of Public Health No. 193 (Ministry of Public Health, 2000). Finally, store the powder in aluminum foil bags at room temperature (30±2°C) for further study.

4. Chemical properties analysis

4.1 Proximate analysis

The proximate composition of the fresh Gac fruit sample as follows: moisture (925.10), ash, (923.03) protein(960.52), fat(920.39), crude fibre (962.09) and carbohydrate (Calculated by difference), was determined (AOAC, 2000).

4.2 pH measurement

The pH of the fresh Gac fruit paste was determined by a digital pH meter (Model Denver instrument UB-10 (ultra-Basic, U.S.A)). A sufficient 50 mL of the sample was taken in a 100 mL beaker and pH was recorded by the pH meter (AOAC, 2000).

4.3 Total soluble solid measurement

The total soluble solids in the fresh Gac fruit sample and the Gac fruit powers were directly recorded by Abbe’s stagehand refractometer (Model N-1E0-25 °Brix ATAGO, Japan) and the results were expressed as percent of soluble solids (°Brix)

4.4 Water activity measurement

The water activity (a_w) was measured using a water activity meter (Aqua Lab, Series 3 WA, U.S.A). Water activity represents the ratio of the water vapor pressure of the food to the water vapor pressure of the pure water under the same conditions and is expressed as a fraction. The water activity scale extends from 0.0 (dry matter) to 1.0 (pure water). Approximation 2_g of ground Gac fruit powder was placed in the water activity tray and a_w was recorded.

5. Physical properties analysis

5.1 Yield measurement

The yield was expressed as a percentage of the mass of the final product compared to the total amount of the dried materials.

5.2 Color measurement

The colors of the fresh Gac fruit paste and the Gac fruit powers were measured using a colorimeter (Minolta, model CR-10, Japan) in CIE chromaticity coordinates L*, a*, and b*, where L* describing lightness on a scale of 0-100 (where 0 = black and 100 = white), a* describing intensity in red-green axis (positive a* values indicate red undertone, negative a* values indicate green undertone), and b* describing intensity in yellow-blue axis (positive b* values mean yellow undertone, negative b* values mean blue undertone). Sample color was evaluated in triplicates (Maisont et al., 2022). The total color difference or change (ΔE) during storage was calculated by the following formula.

$$\Delta E= \sqrt{(L^*_0 - L^*)^2 + (a^*_0 - a^*)^2 + (b^*_0 - b^*)^2}$$

where L^*_0, a^*_0 and b^*_0 are the values of the samples at zero time, and L*, a* and b* are the measured values of each sample after processing or reconstitution.

5.3 Bulk density and solubility measurement

The bulk density was analyzed by following the method described by Goula et al. (2004). The water solubility index (WSI) was measured (Vidović et al., 2014).

6. lycopene and β-carotene analysis

The lycopene and β-carotene contents in the fresh Gac fruit and the Gac fruit powers were analyzed. The concentration of lycopene in a hexane extract was determined by measuring the absorbance of the solution at 503 nm, while the carotenoid measurement was taken at a wavelength of 471 nm (Anthon & Barrett, 2007).

7. Structural morphology analysis

Scanning electron microscope (SEM: JEOL, JSM-IT300) was used to observe structural morphology within the Gac fruit powders. The voltage used in this experiment was 15 kV, with a magnification of 1000x applied. The Gac fruit powder was prepared by defatting it with petroleum ether for 12 hours, followed by a gold coating. This preparation allowed for clear images to be obtained during the SEM monitoring.

8. Shelf-life study

Analysis of the shelf life of the chosen Gac fruit powder was carried out once in two weeks for eight weeks. The samples were packed in laminated aluminum foil bags and stored in three controlled conditions at temperatures of 4, 30, and 40°C, respectively. Storage stability or the shelf-life of products could be defined as the maintenance of the characteristics of power associated with nutraceutical content. Thus, the properties of the final product related to the lycopene, and β-carotene contents change, including color, moisture content, a_w and solubility were observed.

9. Statistical analysis

The Gac fruit powder was prepared in three separate batches; mean values and standard deviations were calculated, and all results were expressed as mean±SD using a Completely Randomized Design (CRD) trial plan. Analysis of variance (one-way ANOVA) was carried out using SPSS (IBM SPSS statistics version 16). Duncan's new multiple range test was used to find out the statistically significant differences in mean values between treatments at the level of $p \le 0.05$.

