Research Article

Development of Pomelo Pastille with the incorporation of Pomelo Pith

Nurin Nabilah Binti Norizam [1]; Heong Man Hin[1] and Noorakmar Ab Wahab[1, 2*]

[1]Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah.
[2]Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia (UTHM), Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia

*akmar@uthm.edu.my

ABSTRACT

The development of pomelo fruit pastilles incorporated with pomelo pith offers consumers a nutritious and natural confectionery option. The pomelo pith, with its high pectin content and strong gel-forming ability, serves as an innovative and sustainable ingredient for pastille products. The pastille formulations of F1-F3 were developed from 10% pomelo flesh and 10-20% pomelo pith. A 9-point hedonic scale, colour analysis, total soluble solid, water activity, pH and vitamin C content were conducted to determine the best formulation in the initial study stage. Subsequently, the proximate content and storage quality (microbial stability, pH and water activity) of the best and control formulations were assessed. The results showed that there were no significant differences in colour, aroma, taste and overall acceptance of the pastille ($p>0.05$). However, the F3 pastille with 20% pomelo pith demonstrated higher elasticity texture acceptance ($p<0.05$). Additionally, the F3 pastille contained a significantly higher amount of total soluble solids and exhibited a brighter yellow colour with values of L* (49.96), a* (2.27), and b* (16.01) compared to other formulations ($p<0.05$). The moisture (18.54%), ash (0.08%), protein (0.26%), and crude fibre (1.05%) content of the best pastille formulation were higher than those of the control pastille ($p<0.05$). The best pastille formulation could be stored for more than six weeks with pH of 3.54, water activity of 0.769, bacteria count of 3.4×10^3 CFU/g as well as yeast and fungi count of 2.0×10^2 CFU/g. In conclusion, pomelo fruit with 20% pith produces an elastic pastille with a bright yellow colour and is a good source of crude fibre.

Received: 30 December 2024
Accepted: 21 August 2025
Published: 30 September 2025
DOI: https://10.51200/ijf.v2i2.5910

Keywords: pastille; pectin; pomelo fruit; pomelo pith

1. Introduction

The confectionery industry, including pastilles, is one of the largest food sectors in the world. The global market size for the candy industry in 2022 is $12.1 billion and is expected to grow at an annual growth rate of around 10.1% from 2022 to 2030 (Zion Market Research, 2023). Pastilles are popular because of their delicious taste, availability, and affordable price.

The pastille product is synonymous with its springy and soft texture. Pastilles have long shelf life of approximately 3 months due to their high sugar content which can reduce water activity, thus reducing the risk of damage caused by microbes (Basiri, 2020). The main ingredients of pectin-based pastille are pectin, sweetening agents like sucrose, glucose or corn syrup, citric acid, flavourings, and colouring agents (Zainol et al., 2019). There are two types of pectin: high-methoxyl (HM) and low-methoxyl (LM) pectin. High-methoxyl pectin is commonly used in the production of pastilles. It has an esterification degree of more than 50%, so it requires a soluble solid content of more than 55% and acidic conditions, at a pH of 2.5–3.5 to form a gel (Lara-Espinoza et al., 2018). Whereas, the temperature of the solution required to activate pectin is between 93-100^{o}C (Efe & Dawson, 2022).

The pomelo fruit (*Citrus grandis)* is the largest citrus fruit with a 15–25 cm diameter. In Malaysia, pomelo fruit is widely grown in the states of Perak, Kedah, and Johor with various varieties. Pomelo fruits are rich in Vitamin C as well as other nutrients such as carotenoids, flavonoids, alkaloid acridone, limonoids, minerals, essential oils, and Vitamin B complexes (Anmol et al., 2021). The pith or albedo part of pomelo also contains various nutrients, bioactive compounds, and dietary fibre that are beneficial to humans. Pomelo pith contributes to 30%-50%(w/w) of the weight of the fruit, and is often discarded as waste due to its bitter taste (Wang et al., 2020). The pomelo pith is reported to contain up to 69.69% of pectin, mostly high-methoxyl pectin, which exhibits strong gel-forming ability with sugar and acids (Krongsin et al., 2014).

In recent years, global food security systems have increasingly emphasised sustainability and resource efficiency to meet the growing demand for safe, nutritious, and affordable food. Countries and organisations worldwide are implementing strategies that focus on reducing food waste, promoting circular economy practices, and enhancing food resilience. One key area of focus is the valorisation of agricultural by-products and food waste into value-added ingredients, aligning with sustainable development goals (SDGs). Efforts to extract natural biopolymers like pectin from fruit waste such as pomelo pith represent a promising approach in reducing reliance on synthetic thickeners while contributing to waste management solutions. Utilising food waste for functional ingredients not only helps to minimise environmental pollution but also lowers the carbon footprint associated with food production.

