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RESEARCH ARTICLE

Impact of maltodextrin concentration on the properties of freeze-dried roselle (*Hibiscus sabdariffa L.*) powder and its effervescent tablet characteristics

Norzaida Yusof *[1], Nur Fadhilah Mohamad Noor[1], Nurul Nadia Muzainy[1], Muhammad Amin Ikram Roslam[2], Nurhayati Yusof[1], Hanis Syazwani Mat Gani[1]

[1]School of Food Industry, Faculty of Bioresources and Food Industry, Universiti Sultan Zainal Abidin, Besut Campus, 22200, Besut, Terengganu, Malaysia
[2]Faculty Agro Based Industry, Universiti Malaysia Kelantan, Jeli Campus, 17600, Jeli, Kelantan, Malaysia

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☒* **CORRESPONDING AUTHOR**
Dr. Norzaida Yusof
School of Food Industry, Faculty of Bioresources and Food Industry, Universiti Sultan Zainal Abidin, Besut Campus, 22200, Besut, Terengganu, Malaysia
Email: norzaida@unisza.edu.my

ABSTRACT

The potentially high therapeutic properties of roselle (*Hibiscus sabdariffa L.*) are limited by its poor stability during storage without additional preservation. To preserve roselle calyxes into shelf-stable powder, a problem arose due to the hygroscopicity of the powder, which drives the development of roselle powder into effervescent roselle tablets. This study first investigated the impact of varying maltodextrin concentrations as an encapsulation material on the physicochemical properties of freeze-dried roselle powder. Roselle calyxes were freeze-dried with the addition of maltodextrin at concentrations of 10%, 20%, and 30%. The powder properties, including analysis of moisture content, water activity, colour, bulk density, tapped density, particle size, and flowability, were analysed. This study observed that the concentration of carrier increased with bulk density (0.52 ± 0.02 - 0.67 ± 0.02), tapped density (0.71 ± 0.00 - 0.83 ± 0.01), and L* value (32.27 ± 0.56 - 45.03 ± 0.48) of colour. The optimum concentration of the carrier was 20% MD, as the powder had slightly poor flowability while retaining the colour. Then, this study aimed to produce effervescent roselle tablets using different percentages (60%, 70%, and 80%) of roselle powder with 20% MD and investigated the effect of different tablet formulations on the tablet characteristics. The tablet with 80% roselle powder was selected as the best tablet due to the high vitamin C content (6.600± 0.000), hardness value (2.649 ± 0.222), and pH of less than 6 (5.403 ± 0.015), and also received higher scores in terms of aroma (4.8 ± 1.0), flavour (4.4 ± 1.5), sourness (4.4 ± 1.3), and overall acceptability (4.8 ± 1.3) as compared to tablets with 60% and 70% roselle powder. Overall, the results confirm that incorporating freeze-dried roselle powder enables the efficient production of roselle tablets with enhanced quality and health-promoting potential.

1.0 INTRODUCTION

Hibiscus sabdariffa var. altissima and *H. sabdariffa var. sabdariffa* are two recognized botanical types of roselle. The altissima variety is primarily cultivated for its fibers, while the sabdariffa variety is grown for its edible calyxes, which are commonly used in food and beverages due to their nutritional and functional properties. Various parts of the roselle plant, including its flowers, leaves, roots, and seeds, are widely used in food applications (Islam et al., 2016). Roselle calyxes (Fig.1), which are the fleshy base of its flower, are rich in calcium, iron, niacin, riboflavin, and a source of antioxidants, anthocyanins (Shruthi et al., 2017). The use of roselle calyxes for beverage production has grown in popularity in recent years, notably in regions including West Africa, Southeast Asia, and the Caribbean (Shruthi et al., 2017). For example, fermented roselle beverages, also known as "cacody tea", are traditionally consumed in Egypt for their refreshing taste and potential health benefits. Meanwhile, Karkade or Zoborodo, which are roselle calyxes boiled with sugar, are introduced in Sudan and Nigeria (Izquierdo-Vega et al., 2020).

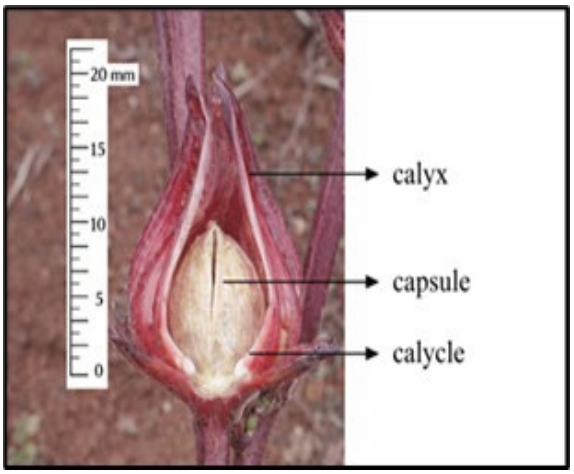

Figure 1: Structure of roselle (Islam et al., 2016)