Results and Discussions

1. Properties of fresh Gac fruit

The initial moisture content of fresh Gac fruit was found to be 83.45% (wet basis, wb), and 0.72% protein, 3.69% fat, 5.38% fiber, and 6.28% carbohydrate contents (db). The moisture content of fresh Gac fruit was consistent with the findings of Dien et al. (2013). Their analysis on a dry basis revealed that Gac fruit contains 94% moisture content Additionally, the contents of lycopene and ß-carotene were reported to be in the ranges of 18.95 to 50.11 mg/100g and 22.68 to 39.16 mg/100g, respectively (Dien et al., 2013). Our findings indicated that the Gac fruit seed aril had a brightness (L*) of 32.85, a redness (a*) of 25.21, and a yellowness (b*) of 19.74. These results are consistent with the experiments conducted by Bhumsaidon and Chamchong (2016). Our analysis of the Gac fruit seed showed different contents for protein, fat, fiber, and carbohydrates compared to other studies, which may be due to differences in species and cultivation area of the Gac fruit at different ageing and maturity stages, as well as analytical methods.

2. Physicochemical properties of Gac fruit powder

Drying gac fruit requires beneficial substances to preserve its nutritional properties and address the challenge of extending the shelf life of gac during periods of high production when immediate sale is not feasible. However, if the extraction of these substances is required before encapsulation, it could result in significantly increased costs. We focus on encapsulation technology, which improves the protection of various important substances during the drying process in food applications.

2.1 Yield, moisture content and water activity of Gac fruit powder

Table 1 shows the yield, moisture and free water content of the Gac fruit seed aril with different drying agents dried by a tray dryer at 60°C for approximately 15 h. The yield of Gac fruit powders were 30.13, 12.64, 31.86, and 13.46%, for maltodextrin (MD), Tween80 (T80), maltodextrin: Tween80 (MD:T80), and Gelatin: Carboxy methyl cellulose (GL:CMC), respectively. The yield of Gac fruit seed aril powder treated with MD and the use of maltodextrin per tween80 (MD:T80) gave slightly different yields; T80, gives the lowest yield. Since MD is a high T_g substance, it can be used to increase product stability (Asma et al., 2014; Chottanom et al., 2020) where T_g or glass transition temperature is the temperature at which macromolecular polymers change from glass (solid) to rubber (viscous liquid). Therefore, if any product is at a temperature lower than T_g, there will be a brittle solid state. T80 is an encapsulation agent belonging to the group of emulsions. It facilitates easy mixing and drying processes, like the substances found in Gac. Additionally, T80 helps reduce drying time, which can lead to a slight yield increase when combined with other agents. However, when T80 is used alone, the yield is low because the final dry product has less yield. Asma et al. (2014) reported that adding CMC reduced the T_g of GL. According to Bopitsuwan & Rojanakorn (2017), the T_g of MD was approximately 76.76°C, subsequently, it raised the T_g of the Gac fruit seed aril product mixture. This is due to the reduced absorption of atmospheric water vapor by MD, which causes the product to dry quickly. In addition, MD is a substance with a significant molecular weight and a large particle size. It has a small overall surface area per weight. Resulting in the low binding force between particles that causes decreased adhesion. Gac fruit seed aril powder, with MD as a drying agent, has a high yield (Bopitsuwan & Rojanakorn, 2017).

Table 1 Yield, moisture content and water activity (a_w) of Gac fruit powder

Drying agents	Content (%)	Yield (%)	Moisture content (%)	Water activity (a_w)
MD	20	$30.13^b \pm 0.15$	$5.05^c \pm 0.18$	$0.34^b \pm 0.00$
T80	1	$12.64^c \pm 0.58$	$6.75^b \pm 0.22$	$0.26^d \pm 0.01$
MD:T80	20:1	$31.86^a \pm 0.92$	$4.43^d \pm 0.07$	$0.31^c \pm 0.00$
GL:CMC	2:1	$13.46^c \pm 0.02$	$8.16^a \pm 0.15$	$0.42^a \pm 0.00$

^{abc}Mean±standard deviation values in the same column for each zone followed by different letters are significantly different ($p \le 0.05$).