After the COVID-19 pandemic, consumers have become more health conscious, seeking more nutritious and natural food products. Certain consumer groups prioritise the sustainability of food products. Pomelo pith is a potential food ingredient to be developed into functional foods as it contains valuable dietary fibre and high-methoxyl pectin which is a sought-after food component that has versatile applications. Limited research has been conducted on utilising pomelo pith for the de

velopment of confectionery products. This research aims to evaluate the potential of pomelo fruit and pith as ingredients in pastille development, focusing on their impact on sensory attributes, physicochemical properties, proximate composition, and shelf life.

2. Materials and Methods

2.1 Raw Materials

Pomelo fruits were purchased from the fresh market in Kundasang, Sabah. Sugar, glucose syrup, citric acid, high-methoxyl pectin were purchased from various suppliers from Sabah. Hydrochloric acid (Chemiz), ethanol (Chemiz) and peptone water (Sigma-Aldrich) were purchased from Syarikat Jaya Usaha.

2.2 Formulation of Pomelo Pastille

The pastille formulation from pomelo fruit is based on Din et al., (2022) with a slight modification whereas sorbitol, gelatine and corn flour were excluded. Din’s et al. (2022) formulated the pastille by replacing ratios of watermelon rind and flesh puree whereas the present study only manipulated the pomelo pith puree concentrations, while keeping the pomelo fruit puree concentration constant. Four pastille formulations were produced, which were the control, F1, F2, and F3 with different percentages of pomelo pith puree (10%, 15%, 20%). The pastille formulations are shown in Table 1.

Table 1. Pastille formulation with different percentages of pomelo pith puree

Ingredients	Composition (%)			
	Control	F1	F2	F3
Pomelo pith puree	0	10	15	20
Pomelo fruit puree	10	10	10	10
Glucose syrup	20	20	20	20
Sucrose	30	30	30	30
High-methoxyl pectin	2	2	2	2
Citric acid	0.1	0.1	0.1	0.1
Water	37.9	27.9	22.9	17.9

Note: F1-pastille with 10% pomelo pith; F2 - pastille with 15% pomelo pith; F3 - pastille with 20% pomelo pith.

2.3 Sample Preparation

Pomelo fruit was peeled, separating the skin that contains the pith, from the flesh that contains the fruit pulp. The fruit pulp was extracted by removing the inedible parts, the fruits were then blended into puree and stored in a freezer until further use. The pith was separated from the pomelo skin and cut into small pieces. They were treated soaked in a salt solution overnight to reduce the bitter taste as according to Sowmya & Lakshmi (2023). The pith was then blanched at 95 °C for 10 minutes to deactivate enzymes such as peroxidase and polyphenol oxidase to prevent enzymatic degradation (Kim et al., 2020). After blanching, the pith was rinsed, stroked and blended into a puree. The pith puree was stored in the freezer at -4 ^{o}C until further use.

With the pomelo fruit puree and pomelo pith puree readied, the pastille was prepared according to the formulation stated in Table 1. High-methoxyl pectin and sucrose were dissolved in 80 °C hot water (Din et al., 2022). In a separate pot, the pomelo pith puree was boiled for 2 minutes. The pomelo fruit puree was added to the mixture containing pectin and sucrose. Both pots of mixture were mixed gradually and stirred until they boiled. Then, glucose syrup was added accordingly. The mixture was cooked until it reached the total soluble solid content of 75 °Brix. The mixture was then adjusted to pH 3.5 with citric acid (Hashim et al., 2021; Sumonsiri et al., 2021). Once ready, this solution was poured into a mould that had been flattened with cornstarch and left to cool at room temperature. The pastilles were then cut into rectangular shape (1.0 cm x 1.5 cm) and coated with castor sugar.

2.4 Analysis of Pectin Content in Pomelo Pith

Pectin was extracted from the pomelo pith using hydrochloric acid (0.1M) (Azim et al., 2013; Khan et al. 2014). The pectin was then filtered and rinsed with 45% ethanol. When finished, the pectin was dried in the drying oven (Thermoline, Sydney Australia) at 40 °C for 24 hours. The pectin content was calculated according to the equation below.

$$Pectin\ (\%) = \frac{P1}{P0} \times 100 \qquad (1)$$

P1= Weight of extracted pectin (g)
P0=Weight of pomelo pith powder before extraction (g)

2.5 Sensory Analysis

This sensory assessment was conducted with 50 semi-trained panellists, consisting of students aged 20-25 with a gender ratio of 1:1 from the Faculty of Food Science and Nutrition, UMS. Product attributes, such as colour, aroma, taste (bitterness), texture and overall acceptability, were assessed using a 9-point hedonic scale from 1 to 9 where: 1- Dislike extremely, 2- Dislike very much, 3-Dislike moderately, 4- Dislike slightly, 5- Neither like nor dislike, 6-Like slightly, 7-Like moderately, 8-Like very much, 9-Like extremely (Wichchukit & O'Mahony, 2015). Four samples were encoded with different 3-digit codes before being served to panel members. Each sample was placed in a small dish along with water for mouth-rinsing.