Fresh roselle is highly perishable due to its high moisture content (typically around 85–90%), which causes it to deteriorate quickly (Shruthi et al., 2017). Therefore, drying is essential to extend its shelf life and improve its availability (Juhari et al., 2021). Processing roselle into dehydrated or powder forms may be a viable option to preserve its quality and facilitate its use in various applications. Freeze-drying is a common method for encapsulating functional compounds, such as antioxidants and vitamins, as it effectively preserves their stability and bioactivity by removing moisture under low temperature and pressure conditions (Tatasciore et al., 2023). This method also helps in forming porous and lightweight powders, making it suitable for incorporating sensitive bioactive ingredients into food and pharmaceutical applications without significant degradation (Papoutsis et al., 2018). In comparison to other drying methods, such as hot air drying, sun drying, and spray drying, freeze-drying offers better retention of shape and colour, rehydration capacity, and retention of heat-labile components such as vitamin C, anthocyanins, and antioxidants (Macura et al., 2019). Coating materials play a crucial role in ensuring the stability of the encapsulation process, particularly in protecting sensitive compounds from degradation. Maltodextrin is commonly used due to its low bulk density, low viscosity, and high solubility at high solid contents.

However, food powders are highly susceptible to environmental humidity. Exposure to high moisture levels can lead to oxidation, clumping, and particle adhesion, particularly during storage (Grumezescu & Holban, 2019). To mitigate these issues, microencapsulation commonly incorporates anti-caking agents such as silicon dioxide, calcium silicate, or tricalcium phosphate, which help reduce hygroscopicity, improve powder flowability, and enhance storage stability (Pui et al., 2020; Maia et al., 2023). Alternatively, converting the powder into tablet form can further minimize humidity-related problems. The popularity of fruit powder tablets has grown due to their advantages, including convenient storage, improved stability, ease of transport, and user-friendly consumption. Effervescent tablets could also prove to be a superb substitute for rapid dissolvability. Several fruits have already been explored for tableting, such as mango, orange, guava, pineapple, and acerola, where the powders are formulated into chewable or effervescent tablets to deliver nutrients like vitamin C and antioxidants in a stable and easy-to-consume form (Ong et al., 2014; Sun et al., 2020; Yusof et al., 2016).

Powder qualities are essential due to their role as the first stage in the manufacturing of effervescent tablets. Based on these issues, this study investigated the effect of maltodextrin concentration on the physical and chemical properties of freeze-dried roselle powder. Additionally, this study examined the impact of the addition of freeze dried roselle powder at optimum properties on the effervescent roselle tablet characteristics.

2.0 MATERIALS AND METHODS

2.1. Plant and materials

Fresh roselle (*H. sabdariffa L.*) calyces (var. UMKL), of average size (5 cm ± 0.5) and with no bruises, were purchased from a farm in Lemboh Bidong, Kuala Nerus, Terengganu, Malaysia. The plant samples obtained were identified by the Terengganu State Department of Agriculture. Maltodextrin (MD) (DE 10-12), used as a carrier agent, was purchased from Sigma–Aldrich Pty. Ltd. All other chemical reagents used in this study were of analytical grade and purchased from Merck (Darmstadt, Germany).

2.2. Preparation of roselle puree

Five kilograms of red calyxes of roselle were washed, cut, and ground into a puree with distilled water in a food processor (MK-F310WSK, Panasonic, Japan) at maximum speed for 40 seconds. The ratio of fresh roselle sample to distilled water used to blend was 1:1 (w/w). Next, different concentrations of maltodextrin were added to the roselle puree, which was mixed using a magnetic stirrer (HPS-380-1, Infitek Bioscience Co., Ltd, China) at 800 rpm for 5 minutes. The three ratios of maltodextrin to the juice were 10%, 20% and 30% weight/volume (w/v). Twenty milliliters of each sample with three different MD concentrations (10, 20, and 30% w/v) were filled into a 50 mL centrifuge tube. Samples were filled to no more than one or two-thirds of the centrifuge tube volume, ensuring maximum surface area and efficient drying.

2.3. Preparation of freeze-dried roselle powder

The three samples with different concentrations of MD were frozen in an air blast freezer (DW-40L418D, Haier Biomedical DW, China) at -40 0C for 48 hours. Then, the frozen samples were transferred into the freeze-dryer (Alpha 3-4 LSC basic, Martin Christ, Germany) that operated at a condenser temperature of -55°C and vacuum pressure of 0.04 mbar for 90.5 hours. The operation settings chosen were based on preliminary trials, which are not reported here. After the freeze-drying process, the samples were removed from the drying chamber. The freeze-dried roselle was ground for 1 min using a food processor (MK-F310WSK, Panasonic, Japan), transferred into an aluminium pouch, and kept at room temperature for further analysis.

2.4. Physicochemical analysis of freeze-dried roselle powder

2.4.1 Determination of moisture content

The moisture content of the powders was determined based on the AOAC (2016) method. The roselle powders (2 g) were weighed and spread evenly on the petri dishes. The sample was then dried at 105°C in an oven (Memmert 600, Germany) for 24 hours. Then, the powders were removed from the oven, cooled in a desiccator, and weighed. Moisture content calculations can be done using Eqn. 1.