^{ns}Mean±standard deviation values in the same column for each zone followed by different letters are non-significantly different ($p \le 0.05$).

The moisture content mean values were 5.05, 6.75, 4.43, and 8.16 %, for the powder containing MD, T80, MD:T80, and GL:CMC, respectively, as shown in Table 1. There was a statistical difference ($p \le 0.05$). Using GL:CMC as a drying agent had the highest moisture followed by T80, MD, and MD : T80, respectively. The difference in residual moisture in Gac fruit powder depends on its ability to bind water to drying agents of different properties especially MD with high T_g value, resulting in good drying performance with low product moisture content (Asma et al., 2014; Chottanom et al., 2020).

The free water content of the powdered gac fruit seed aril dried by a tray dryer had a trend of change consistent with the moisture content. According to Table 1, the free water content of Gac fruit powder is between 0.26-0.42, which is in the criteria specified by the dry food products. The free water content must be less than 0.6 (Jay, 1998).

2.2 Color of Gac fruit powder

The color of the dried products is an important quality factor, which reflects the sensory attractiveness, and the quality of the powders (Çalışkan et al., 2015) Thus, the color of the processed products should ideally remain unchanged after drying. The variation of color value for Gac fruit powder samples depends on the drying agents contained as shown in Table 2. The L*, a*, b*, and delta E values of Gac fruit powder containing other carriers were significantly different ($p \le 0.05$).

Table 2 L*, a*, b* and ΔE of Gac fruit powder

Drying agents	Content (%)	L*	a*	b*	ΔE
MD	20	$49.82^{a}\pm0.69$	$27.11^{b}\pm0.60$	$36.15^{b}\pm0.46$	$2091.59^{b}\pm1.71$
T80	1	$41.33^{b}\pm0.60$	$25.58^{c}\pm0.43$	$27.04^{c}\pm1.01$	$1426.83^{d}\pm0.96$
MD:T80	20:1	$50.16^{a}\pm1.11$	$24.76^{d}\pm0.28$	$38.52^{a}\pm1.35$	$2147.00^{a}\pm2.00$
GL:CMC	2:1	$41.24^{b}\pm0.73$	$36.58^{a}\pm0.34$	$25.46^{d}\pm0.59$	$2027.55^{c}\pm1.60$

^{abc}Mean±standard deviation values in the same column for each zone followed by different letters are significantly different ($p \le 0.05$).
ΔE of fresh Gac fruit = 1058.06

The mean L* values were 49.82, 41.33, 50.16, and 41.24 for the powder containing maltodextrin (MD), Tween80 (T80), Maltodextrin: Tween80 (MD:T80), and Gelatin: Carboxy methyl cellulose (GL:CMC), respectively, as shown in Table 2. Gac fruit Powder treated with MD and MD:T80 had the highest values, which were not significantly different ($p>0.05$). The dried Gac fruit powder with MD:T80 as a carrier, was the most likely bright yellow-red color product, followed by the Gac fruit powder containing MD, T80, and GL:CMC, respectively. This corresponds with the findings of Tkacz et al. (2020), which showed that the addition of MD increased the brightness of Sea buckthorn powder. Furthermore, Tkacz et al. (2020) noted that the addition of MD also increases the brightness of raspberry powder, orange powder, and mango powder. This improvement in brightness may result from a combination of substances present in the juice and the drying agent, which leads to the release of compounds that undergo further reactions. Generally, higher brightness (L* values) is associated with lower redness.

The a* value indicated the reddish color of Gac fruit powder using GL:CMC was the highest (Table 2). The redness of the Gac fruit powder was different ($p \le 0.05$). The b* values, where positive values indicate yellowness, had mean values of 36.15, 27.04, 38.52, and 25.46 for the Gac fruit powder containing MD, T80, MD:T80, and GL:CMC, respectively. The use of MD and MD:T80 had the highest b* color values, indicating that the addition of MD resulted in the yellowing of the Gac fruit powder.

Significant differences ($p \leq 0.05$) in ΔE of gac fruit powder were observed across the encapsulation substances (Table 2). The ΔE values were 2091.59, 1426.83, 2147.00, and 2027.55 for the Gac fruit powder containing MD, T80, MD:T80, and GL:CMC, respectively. The variation in drying agents may cause the release of certain substances that further react with each other in the dried mixtures (Tkacz et al., 2020). The addition of MD results in a more significant color shift.