2.6 Physicochemical Analysis

2.6.1 Water Activity

The water activity (Aw) was determined using the water activity meter (AquaLab Cx- 2, England). Samples were prepared by crushing the pastilles into smaller pieces. Then, a total of 2.00±0.01 g of the sample was placed in the water activity meter plate.

2.6.2 pH

The pH value of pastille samples was determined using a pH meter (Metter Toledo Inlab 413, England) based on the AOAC method (2000). Approximately 2.00±0.01 g of the pastille samples was mixed and dissolved with 8 mL of distilled water.

2.6.3 Total Soluble Solids

The total soluble solid (TSS) is the amount of solid content dissolved in the material. It was measured using a pocket refractometer (Atago N-3E, Japan). Before °Brix was measured, the surface of the refractometer prism was wiped dry before placing the crushed pastille sample onto the prism surface. Then, the sample's °Brix readings were read and recorded.

2.6.4 Vitamin C Content

Vitamin C content was determined by the dye titration method 2-6 dichloroindophenol (DCIP) (Kareem, 2020). A dye solution of 2-6 DCIP was prepared by dissolving 0.50±0.01 g 2-6 DCIP into 975 mL of water, which was then added with 25 mL of 0.05M phosphate buffer with pH 7. A 1% solution of oxalic acid was also prepared by dissolving 10 g of oxalic acid into 1000 mL of distilled water. Then, standard ascorbic acid of 0.1 mg/mL was prepared by dissolving 50.00 mg of ascorbic acid with 1% oxalic acid in a 500 mL volumetric flask. Pastille samples were also prepared by grinding 100±0.01 g samples with approximately 50 mL of distilled water. The solution was filtered and collected in a volumetric flask. A solution of oxalic acid was added to make a final solution of 100 mL in a volumetric flask. The vitamin C content for each sample was calculated using the equation below.

$$Vitamin\ C\ Content\ (\%) = \frac{X}{Y \times Z} \times 100 \qquad (2)$$

X = Vitamin C equivalent to 2ml of dye (mg)
Y = Sample used in titration (mL)
Z = Sample equivalent to 1mL extract (g)

2.6.5 Colour Analysis

A colourimeter (Hunterlab Colourflex, USA) was used to determine the colour of the pastilles. The pastilles were cut into flat pieces to cover the entire container. The results were then recorded accordingly.

2.7 Proximate Analysis

2.7.1 Moisture Content

Based on AOAC (2000), the pastille's moisture content was determined using the oven drying method. Moisture content is calculated based on the equation below.

$$Moisture\ Content\ (\%) = \frac{(Y - Z)}{(Y - X)} \times 100 \qquad (3)$$

X = Weight of crucible (g)
Y = Weight of crucible + sample before drying (g)
Z = Weight of crucible + sample after drying (g)

2.7.2 Ash Content

The ash content analysis was carried out based on the AOAC method (2000). The ash content is calculated based on the equation below.

$$Ash\ Content\ (\%) = \frac{(Y - Z)}{(Y - X)} \times 100 \qquad (4)$$

X = Weight of crucible (g)
Y = Weight of crucible + sample before desiccation (g)
Z = Weight of crucible + sample after desiccation (g)

2.7.3 Crude Protein Content

According to AOAC (2000), protein determination content tests were determined by the Kjedahl method using the FOSS Kjeltec 2300 automated analyser (FOSS, Denmark) with nitrogen-to-protein factor of 6.25. The final content of the protein was displayed on the Kjeltec screen expressed as percentage and recorded.

2.7.4 Fat Content

Fat content analysis used Soxhlet extraction (Soxhtec™ 2050, Germany) (AOAC, 2000). Fat content is calculated based on the equation below.

$$Fat\ content\ (\%) = \frac{(Y - X)}{Z} \times 100 \qquad (5)$$

X = Weight of Soxhlet flask (g)
Y = Weight of Soxhlet flask + fat (g)
Z = Weight of sample (g)

2.7.5 Crude Fibre Content

Crude fibre content was determined using Fibretherm (Gerhardt, Germany). The sample weight is weighed and recorded as W4.

$$Crude\ fibre\ content\ (\%) = \frac{(W3 - W1) - (W4 - W5)}{W2} \times 100 \qquad (6)$$

W1 = Fibre bag weight (g)
W2 = Weight of sample (g)
W3 = Weight of crucible and fibre bag after digestion (g)

W4 = Weight of crucible and ash (g)
W5 = Weight of empty value of empty fibre bag (g)