Moisture content (%d) =

$$\frac{(Sample\ weight - dry\ weight)\ g}{(Dry\ weight)\ g}\ x\ 100 \qquad \text{Eqn. 1}$$

2.4.2 Determination of water activity

The water activity of roselle powder was measured using a water activity meter (AQUALAB Series 3 TE, USA). Two grams of roselle powder was evenly spread in the sample cup and placed in the sealed measurement chamber until equilibrium was reached. Measurements were conducted at 25 ± 0.5 °C and performed in triplicate. Water activity was defined as the ratio of the vapor pressure of water in the sample (p) to the vapor pressure of pure water (p_0) at the same temperature, as expressed in Eqn. 2.

$$a_w = \frac{\rho}{\rho_o} \qquad \text{Eqn. 2}$$

2.4.3 Determination of particle size

Particle size analysis was determined using a particle size analyser (Litesizer DLS 701, Antor Paar, Austria). This technique is based on measuring the time-dependent fluctuations in the intensity of the scattered light signals. Approximately 0.5 g of freeze-dried roselle powder was dispersed in 99.5 mL of ultrapure water. The mixture was dispersed thoroughly by homogenisation using a magnetic stirrer (HPS-380-1, Infitek Bioscience Co., Ltd, China). A homogenised dispersed sample was fed into the particle size analyser to determine the distribution of particle sizes. Triplication of results was collected from each analysed roselle powder sample.

2.4.4 Determination of bulk and tapped density

Bulk density was determined by measuring the ratio of the powder mass to powder volume. Approximately 30 g of roselle powder was poured into a 250 ml measuring cylinder. The calculation of bulk density is based on Eqn. 3.

Bulk density, $\rho_B (\frac{g}{cm^3}) =$

$$\frac{Mass\ of\ roselle\ powder\ (g)}{Volume\ occupied\ by\ powder\ (cm^3)} \qquad \text{Eqn. 3}$$

Tapped density was measured using an Electrolab tap density tester (Electrolab, India). Thirty grams of powder were placed into a 250 ml measuring cylinder, and the initial volume was recorded. The cylinder was tapped 100 times at 249 drops/min, and the final volume was recorded after the volume of powders in the measuring cylinder remained constant (Guerin et al., 1999). The tapped density is calculated based on Eqn. 4.

Tap density, ρ_t (g/cm^3) =

$$\frac{Mass\ of\ roselle\ powder\ (g)}{Final\ tapped\ volume\ (cm^3)} \qquad \text{Eqn. 4}$$

2.4.5 Determination of flowability

The flowability powder was evaluated in terms of the Carr Index (CI) (Table 1), as described by Jinapong et al. (2008). It was calculated from the bulk and tapped densities of the powder, as shown in Eqn. 5. Based on Table 1, CI values of 0–10% indicate excellent flowability, while increasing CI values correspond to reduced flow properties, ranging from good to extremely poor flowability.

$$\text{Carr Index (CI)} = \frac{\rho t - \rho\beta}{pt}\ x\ 100 \qquad \text{Eqn. 5}$$

Where;
ρ_B = bulk density
ρ_t = tapped density

Table 1: Flowability classification, Carr (1965)

Relative Flowability	Carr Index (CI), %
Excellent	0-10
Good	11-15
Fair	16-20
Slightly poor	21-25
Poor	26-31
Very poor	32-37
Extremely poor	>38

2.4.6 Determination of colour

The colour of roselle powder was measured using a Colorimeter (Konica Minolta CR-400, Japan). Calibration was performed against a standard white ceramic tile prior to analysis. The outcome results were expressed as Hunter colour values based on L*, a*, and b* value, where the L* value is used to presents the lightness (+) and darkness (-), a*

value used to present the redness (+) and greenness (-), and the b* value presents yellowness (+) and blueness (-). All the reading of colour was performed in triplicate.

2.5. Roselle effervescent tablet preparation

The direct compression method was used to turn the freeze-dried roselle powder into tablets. Roselle powder with 20% MD was chosen to further develop an effervescent tablet because it exhibits better characteristics compared to 10% and 30% MD, as shown in Table 3. A different formulation of effervescent roselle tablets was based on the formulation in Table 2. Preliminary experiments were conducted to determine the optimal ratio of effervescent agents. From the result, the optimum ratio of sodium bicarbonate to citric acid to malic acid (3: 0.5: 1.5) was applied for the development of several formulations of effervescent roselle tablets by varying the percentage of freeze-dried roselle powder (60-80%) as shown in Table 2.

The formulated roselle powder was weighed and poured into a die of cylindrical uniaxial shape, and the 8 mm diameter of the tablet was chosen. Approximately 200 mg of tablet mixtures (Table 2) were compressed into tablet form using uniaxial die compaction with a single-action mechanism. After the powder mixture was compressed, it was ejected from the die. After these tablets were ejected, their thicknesses were measured. The effervescent tablets were wrapped in aluminum foil for further analysis.