2.3 lycopene, and β-carotene of Gac fruit powder

The lycopene and β-carotene content of Gac fruit powder is presented (Table 3). The average lycopene contents were 26.48, 56.24, 15.20, and 57.55 mg/100g for the dried Gac fruit seed aril containing maltodextrin (MD), Tween80 (T80), Maltodextrin: Tween80 (MD:T80), and Gelatin: Carboxymethyl cellulose (GL:CMC), respectively. Among the drying agents used, Gac fruit powder containing GL:CMC had the highest lycopene content, followed by T80, MD:T80, and MD, respectively. MD has a large particle size and high molecular weight, resulting in a small overall surface area per weight. As the dried powder is very porous, the product properties are expressed as the properties of the drying agent (Tkacz et al., 2020). Therefore, the lycopene content of Gac fruit powder containing MD is lower than other drying substances. The β-carotene contents of Gac fruit powders were 22.82, 41.91, 32.23, and 36.94 mg/100g for MD, T80, MD:T80, GL:CMC, respectively. Among the drying agents used, GL:CMC had the highest β-carotene content, followed by MD:T80, and MD, respectively. This increase may be attributed to the surfactant properties of T80, which enhance the extraction of β-carotene (Oncel & Sedef Dogan, 2016).

2.4 Bulk density and solubility of Gac fruit powder

The bulk density values and solubility of Gac fruit powders are presented in Table 3.

Table 3 Lycopene, β-carotene contents, Bulk density and solubility of Gac fruit powder

Drying agents	Content (%)	Lycopene (mg/100g Sample)	β-carotene (mg/100g Sample)	Bulk Density (g/cm^3)	Solubility (%)
MD	20	26.48^{b}±0.02	22.82^{c}±0.01	0.43^{a}±0.01	67.39^{b}±2.64
T80	1	56.24^{a}±3.95	41.91^{a}±7.52	0.36^{b}±0.01	55.29^{c}±1.35
MD:T80	20:1	24.43^{b}±0.63	32.23^{b}±0.05	0.43^{a}±0.01	71.87^{a}±0.91
GL:CMC	2:1	57.55^{a}±0.85	36.94^{ab}±1.54	0.36^{b}±0.00	40.68^{d}±0.95

^{abc}Mean±standard deviation values in the same column for each zone followed by different letters are significantly different ($p \leq 0.05$).

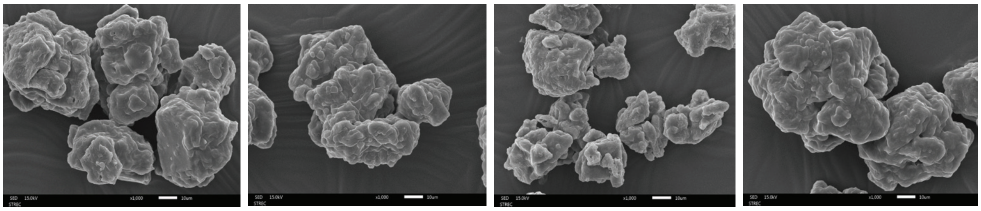
The surfactant properties of T80 enhance the extraction of Lycopene and β-carotene (56.24 and 41.91 mg/100g). In contrast, GL: CMC likely resulted in a higher lycopene content due to the stabilizing and protective properties of these polymers, however, may also impact the solubility or increase the susceptibility of β-carotene to oxidative or thermal degradation during the encapsulation process.

The bulk density values of the Gac fruit powder were 0.43, 0.36, 0.43, and 0.36 g/cm^3, respectively. The density of the Gac fruit powder was the highest when MD and MD:T80 were used, and the values were not statistically different ($p \le 0.05$) when compared to using T80 and GL: CMC.

Regarding the solubility of the Gac fruit powder, the average values were 67.39, 55.29, 71.87, and 40.68%, respectively. The solubility of the powdered Gac fruit seed aril was highest when using MD:T80 and MD, followed by T80 and GL:CMC as drying agents, respectively. These experimental results were consistent with the findings of Suriyajunhom & Phongpipatpong (2017), who reported that the solubility of gac fruit powder used for drying maltodextrin ranges from 57.57 to 76.28%.