2.7.6 Carbohydrate Content

The carbohydrate content was calculated using the equation below, where A, B, C, D and E are the sum of (g) moisture content, ash, fat content, crude fibre, and protein, respectively.

$$Carbohydrate\ content\ (\%) = 100 - (A + B + C + D + E) \qquad (7)$$

2.7.7 Energy Content

The energy content of the sample was calculated based on the equation below with kilocalorie units (kcal) as specified in the Food Act (1983) and Food Regulations (1985).

$$Energy\ content\ (kcal) = [carbohydrate\ (g) \times 4\ kcal] + [protein\ (g) \times 4\ kcal] + [fat\ (g) \times 9\ kcal] \qquad (8)$$

2.8 Shelf-life study

The shelf-life analysis for the control and best formulation samples was performed over a 6-week period at intervals of two, four, and six weeks, respectively. The sample was stored in an airtight plastic bag and placed at room temperature (25±1°C) and relative humidity of 35±5%. The content of water activity and pastille pH is determined based on the methods specified in 2.6.1 and 2.6.2.

2.8.1 Microbiology test

Microbiology tests were conducted every two weeks, four weeks, and six weeks in storage periods. In this test, the Plate Count Agar (PCA) medium was used to detect the presence of bacteria with the pour plate technique whereas, Potato Dextrose Agar (PDA) medium was used to detect the presence of yeast and fungi using the spread plate technique. Both analyses were conducted in triplicate. For sample preparation, 2g of the cut sample was mixed with 18mL of peptone water. The sample was crushed with a Stomacher bag (Bag Mixer 400) (Teixeira-Lemos et al., 2021). The sample released was a 10-1 dilution. A series of dilutions was carried out to obtain 10^{-2}, 10^{-3}, and 10^{-4} dilution sample.

For bacterial presence analysis, 1 mL for each dilution sample of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} was pipetted into an empty petri dish and the pour plate technique was performed. Meanwhile, for the yeast and fungi analysis, 0.1 mL of each dilution sample 10^{-1}, 10^{-2}, and 10^{-3} was pipetted into a petri dish that contained PDA agar and then prepared using the spread plate technique. After that, all plates were put into the incubator (CONTHERM, Australia) in the upside-down position at 35 °C for 24 hours for PCA samples and 3 days for PDA samples. Finally, the average colony estimate was calculated as Colony Forming Unit CFU/g using the equation below.

$$Total\ plate\ count, \frac{CFU}{g} = \frac{(Y \times X)}{W} \times 100 \qquad (10)$$

X = Number of colonies
Y = Total dilution factor
W = Volume of culture plate (mL)

2.9 Statistical Analysis

The analysis in this study was done in triplicate. The IBM SPSS Statistics program analysis (version 29.0.0.0) was used to analyse the data obtained from all tests. One-way Analysis of Variance (ANOVA) was used to compare the means of two or more groups of dependent variables to identify whether there was any significant difference between different formulations and to determine the best pastille formulation. Tukey's post-hoc test was used to identify the significant differences between the best pastille sample formulation and control samples using paired comparisons test. A t-test analysis was carried out on data that had only one dependent variable (Ross & Willson, 2017). The data were then presented in the form of a mean score ± standard deviation, with a significant difference value set at $p < 0.05$.

3. Results and Discussion

3.1 Pectin Content in Pomelo Pith

Pectin, a form of dietary fibre, is predominantly found in the cell wall and middle lamella of plant cells, particularly in fruits such as apples, oranges, and limes (Mudgil, 2017). In the manufacturing of products like jams, jellies, and pastilles, the pectin content of the fruit is often assessed prior to production, allowing for precise formulation adjustments to achieve the desired textural properties.

The pectin yield from pomelo pith in the present study exhibited a mean value of 27.27%, which surpasses the 19.33% yield reported by Krongsin et al. (2014). This discrepancy in pectin content is attributed to variations in extraction techniques and the specific type of pomelo analysed. According to Rahman et al. (2023), the quality and yield of pectin extracted from fruit peels are influenced by several factors, including the fruit's type, variety, and ripeness. Additionally, parameters such as pH, temperature, extraction duration, method, and post-extraction treatments play critical roles in determining pectin quality and yield. Nonetheless, the findings of this study indicate that the pomelo pith used contains a relatively high pectin content.

3.2 Sensory Characteristics of Pastille

Table 2 shows the sensory characteristics of all pastille formulations including attributes of colour, aroma, taste (bitterness), texture (elasticity), and overall acceptance. Referring to Table 2, the hedonic results of the colour attributes did not show a significant difference (p>0.05) for all formulations. This suggests that most panellists agreed that the increase in the percentage of pomelo pith by 10% to 20% into the pastille did not contribute to a significant difference in the colour of the pastilles. In addition, the mean score value for all formulations was high, between 7.48 and 7.74. This suggests that the colours of pastilles made from pomelo fruit were favoured by panellists.