Table 2. Tablet formulation of different percentages of freeze-dried roselle powder, standard formulation and function for each ingredient.

Ingredients		Formula (%)			Reference range (%)(Mishra et al., 2022)
		F1	F2	F3	
Freeze-dried roselle powder (20% MD)		60	70	80	-
PEG 8000 (lubricant)		1.00	1.00	1.00	0.5-1.00
Sorbitol (bulking agent)		0.20	0.20	0.20	0.3-2.00
Sucralose (high-intensity sweetener)		0.10	0.10	0.10	0.1-1.00
Effervescent Agent	Sodium bicarbonate (alkali source)	23.22	17.22	11.22	20-30.0
	Citric acid (acid source)	3.87	2.87	1.87	15-25
	Malic acid (acid source)	11.61	8.61	5.61	

All values are % w/w. Effervescent agent ratio: Sodium bicarbonate: citric acid: malic acid = 6:1:3

2.6 Physicochemical properties of roselle effervescent tablet

2.6.1 Hardness of tablet

The hardness of the effervescent roselle tablet was tested by a hardness tester (SWFT-5, Electrolab, India). The test was performed by placing an effervescent roselle tablet vertically between two flattened plates. This machine applied forces (N) towards the diameter and thickness of the tablets until a clear crack emerged in the compacted tablets. Eqn. 6 shows the calculation for tablet hardness.

$$\text{Tablet hardness, } \sigma = \frac{2F}{\Pi DH} \qquad \text{Eqn. 6}$$

Where;
F = The crushing force or tensile force (N)
D = Compact diameter (m)
H = Compact thickness (m)

2.6.2 Dissolution time

200 milliliters of water at a temperature of 37 °C ± 1 °C was prepared to observe the dissolution time of each tablet sample (Oktavia et al., 2020). The time taken for the effervescent roselle tablet to disintegrate and disperse in 200 mL of 37 °C water was recorded. Samples were analyzed in triplicate to obtain the mean value.

2.6.3 Effervescent solution pH

The pH of the effervescent solution was measured after the disintegration time of an effervescent roselle tablet using a pH meter (MS 3411, Microset, India). Samples were analyzed in triplicate to obtain the mean value.

2.6.4 Determination of ascorbic acid (vitamin C) content in effervescent roselle tablet by titrimetric method

Two effervescent roselle tablets were dissolved in 120 ml of distilled water. 25 ml of the solution was transferred into a conical flask containing 10 drops of 1% starch solution. Then, this solution was titrated against the iodine solution. Titration was ended upon changes of the initial colour of solutions to a purple colour that persisted for 20 seconds. The titration process was done in triplicate. The final volume of iodine solution in the burette was recorded and subtracted from the initial volume for the determination of vitamin C presence in different effervescent tablet formulations using Eqn. 7 (Olotu et al., 2020):

$$Vitamin\ C\ (mg) = M_{12} \times V_{12} \times \frac{176.12mg}{mmol} \qquad \text{Eqn. 7}$$

Where;
M_{12} = Concentration of iodine solution
V_{12}= Volume of iodine solution used
Molar mass of Vitamin C = 176.12 g/mole

2.6.5 Sensory analysis

The effervescence roselle tablet drink was prepared by mixing 1 tablet in 30 ml of drinking water and evaluated by 30 untrained panel members (n=30), who were young adults in Malaysia, including those aged 18-35 years old. The roselle tablets (F1-F3) were dissolved in water, which coded with a random three-digit number. All volunteers were asked to refrain from drinking or eating for 30 minutes prior to the test. A 7-point hedonic scale (1-disliked extremely to 7-like extremely) was employed to evaluate the color, aroma, flavour, sourness, and overall acceptability of the roselle drink. The participants were given water alternately after each round of the sensory evaluation test. The sensory evaluation was conducted following approval by the Ethics Committee of the Universiti Sultan Zainal Abidin, Malaysia (Ethics approval number: UniSZA/UHREC/2023/506).

2.7 Statistical analysis

The results were presented as mean values and standard deviation. Before statistical analysis, data were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. One-way analysis of variance (ANOVA) was then conducted to determine significant differences among the mean values, followed by Duncan's multiple range test for post hoc comparisons at a significance level of $p < 0.05$. All statistical analyses were performed using the statistical software SPSS 20.