3. SEM surface morphology

Figure 1 illustrates the SEM magnification images of Gac fruit power using MD, T80, MD:T80, and GL:CMC as drying agents. Images were magnified 1000x to display the surface morphology and structural characteristics of the encapsulated particles from samples subjected to various drying agents. The results indicate that the particles may have a smooth appearance if the encapsulation is uniform, suggesting successful coating by the encapsulating materials (Figure 1). Maltodextrin and gelatin typically create a dense matrix that surrounds the gac fruit powder, while Tween80, a surfactant, enhances dispersion and helps stabilize the emulsion. This may contribute to the uniformity of the particle surface. Additionally, carboxymethyl cellulose (CMC) improves viscosity and structural integrity, which could result in smoother or more compact particles (Chaudhary et al., 2024).



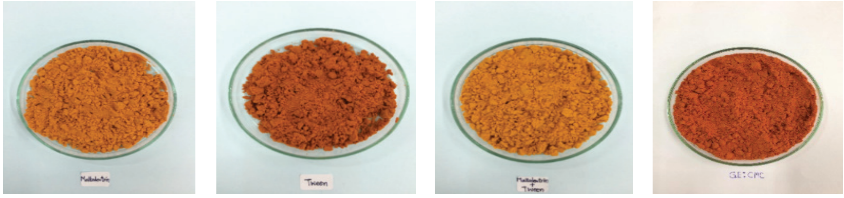
MD T80 MD:T80 GL:CMC

Figure 1 SEM images of Gac fruit power under 1000x magnification

4. Shelf life of Gac fruit powder

Storage stability, or the shelf life of products, refers to the ability to maintain the characteristics and potency associated with their nutraceutical content. The properties of the final product can change over time. The variations in color, moisture content, a_w, and solubility, particularly with lycopene and β-carotene levels, were demonstrated.

The initial color at week 0 of the Gac fruit powder containing maltodextrin (MD), Tween 80 (T80), Maltodextrin: Tween80 (MD:T80), and Gelatin: Carboxy methyl cellulose (GL:CMC) were presented in Figure 2. The changes in the color of L*,a*, and b* values of Gac fruit powder stored at different temperatures for 8 weeks are demonstrated in Figure 3.



MD T80 MD:T80 GL:CMC

Figure 2 Characteristic of dried Gac fruit

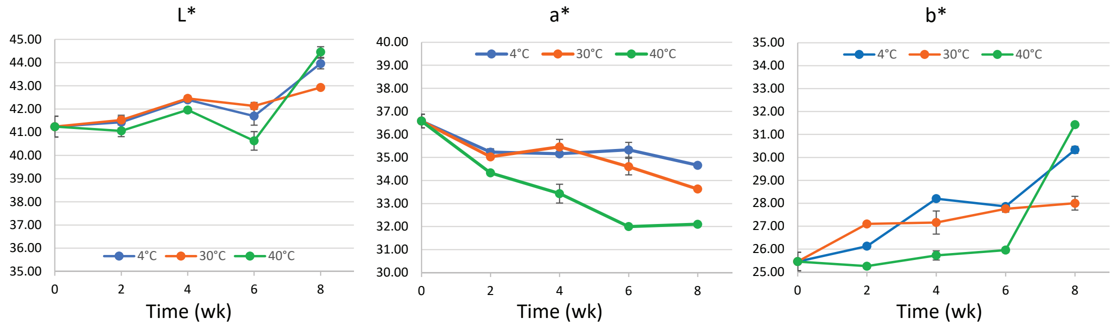


Figure 3 Color of Gac fruit powder during storage

During the storage period, the lightness (L*) of Gac fruit powder increased significantly ($p \leq 0.05$) at all temperatures. The initial lightness value of Gac fruit powder at week 0 was 41.24, and there was no significant difference in brightness for Gac fruit powder stored at 4°C and 30°C for up to 6 weeks of storage. After eight weeks of storage, the L* values of Gac fruit powder were 43.96 and 42.93 at temperatures of 4°C and 30°C, respectively. For Gac fruit powder stored at 40°C, there was no significant difference in brightness after four weeks of storage, but at the sixth and eighth weeks of storage, the Gac fruit powder became brighter. The lightness values were 40.63 and 44.46 at 4°C and 30°C, respectively, after eight weeks of storage.