Table 2. Sensory characteristics of pastille formulations

Attribute	Mean score ± standard deviation			
	Control	F1	F2	F3
Colour	7.70 ± 1.298 ^{a}	7.48 ± 1.282 ^{a}	7.54 ± 1.297 ^{a}	7.74 ± 1.367 ^{a}
Aroma	6.26 ± 1.639 ^{a}	6.16 ± 1.646 ^{a}	6.26 ± 1.601 ^{a}	6.22 ± 1.788 ^{a}
Taste (bitterness)	6.38 ± 1.828 ^{a}	6.00 ± 1.702 ^{a}	6.02 ± 1.744 ^{a}	6.32 ± 1.778 ^{a}
Texture (elasticity)	6.34 ± 1.493 ^{a}	6.38 ± 1.537 ^{a}	6.92 ± 1.322 ^{ab}	7.10 ± 1.165 ^{b}
Overall acceptance	6.48 ± 1.752 ^{a}	6.20 ± 1.616 ^{a}	6.36 ± 1.396 ^{a}	6.52 ± 1.460^{a}

Note: F1, pastille with 10% pomelo pith; F2, pastille with 15% pomelo pith; F3, pastille with 20% pomelo pith.
Note: Mean values ± standard deviations with different alphabets in the same row indicate a significant difference (p<0.05) between the formulations.

In sensory evaluation, aroma is a critical attribute in food products, as it aids consumers in distinguishing between different types of food and often influences their purchasing decisions and acceptance of a product (Bortnowska, 2018). The hedonic test results for the aroma attribute in this study showed no significant difference (p>0.05) among all pastille formulations. The mean aroma scores ranged from 6.16 to 6.26, indicating that the aroma of pastilles made from pomelo pith was generally acceptable to consumers. Pomelo fruit typically emits a milder aroma compared to other citrus species due to its primary aromatic compound, nootkatone, which imparts woody and bitter notes (Gous et al., 2019; Chen et al., 2023). As a result, the aroma profile of the pomelo-based pastille was less tangy than that of pastilles derived from other citrus fruits.

Taste is another crucial sensory attribute, as it largely determines consumer preference and acceptance before a product is commercialised. The hedonic test for taste focused on consumer acceptance of the bitterness in pastilles made from pomelo fruit and its pith. As shown in Table 2, no significant differences (p>0.05) were found between the formulations for taste attributes, with mean scores ranging from 6.00 to 6.38. These scores were slightly lower than those for other sensory attributes.

Pomelo fruit, especially its pith, is well known for its bitter taste, primarily due to the presence of limonin and naringin (Pichaiyongvongdee et al., 2015). However, blanching treatment was effective in reducing the bitterness of the pith. In contrast, the bitterness of pomelo juice puree remained, as it contains the fruit's pulp, which is rich in narirutin, naringenin, and limonin compounds responsible for its bitter flavour (Gupta et al., 2021; Chen et al., 2023). These flavonoids contribute to the bitterness observed in the pastille formulations.

According to the study by Oktaviana et al. (2013), jelly confectionery produced from pomelo pith and roselle exhibited a bitter taste, which increased with the percentage of pomelo pith incorporated. Similarly, Gous et al. (2019) reported that naringin, a compound found in grapefruit, significantly contributes to the bitterness of juice products made from the fruit. However, their study also found that grapefruit juice drinks with a higher °Brix value of 12 indicating greater sugar content enhanced consumers' perception of sweetness, thereby masking the bitter taste of the juice. This suggests that increasing the °Brix value can be an effective strategy to balance bitterness in citrus-based products.

Regarding the texture attributes of the pastille formulations, a significant difference (p<0.05) was observed between formulation F3 and both the control formulation and F1. However, no significant differences (p>0.05) were noted between formulations F3 and F2. The variation in texture between F3 and the control and F1 formulations is attributed to the differing percentages of pomelo pith. Formulation F3 contains 20% pomelo pith, whereas the control and F1 formulations contain 0% and 10% pomelo pith, respectively. High-methoxyl pectin gels are known to form effectively in systems with high soluble solid content and a pH value below 3.5 (Said et al., 2023).

Total soluble solids, which include sugar, soluble proteins, amino acids, and other organic compounds, contribute to the texture of food products (Kusumiyati et al., 2020). The higher pomelo pith content in formulation F3 increases the total soluble solids, resulting in a superior pastille texture. Additionally, the high pectin content in the pomelo pith used in this study further enhances gel formation, supporting the development of a desirable texture in pastille formulations (Krongsin et al., 2014).