3. RESULT AND DISCUSSION

3.1 Physicochemical analysis of powder

3.1.1 Moisture content and water activity

Table 3 shows the result of how different concentrations of maltodextrin affect the moisture content and water activity of freeze-dried roselle powder. Moisture content represents the water composition, which is both free and bound water in a food system, and water activity is seen as the content of free water in a food system (Seerangurayar et al., 2017). During the sublimation phases, moisture content in food products is converted into gaseous form without the intermediate liquid state phase (Ryszard et al., 2019). Due to the lack of moisture content, freeze-dried products are able to have longer shelf life without any possibility of changing composition or infections by microbial contaminants (Ellab Validation Solutions, 2018). Based on Table 3, it was evident that a significant amount of moisture and water activity was removed during the freeze-drying process. Table 3 also shows that as the concentration of maltodextrin increases, the moisture content and water activity decrease. In this study, water activity (a_w) is seen as the ratio of the vapour pressure of water in a sample to the vapour pressure of pure water (Saifullah et al., 2016). It becomes the parameter of the powder stability and shelf life. Measurements of water activity are predicting the optimum environment for the storage of freeze-dried roselle powder. According to Naji-Tabasi et al. (2021), low moisture content of powder minimises the sticking of powder and increases the surface area of powder contacting with water during dissolution. The amount of maltodextrin used in the production of powder is inversely proportional to moisture content due to the ability of maltodextrin to bind with water and reduce free water (Naji-Tabasi et al., 2021).

Table 3: Physical properties of roselle powder

Concentration of MD	10%	20%	30%
Moisture Content (%)	2.85±0.05^{a}	1.53±0.05^{b}	1.44±0.04^{b}
Water Activity (a_w)	0.12±0.04^{a}	0.04±0.00^{b}	0.03±0.00^{b}
Particle Size (nm)	1530.27±89.31^{a}	1289.63±73.55^{a}	935.80±166.38^{b}
Bulk Density (g/cm³)	0.52±0.02^{c}	0.58±0.00^{b}	0.67±0.02^{a}
Tapped Density (g/cm³)	0.71±0.00^{c}	0.75±0.00^{b}	0.83±0.01^{a}
Carr Index	26.58±2.83^{a}	23.08±0.03^{ab}	18.59±2.94^{b}

Values are expressed as mean ± standard deviation.
$^{a-c}$ Means indicated with different superscript letters differ significantly ($p<0.05$).
Values within the same row followed by the same superscript letters are not significantly different ($p>0.05$).

3.1.2 Flowability, bulk density, tapped density, and particle size

Table 3 shows that roselle powder produced from different maltodextrin concentrations varies the value of particle size, bulk density, tapped density, and flowability. Primarily, the size of roselle powder influences its flowability. This is due to the inverse relation between powder flowability and cohesiveness (Seerangurayar et al., 2017).

Bulk density is closely related to the storage capacity of powdered food. Based on Table 3, the bulk density of freeze-dried roselle powder with MD 10%, 20% and 30% are 0.52 g/cm³, 0.58 g/cm³ and 0.67 g/cm³, respectively. A higher concentration of maltodextrin, ranging from 10% to 30%, significantly increases the bulk density value. Due to the increasing amount of encapsulation materials, the mass of powder becomes denser, which increases bulk density (Seerangurayar et al., 2017). As a result of particle size, the trend is decreasing with increasing MD concentration. From Table 4, it is clear that bulk density increased with decreasing particle size of freeze-dried roselle powder from 10% to 30% of MD. The flow of roselle powder with the smallest particle size is observed as the best among others. Seerangurayar et al. (2017) define powder flow as the relative movement of bulk particles among neighbouring particles. The higher bulk density of roselle powder indicates a smaller particle size,

which leads to better powder flow.

The flowability of powder is referred to as the value of Carr Index, as in Table 3. According to the value, freeze-dried roselle powder with 10%, 20%, and 30% of MD are classified as powder with poor, slightly poor, and fair flowability, respectively. Higher concentrations of MD resulted in a lower Carr Index, indicating improved flowability of the roselle powder. This outcome is expected because MD acts as an effective drying aid, reducing interparticle cohesion by producing smoother, more spherical particles with a lower moisture content and reduced surface stickiness (Sarabandi & Sadeghi, 2018). As the MD level increases, the powder becomes less prone to agglomeration and frictional resistance, thereby enhancing its flow characteristics. Improved flowability is crucial for downstream operations, such as powder handling, capsule filling, and tablet compression, as powders with good flowability ensure uniform die filling, consistent tablet mass, and reduced processing defects (Shah et al., 2023).

Tapped density is the measure of restriction for particle movement when tapped. Based on Table 3, the tapped density of freeze-dried roselle powder of MD 10%, 20% and 30% are 0.71 g/cm³, 0.75 g/cm³, and 0.83 g/cm³, respectively. Similarly, Alibekov et al. (2025) reported that increasing MD concentration from 10% to 20% in freeze-dried cow milk raised tapped density from about 0.63 to 0.73 g/cm³, comparable to the values observed in this study. The tapped density significantly increases with increasing MD concentration as the addition of maltodextrin produces larger particles with a wider distribution range, as maltodextrin forms a more cohesive matrix during freezing that leads to larger structures remaining after sublimation. These larger, denser particles achieve higher tapped densities by more effectively filling voids between particles and reducing interparticle space compared to smaller particles (Michalska-Ciechanowska et al., 2020). Furthermore, tapped density values are reported as higher than bulk density. This is due to the tapping movement that enables the occupation of smaller particles into the voids between larger particles. Among the three MD concentrations, roselle powder encapsulated with 20% maltodextrin exhibited the most balanced physical properties. This formulation exhibited a significantly lower moisture content (1.53%) and water activity (0.04%) compared to the 10% MD, indicating improved powder stability. The particle size (1289.63 nm) was reduced relative to 10% MD while maintaining a suitable range for powder handling. In addition, the 20% MD powder had higher bulk (0.58 g/cm³) and tapped densities (0.75 g/cm³), reflecting better packing characteristics. Moreover, its Carr Index value (23.08%) was lower than that of 10% MD and within the acceptable flowability range, supporting its suitability for further tablet production.