The a* values of Gac fruit powder decreased significantly when the storage time increased for all temperatures ($p \le 0.05$). At week 0, the a* value was 35.58 for all temperatures. At 4°C, there were no statistically significant differences in a* values between weeks 2, 4, and 6. For the temperature of 30°C and 40°C, the a* values decreased when the storage time increased.

The b* values of Gac fruit powder significantly increased ($p \le 0.05$) when the storage time increased for all temperatures. The b* value was 25.46 at week 0 for all temperatures. After eight weeks of storage, the Gac fruit powder demonstrated the highest yellow b* value at a temperature of 40°C, with an average of 31.43. This was followed by the average at 30°C, which was 28.00, and the average at 4°C, also at 31.43.

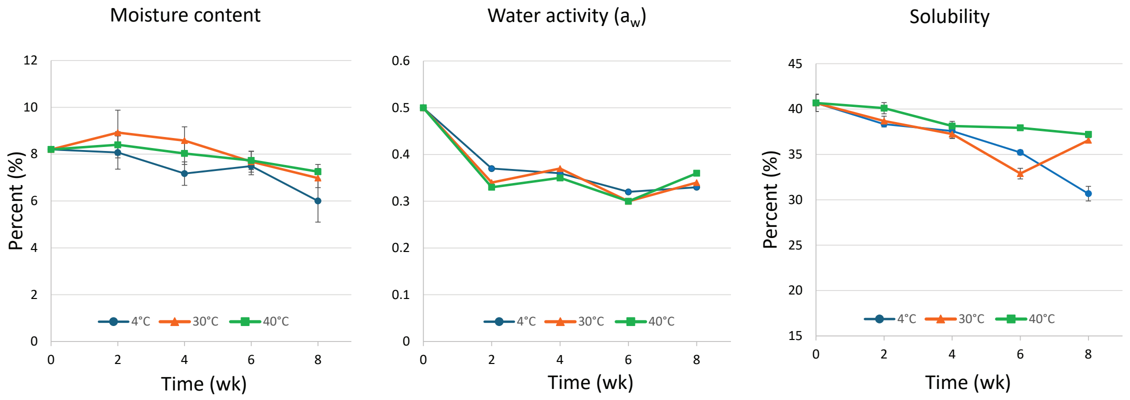


Figure 4 Moisture content, water activity, and solubility of Gac fruit powders during storage

The moisture content, water activity, and solubility of dried Gac fruit powders were evaluated after being stored at 4°C, 30°C, and 40°C for eight weeks, as shown in Figure 4. The GL:CMC sample was selected as a benchmark for analyzing the changes during storage. Throughout the storage period, the moisture content consistently decreased. Initially, at week 0, the average moisture content of the Gac fruit powder stored at 4°C was 8.20%. During weeks 2, 4, and 6, there were no statistically significant differences in moisture content. However, by week 8, the moisture content of the Gac fruit powder stored at 4°C had dropped to its lowest level, measuring 6.00%. For the Gac fruit powder stored at 30°C, the initial moisture content was high at week 0, but it decreased during the 2nd, 4th, 6th, and 8th weeks of storage. Similarly, the moisture content of the powder stored at 40°C remained statistically unchanged during the 0, 2nd, and 4th weeks of storage.

Different storage temperatures at 4°C, 30°C and 40°C had a different effect on the water activity ($p \leq 0.05$), with all storage temperatures at week 0 having a value of 0.50 and at the 8th week of storage, the water activity values were 0.33, 0.30, and 0.30 for sample stored at temperatures at 4°C, 30°C and 40°C, respectively. It was observed that the amount of free water decreased weekly at all storage temperatures. Free water decreased and then consistently maintained at an aw of 0.3 across all storage temperatures, indicating a stable aw for our rice powder sample.

The solubility of Gac fruit powder was found to be statistically significant ($p \leq 0.05$). In the 8th week of the storage, the Gac fruit powder stored at 40°C demonstrated the highest solubility at 37.21, followed by the powder stored at 30°C with a value of 36.56, and the powder stored at 4°C, which had the lowest solubility at 30.68. These findings align with the experimental results reported by Suriyajunhom and Phongpipatpong (2017), which indicated that the solubility of Gac fruit powder ranged from 57.57% to 76.28%, confirming that the solubility was lowest at 4°C.