In terms of overall acceptance, this attribute is essential for evaluating consumers' general preference for a product and its market potential (Wanjiru Maina, 2018). No significant differences (p>0.05) were observed in the overall acceptance scores among the various formulations, indicating that varying pomelo pith percentages did not significantly affect sensory attributes such as colour, aroma, or taste. However, formulation F3 achieved the highest mean score of 6.52, likely due to its high level of acceptance of its texture.

Despite this, overall acceptability scores for all formulations were low, indicating that pastille products derived from pomelo fruit and pith had little market appeal. The sensory attributes of light-yellow colour, mild aroma, and slightly bitter taste most likely led to this low acceptance. Therefore, while pomelo-based pastille shows potential, further improvements in formulation are necessary to enhance their commercial viability and market appeal.

3.3 Physicochemical Properties

3.3.1 Water Activity

Water activity is a critical indicator of the stability and shelf life of food products (Rahman et al., 2019). Table 3 shows that there was no significant difference (p>0.05) in water activity among the control, F1, and F3 formulations. There were also no significant differences (p>0.05) between formulations F2 and F3.

To prevent microbial growth in food products, water activity levels must be less than 0.95. This includes bacteria, yeast, and fungi. In general, lower water activity ratings indicate greater product stability. Specifically, the recommended range for water activity in gummy, pastille, and jelly products is between 0.50 and 0.75 to ensure stability (Ergun et al., 2010). Given that the water activity values for all pastille formulations in this study ranged from 0.736 to 0.749, they fall within the safe and acceptable range, indicating that the pastilles are sufficiently stable for storage.

3.3.2 Total Soluble Solids

According to Table 3, there was a significant difference (p<0.05) in total soluble solids between formulations F3 and F2 compared to the control and F1. Formulation F3 was found to have the highest amount of total soluble solids, indicating an increase in soluble solids as the proportion of pomelo pith increased. This is likely due to the high pectin content in pomelo pith, as pectin is a complex carbohydrate that can contribute to the total soluble solids content (Rahman et al., 2019).

For soft confectionery products like jelly and pastilles, the total soluble solids content should reach at least 75% to inhibit fungal growth and ensure product stability (Delgado & Bañón, 2014). In addition to providing microbial stability, a high concentration of soluble solids can also help mask the natural bitterness of pomelo (Gous et al., 2019). Table 3 showed that all pastille formulations met the required levels of soluble solids, indicating that they are safe for consumption and suitable for storage.

Table 3: Physicochemical properties of pastille

Parameters	Mean score ± standard deviation			
	Control	F1	F2	F3
Water Activity (Aw)	0.737 ± 0.003 [a]	0.736 ± 0.004 [a]	0.749 ± 0.007 [b]	0.743 ± 0.002 [ab]
Total Soluble Solids (°Brix)	77.300 ± 0.200 [a]	78.100 ± 0.306 [b]	78.800 ± 0.736 [c]	79.000 ± 0.200 [c]
pH	3.150 ± 0.025 [a]	3.180 ± 0.015 [a]	3.150 ± 0.015 [a]	3.170 ± 0.005 [a]
Vitamin C (%)	2.073 ± 0.035 [a]	2.047 ± 0.050 [a]	2.050 ± 0.036 [a]	2.067 ± 0.015 [a]
Colour (L*)	47.627 ± 0.067 [a]	48.367 ± 0.040 [b]	49.460 ± 0.036 [c]	49.957 ± 0.040 [d]
Colour (a*)	2.073 ± 0.071 [a]	2.100 ± 0.361 [ab]	2.707 ± 0.127 [b]	2.273 ± 0.093 [b]
Colour (b*)	15.373 ± 0.031 [a]	15.563 ± 0.029 [a]	16.067 ± 0.006 [b]	16.007 ± 0.162 [b]

Note: Mean values ± standard deviations with different alphabets in the same row indicate a significant difference (p<0.05) between the formulations.

3.3.3 pH

The pH values of all pastille formulations showed no significant differences (p>0.05), as the same amount of citric acid (0.1 g) was used in each formulation. The pH values for all formulations ranged from 3.15 to 3.17. Generally, a low pH value imparts a sour taste to pastille products, which can help mask the bitter aftertaste of pomelo (Tua et al., 2018). Additionally, citric acid not only enhances the sourness but also plays a crucial role in improving the texture of the pastille by activating pectin, facilitating better gel formation and overall product consistency (Tua et al., 2018).

3.3.4 Vitamin C

Vitamin C is a powerful antioxidant that helps protect cells from oxidative stress caused by free radicals. Studies have suggested that vitamin C has potential health benefits on the immune system, skin health, collagen synthesis and cardiovascular health (Hemilä, 2017; Pullar et al., 2017). Vitamin C also plays an important role in enhancing iron absorption as a reducing agent (Lane & Richardson, 2014). The vitamin C content in all pastille formulations showed no significant differences (p>0.05), as each formulation used the same amount (10%) of pomelo juice puree. The mean vitamin C content across the formulations ranged from 2.047 to 2.073. However, compared to other fruit pastille products on the market, the vitamin C content in these pomelo-based pastilles is notably lower. This decrease is due to the breakdown of vitamin C during the cooking process.