3.1.3 Analysis Colour

Table 4 shows the L*, a*, and b* values for colour measurement in freeze-dried roselle powder at different concentrations of maltodextrin. The L*, a*, and b* values for roselle powder with increasing MD concentrations from 10%, 20%, and 30% (w/v) of MD were significantly different ($p<0.05$). The roselle powder with 30% (w/v) MD exhibited the highest lightness (L* = 45.03) compared to the other concentrations (Fig. 2). This increase in lightness can be attributed to the dilution effect of maltodextrin on the native anthocyanin pigments of roselle, as higher MD levels reduce the relative pigment concentration per unit mass of powder. Similar dilution-induced lightening effects have been reported in spray and freeze-dried fruit powders enriched with maltodextrin (Lestario et al., 2023; Maramy et al., 2025; Padzil et al., 2018; Sukri et al., 2018). Maltodextrin is a white, low-colour carrier with minimal flavour contribution, and its increasing proportion in powder formulations has been shown to reduce colour intensity by masking or dispersing natural pigments (Quek et al., 2007). Consequently, increasing MD concentration resulted in roselle powders that were lighter (higher L*), less red (lower a*), and less yellow/blue chromaticity (lower b*). Freeze drying is one dehydration technique that allows the drying of products under low temperatures and vacuum (Ellab Validation Solutions, 2018). These conditions have been widely reported to preserve heat-sensitive compounds, including anthocyanins (Ryszard et al., 2019), thus, the observed colour changes in the present study are primarily governed by maltodextrin concentration rather than degradation of roselle pigments during drying.

Table 4: Colour composition of freeze-dried roselle powder

Concentration of MD	10%	20%	30%
L* value	32.27±0.56^{c}	37.83±0.50^{b}	45.03±0.48^{a}
a* value	41.14±0.18^{a}	38.40±0.27^{b}	39.91±0.31^{c}
b* value	10.91±0.11^{a}	6.68±0.13^{b}	3.37±0.22^{c}

Values are expressed as mean ± standard deviation.
$^{a-c}$ Means indicated within the same row with different superscript letters differ significantly ($p<0.05$).

Figure 2: Freeze-dried roselle powder at different maltodextrin (MD) concentrations: (A) 10% MD, (B) 20% MD, and (C) 30% MD. Corresponding colour parameters (L*, a*, b*) were determined using a colorimeter and are presented in Table 4.

3.2.1 Colour of roselle tablet

Colour strongly influences consumer acceptance of effervescent fruit tablets, so L*, a*, and b* are important quality indicators. L* values, which range from 0 to 100, were used to describe product lightness. The L* values of all formulations (48.71–50.22) did not differ significantly, indicating that increasing the proportion of freeze-dried roselle powder from 60% (F1) to 80% (F3) did not produce a visually perceptible change in tablet lightness; all tablets remained in a similar mid-dark red range, which is advantageous for maintaining a consistent tablet appearance between batches. The redness index (a*) increased significantly from 27.273 ± 1.116 (F1) to 33.313±0.505 (F3), whereas b* increased from 4.350 ± 0.286 (F1) to 7.237 ± 0.211 (F2). Higher a* values indicate a more intense red hue, which reflects the greater anthocyanin content at higher roselle loadings, since cyanidin- and delphinidin-based anthocyanins are the main red pigments of roselle calyces (Yusoff et al., 2024). The increase in b* suggests a shift toward a slightly more yellowish–red tone, which has also been reported for roselle and other anthocyanin-rich products when pigment concentration increases or when co-pigmentation and light scattering effects intensify (Vieira et al., 2019). Similar colour trends have been observed in effervescent bael tablet-based formulations, where increasing fruit powder content resulted in increased L* values and a* values, reflecting a stronger expression of the characteristic fruit colour, while higher maltodextrin levels diluted pigment intensity and produced lighter tablets, consistent with roselle-based systems (Islam & Hasan, 2024).

3.2.2 Hardness of roselle tablet

Compression pressure and the type of felt material are two factors that affect tablet hardness (Herlina et al., 2020). Effervescent tablets typically have a lower hardness than conventional tablets. Low hardness is typically used for chewable tablets, whereas high hardness is used to protect coated tablets during coating (Oktavia et al., 2020). Based on the result obtained in Table 5, the hardness of effervescent roselle tablets in different percentages of freeze-dried roselle powder ranged from 1.094 N to 2.878 N. In 60 % (F1) freeze-dried roselle powder of effervescent tablet, the hardness was 1.094 N, which is significantly different from F2 and F3. By increasing the amount of freeze-dried roselle powder to 70 % and 80 %, the hardness of the tablet significantly increased, which were 2.878 N and 2.649 N, respectively. This might be due to higher roselle powder levels, which caused better natural binding, increased contact surface area, and improved compressibility characteristics, making the tablet mechanically more robust (Aznan et al., 2021).