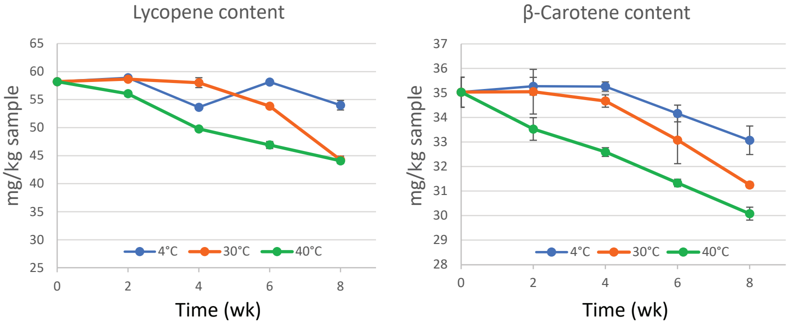


Figure 5 Lycopene and β-Carotene of Gac fruit powder during storage

The contents of lycopene and β-carotene of Gac fruit powder were observed in Figure 5 during eight weeks of storage at temperatures of 4°C, 30°C, and 40°C. The study showed that the lycopene content significantly decreased with longer storage times ($p \leq 0.05$). The average lycopene content in the Gac fruit powder was 58.20 mg/100g during week 0 of storage at 4°C, 30°C, and 40°C. However, there was no significant difference in lycopene content during weeks 0, 2, and 4 of storage. On the 8th week of storage at 4°C, the average lycopene content was 54.01 mg/100g, while at 30°C and 40°C, the average lycopene content was 44.26 mg/100g and 44.08 mg/100g, respectively. Lycopene content decreased as storage time increased, which was consistent with the study of Bhumsaidon & Chamchong (2016) where the Gac fruit powder was stored for 8 weeks at 26°C and 7°C. The study showed that high temperatures during storage decreased lycopene content because the heat stimulated oxidation, causing the decomposition of lycopene through a chain reaction involving free radicals with oxygen, light or heat as initiators (Chottanom et al., 2020).

The β-carotene content in Gac fruit powder significantly decreases ($p \leq 0.05$) with increasing storage time (Figure 5). The study found that at week 0, the β-carotene content was 35.03 mg/100g at all storage temperatures. There was no significant difference ($p \leq 0.05$) in the β-carotene content during weeks 0, 2, 4, and 6 when stored at 4°C and 30°C. However, Gac fruit powder stored at 40°C exhibited a notable difference, with an average β-carotene content of 30.08 mg/100g. Additionally, Gac fruit powder stored at 40°C showed a rapid decrease in β-carotene content each week, while the Gac fruit powder stored at 4°C experienced a slower decline. By the eighth week of storage, the Gac fruit powder at 4°C had a β-carotene content of 33.07 mg/100g, whereas the powder at 30°C had an average of 31.25 mg/100g. The lowest β-carotene content was observed in the Gac fruit powder stored at 40°C, averaging 30.08 mg/100g.

Conclusions

This research investigated the suitability of various encapsulating materials for producing Gac fruit powder using tray drying and evaluated its stability during storage under different temperature conditions. The combination of 20% Maltodextrin and 1% Tween80 emerged as the optimal encapsulant for achieving high encapsulation yield and solubility, making it suitable for applications where cost efficiency and process scalability are priorities. In contrast, 1% Tween80 and the mixture of 2% Gelatin and 1% Carboxymethyl cellulose (w/w) demonstrated superior retention of active compounds like β-carotene and lycopene, which is critical for maintaining the nutritional and pigment integrity of the powder. Vacuum-sealed packaging and low-temperature storage (4°C) are recommended to mitigate nutrient degradation and preserve physical and sensory quality. This study underscores that the choice of encapsulation materials depends on the desired balance between functionality (e.g., pigment stability) and production considerations (e.g., solubility and yield). The results provide valuable insights for optimizing Gac fruit powder production and storage, ensuring both quality and cost-effectiveness in food applications. This powder is suitable for use in a variety of products, including baked goods, beverages, noodles, and Thai desserts. Additionally, it can enhance the natural color of these items. Future research should focus on incorporating Gac fruit powder into various food products and investigating its shelf life within those formulations. Different processing methods and food matrices may affect the stability of β-carotene, lycopene, and the color properties of the final products.

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