Vitamin C, a water-soluble and temperature-sensitive compound, is prone to degradation when exposed to high temperatures and prolonged cooking times (Lee et al., 2017). Essodolom et al. (2020) demonstrated that vitamin C degrades rapidly at temperatures between 85 °C and 95 °C, especially after 10 minutes of cooking. This explains the lower vitamin C levels in the pomelo pastilles, despite the use of fresh juice puree.

3.3.5 Colour

Table 3 presents the mean scores for colour analysis of pastilles made from pomelo fruit and pith, a key attribute that significantly influences consumer acceptance. The results show a significant difference (p<0.05) in L* values across all pastille formulations. The L* value represents brightness, with higher values indicating brighter colours and lower values indicating darker shades (Cloudhury, 2014). Formulation F3 had the highest L* score (49.957), while the control sample had the lowest score (47.627), suggesting that the F3 formulation had a brighter appearance.

The a* value represents the red-green colour axis, with negative values indicating a shift toward green and positive values toward red (Cloudhury, 2014). Significant differences (p<0.05) were observed between the control and F1 formulations and the F2 and F3 formulations. The a* values for all formulations ranged from 2.073 to 2.273, reflecting a very slight shift toward red, but the overall transition was minimal.

The b* value represents the blue-yellow colour component, where negative values indicate blue and positive values indicate yellow (Cloudhury, 2014). There was a significant difference (p<0.05) in b* values between the control and F1 formulations and the F2 and F3 formulations. All pastille formulations exhibited a skew toward yellowness, with F2 and F3 having higher b* scores than the control and F1 samples. This indicates a stronger yellow component in F2 and F3, likely due to the increased percentage of pomelo pith, which enhanced the yellow colour. The pomelo used in this study has a yellowish-white flesh, and the commercial pectin used also contributes to the yellow hue (Tien et al., 2022).

As a result, the pastilles produced from pomelo fruit and pith exhibit a light-yellow colour with a high level of brightness, and the intensity of the yellow colour increases with the amount of pomelo pith used. This suggests that the pomelo pith contributes significantly to the overall colour of the final product.

3.4 Best Formulation

Based on the sensory and physicochemical properties of all formulations, the F3 formulation was identified as the optimal pastille product. In terms of its sensory characteristics, the F3 sample achieved the highest mean score in texture and overall acceptability, indicating strong user preference. Additionally, in the physicochemical properties, the F3 formulation contained the highest amount of total soluble solids, which enhances the pastille's stability and resistance to fungal growth (Delgado & Bañón, 2014). The high soluble solids content also contributes to sweetness and helps mask the bitterness of the pomelo fruit (Gous et al., 2019).

The water activity value of the F3 formulation was 0.743±0.002, which falls within the safe range for pastille products, ensuring shelf stability. Moreover, the high pomelo pith content in the F3 formulation improves its physicochemical properties and provides nutritional benefits. Therefore, the F3 formulation was selected as the best formulation due to its superior texture, stability, and balanced sensory profile.

3.5 Proximate Composition

The proximate composition for the control pastille and the best formulation (F3) is presented in Table 4. Moisture content is a crucial factor in assessing food quality, particularly in products like pastilles, as it affects freshness, shelf life, and susceptibility to spoilage (Hashim et al., 2021). The results showed a significant difference ($p<0.05$) in moisture content between the control pastille and the F3 formulation, with the F3 formulation having a higher moisture content (18.538%) compared to the control (16.520%). This increase can be attributed to the higher pomelo pith content in the F3 pastille, as pomelo pith has a moisture content of approximately 16.13% (Zain et al., 2014). Both formulations fall within the safe moisture content range of 8–22% for soft confectionery products, which helps inhibit microbial growth and ensures product safety (Ergun et al., 2010).

Ash content, representing the mineral residue left after organic material combustion, also shows a significant difference ($p<0.05$) between the control and the F3 formulation. The F3 formulation has a higher ash content (0.079%) compared to the control (0.033%), likely due to the higher percentage of pomelo pith, which contains about 3.41% ash (Zain et al., 2014). This increased ash content suggests a higher mineral concentration in the F3 pastille, including essential minerals like calcium, potassium, and sodium (Harris & Marshall, 2017).