3.2.3 Dissolution time

The solubility times of effervescent tablets are measured to determine how long it takes for the effervescent tablets to dissolve in water. The dissolution of all effervescent solid components into a solution marks the end of effervescent solubility, and no more gas bubbles form. The shorter time required to dissolve the effervescent component indicates that its solubility is high (Herlina et al., 2020). The dissolution time of effervescent roselle tablets increased significantly ($p<0.05$) from F1 to F3, with mean values of 1.437 ± 0.025, 3.290 ± 0.156, and 5.513 ± 0.038 minutes, respectively (Table 5). F1 and F2 complied with the commonly accepted limit for effervescent products (≤5 mins in 200–250 mL water at room temperature), whereas F3 slightly exceeded this limit (Taymouri et al., 2019). This might be due to the F3 formulation being too compact and containing an excessive proportion of insoluble roselle solids, which likely slowed water penetration and CO_2 release.

Table 5. Colour, hardness, and dissolution time of effervescent roselle tablet.

Formulation		F1	F2	F3
Color	L* value	48.713±0.985^{a}	50.377±1.237^{a}	50.220±0.403^{a}
	a* value	27.273±1.116^{b}	33.310±0.612^{a}	33.313±0.505^{a}
	b* Value	4.350 ± 0.286^{b}	7.237 ± 0.211^{a}	7.007 ± 0.196^{a}
Hardness (N)		1.094 ± 0.207^{b}	2.878 ± 0.532^{a}	2.649 ± 0.222^{a}
Dissolution Time (min)		1.437 ± 0.025^{c}	3.290 ± 0.156^{b}	5.513 ± 0.038^{a}

Values are expressed as mean ± standard deviation.
Values within the same row followed by the same superscript letters are not significantly different ($p>0.05$).

3.2.4 Effervescent solution pH

Based on the results obtained (Table 6), the pH of the roselle puree is 2.430, indicating an acidic nature. This result is similar to that of Fasoyiro (2014), who observed that the pH of dark roselle calyces ranged from 2.01 to 3.74. There is no significant difference in pH value between puree and freeze-dried roselle powder. The pH test is necessary because an excessively acidic or alkaline effervescent solution can irritate the stomach and leave a bitter or unpleasant taste in the mouth. The different concentrations of the effervescent mix may be the cause of pH value variations. Based on Table 6, the result showed that the pH of the product tablets is significantly impacted by the different percentages of the roselle powder in effervescent tablets (F1-F3), with the average effervescent solution pH ranging from 5.333 to 5.947. The measured pH values of all effervescent tablet solutions (pH 5–6) were within the desired range (below 6), which is considered favourable for enhancing absorption of effervescent preparations (Herlina et al., 2020). Therefore, the

effervescent formulation was regarded as safe for consumption.

3.2.5 Vitamin C of the effervescent roselle tablet

The vitamin C of roselle puree, as shown in Table 6 (13.024 mg/mL), was significantly higher compared to others, and this finding is similar to those reported by Abdel-Moemin (2016), who observed (16 mg/ 100 g) in roselle calyces and (11 mg/ 100 g) in roselle extract. The freeze-drying process results in a slight decrease in vitamin C content in freeze-dried roselle powder, with 7.876 mg/ml shown after 48 hours of drying. The reduction in vitamin C content may be attributed to the effect of processing temperature (Ojike et al., 2020). The data in Table 6 also demonstrates a clear correlation between the higher proportion of freeze-dried roselle powder and a substantial rise in the vitamin C concentration found in effervescent roselle tablets. The significant difference in the vitamin C content between F1, F2, and F3 and freeze-dried roselle powder may be due to the degradation of vitamin C when exposed to light and oxygen.

Table 6: Effervescent solution pH and vitamin C content of different formulations of effervescent roselle tablet

Formulation		Effervescent solution pH	Vitamin C
Roselle puree		2.430± 0.008^{a}	13.200±0.000^{a}
Freeze-dried roselle powder (20% MD)		2.430± 0.000^{a}	7.876 ± 0.076^{b}
Roselle Tablets	F1	5.947± 0.012^{d}	5.236 ± 0.076^{e}
	F2	5.333± 0.110^{b}	6.248 ± 0.152^{d}
	F3	5.403± 0.015^{c}	6.600± 0.000^{c}

Values are expressed as mean ± standard deviation.
Values within the same column followed by the same superscript letters are not significantly different (p>0.05).

3.2.6 Sensory evaluation

The sensory evaluation scores for color, aroma, flavour, sourness, and overall liking were obtained from untrained panelists are shown in Table 7. Results indicate that the effervescent roselle tablet from F3 with 80% of freeze-dried roselle powder received the significantly highest score for aroma (4.767 ± 0.971), flavour (4.433±1.547), sourness (4.400 ± 1.276), and overall acceptability (4.767 ± 1.278) as compared to the other samples, which indicate 4 “Neither like nor dislike”. For attribute colour, the effervescent roselle tablet F2 is more preferred by panelists but did not differ significantly from F1 and F3. Color is important in product appearance because it influences consumer acceptance of a food product, particularly a drink.

For aroma, the effervescent roselle tablet from F3 is more preferred by panelists but does not differ significantly from F1 and F2. In general, the roselle aroma consists of earthy, green, floral, and fruity aromas, primarily derived from volatile compounds associated with organic acids and phenolic constituents (Jung et al., 2013). F3 is slightly higher preference in aroma scores may be attributed to the higher proportion of freeze-dried roselle powder, which enhances the release of characteristic volatiles upon reconstitution. Previous studies on fruit-based tablets and effervescent systems have shown that increasing the level of fruit powder generally enhances aroma intensity and overall acceptability, because more aroma-active compounds are available in the final beverage (Sun et al., 2020). In addition, the presence of effervescent agents such as citric acid and sodium bicarbonate may also modify the final aroma profile through rapid CO_2 release, which can either enhance volatile release or partially mask delicate floral notes depending on formulation balance (Patel et al., 2025).

Table 7: Sensory characteristics of the effervescent roselle tablet drink.

Attributes	*F1*	*F2*	*F3*
Colour	5.7 ± 1.2^{a}	5.7 ± 1.1^{a}	5.5 ± 1.4^{a}
Aroma	4.4 ± 1.3^{a}	4.7 ± 1.3^{a}	4.8 ± 1.0^{a}
Flavour	3.8 ± 1.7^{a}	3.9 ± 1.8^{a}	4.4 ± 1.5^{a}
Sourness	4.1 ± 1.6^{a}	4.1 ± 1.5^{a}	4.4 ± 1.3^{a}
Overall Acceptance	4.5 ± 1.5^{a}	4.1 ± 1.7^{a}	4.8 ± 1.3^{a}

Values are expressed as mean ± standard deviation.
Values within the same row followed by the same superscript letters are not significantly different (p>0.05).

On the other hand, flavour is a key determinant of consumer acceptance, and roselle is known for its distinctive sweet–sour taste, comparable to cranberry and other acid-rich fruits cranberry (Avalos-Martínez et al., 2019). The higher flavour score observed for F3 (4.4 ± 1.5) indicates that the increased roselle powder content likely intensified the characteristic tart and fruity flavour, improving palatability. Similar findings have been reported in fruit-based effervescent or fast-dispersible tablet studies, where formulations containing higher proportions of fruit solids, combined with a well-balanced citric acid–bicarbonate system, showed improved flavour scores and overall consumer acceptance compared with lower fruit or over-acidic formulations (Islam & Hasan, 2024). In terms of sourness, F3 shows the highest acceptability among all panelists with a mean value of 4.4 ± 1.3. The sour taste of the effervescent roselle tablet was also contributed by the addition of malic acid and citric acid in the formulation by 15 % and 5 %, respectively. Overall, F3 was rated the most acceptable by the panelists with the highest mean value of 4.8 but did not differ significantly from F1 and F2.

4. CONCLUSION

In conclusion, several analyses have been conducted to produce freeze-dried roselle powder with different concentrations of carrier. The different concentrations of the carrier (10%, 20%, and 30%) of the freeze-dried roselle powder were measured to look into their bulk density, colour, flowability, particle size, tapped density, moisture content, and water activity before they were formulated into an effervescent roselle tablet. Different formulations of effervescent roselle tablets were produced and determined for tablet characteristics of hardness, dissolution time, effervescent solution pH and vitamin C content.

The findings indicated that increasing the concentration of maltodextrin with decreasing composition of roselle puree results in decreasing water activity, moisture content, particle size, a* value and b* value of colour measurement for freeze-dried roselle powder. Meanwhile, bulk density, tapped density and L* value of colour increase as the concentration of carriers increases. The optimum concentration of carriers was 20% with slightly poor flowability. Increasing the percentage of freeze-dried roselle powder (20% MD) to 80% increases the red color of the tablet, hardness, dissolution time, and vitamin C content. Thus, F3 is chosen as the best formulation to produce an effervescent roselle tablet with good physicochemical properties due to the high vitamin C content, hardness value, and pH of less than 6 which is required to increase the absorption of effervescent tablets and also received higher scores in terms of aroma, flavour, sourness, and overall acceptability as compared to the other formulation which indicates 4 “Neither like nor dislike”. Increasing roselle loading improved the nutritional and functional value of the effervescent tablets, but it was accompanied by higher hardness and prolonged dissolution, indicating a trade-off between maximizing roselle content and achieving rapid effervescence. Future optimisation should therefore focus on maintaining a high roselle level while modifying excipient composition and compression conditions to keep dissolution within the recommended effervescent limit.

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