Crude fibre content also significantly differs ($p < 0.05$) between the two formulations, with the F3 pastille having a much higher fibre content (1.046%) than the control (0.084%). The pomelo pith is a rich source of fibre, containing approximately 68% fibre, of which 44.79% is insoluble and 23.03% is soluble (Boontongkong et al., 2018). The high pectin content in pomelo pith further contributes to the crude fibre content, as pectin is classified as soluble dietary fibre due to its ability to form gels (Blanco-Pérez et al., 2021).

In terms of fat content, there is a significant difference ($p<0.05$) between the control and the F3 pastille. The F3 formulation had a slightly higher fat content (0.552%) compared to the control (0.382%). This increase in fat content is due to the pomelo pith, which contains between 0.09% and 1.56% fat (Zain, 2014). Both formulas comply with the Malaysian Food Regulations (1985), which state that confectionery products should include no more than 10% fat.

Protein content also shows a significant difference ($p<0.05$) between the two formulations. The F3 formulation has a higher protein content (0.260%) compared to the control (0.237%). The pomelo pith contributes to this increase, as it contains approximately 6.27% protein (Zain, 2014), enhancing the nutritional value of the F3 pastille.

Finally, carbohydrate content shows a significant difference ($p<0.05$) between the control and F3 formulations. The control pastille has a higher carbohydrate content (81.993%) compared to the F3 formulation (79.526%). Both formulations have high carbohydrate levels, primarily due to the sugar and glucose syrup used in the formulations. Carbohydrates, which include sugars, starches, and cellulose, form a major component of these pastilles, indicating that both formulations can contribute significantly to daily carbohydrate intake (Leong et al., 2019).

There is a significant difference ($p<0.05$) in the energy content of the control pastille and the best formulation pastille. The calorie value of the control pastille was slightly higher than the best formulation pastille with a difference of 10.887 kcal. This is because the control pastille has a higher carbohydrate content than the best formulations.

Table 4. Proximate composition in the control and the best formulation pastille

Proximate Composition	Sample	
	Control	Best formulation
Moisture (%)	16.520 ± 1.040 [a]	18.538 ± 0.526 [b]
Ash (%)	0.033 ± 0.010 [a]	0.079 ± 0.004 [b]
Protein (%)	0.237 ± 0.010 [a]	0.260 ± 0.011[b]
Fat (%)	0.382 ± 0.057 [a]	0.552 ± 0.094 [b]
Crude fibre (%)	0.084 ± 0.013 [a]	1.046 ± 0.023 [b]
Carbohydrate (%)	81.993 ± 1.010 [b]	79.526 ± 0.421 [a]
Energy (kcal)	335.002 ± 1.041[b]	324.115 ± 2.495 [a]

Note: Mean values ± standard deviations with different alphabets in the same row indicate a significant difference (p<0.05) between the formulations.

3.6 Shelf-life Study

3.6.1 pH

The data in Table 5 reveals the changes in pH values for both the control and the best formulation pastille (F3) over a six-week storage period. Monitoring the pH of pastille is critical, as it serves as an indicator of product stability. Low pH values are known to enhance the shelf life of food products by inhibiting microbial growth, which can cause spoilage (Tua et al., 2018). Thus, the stability of the pH in pastille is crucial for maintaining product quality and safety during storage.

Table 5 shows a significant difference (p<0.05) in the change in pH values across both formulations in the six-week period. The pH levels for both the control and F3 formulations gradually increased over time, peaking at the sixth week. This increase in pH can be attributed to the breakdown of polysaccharides into simpler sugars like monosaccharides and disaccharides (Kurzyna-Szklarek et al., 2022). Thus, this not only increases the sweetness of the pastilles but also decreases its sourness.

The gradual rise in pH over time suggests that the pastilles may become slightly less acidic in storage over time, which could influence the taste profile by reducing the sourness imparted by ingredients like citric acid. This change in acidity could affect consumer perception of the product's flavour, potentially making it more appealing as it ages, depending on personal preferences for sweetness and sourness. However, the increase in pH may also affect microbial stability and should be carefully monitored to ensure that the product remains safe for consumption throughout its shelf life.

Table 5. pH value of the control and the best formulation pastille

Formulation	Week			
	Week 0	Week 2	Week 4	Week 6
Control	3.15 ± 0.025 [a]	3.21 ± 0.017[b]	3.39 ± 0.040[b]	3.44 ± 0.021[c]
Best Formulation	3.17 ± 0.005 [a]	3.27 ± 0.025 [b]	3.52 ± 0.010 [c]	3.54 ± 0.010 [c]

Note: Mean values ± standard deviations with different alphabets in the same row indicate a significant difference (p<0.05) between the formulations.

3.6.2 Water Activity

Table 6 displays the changes in water activity of pastille samples over a six-week storage period. Water activity (Aw) is a critical factor in evaluating the shelf life of food products, as it represents the amount of free water available for microbial growth and chemical reactions (Mohos, 2016). The stability and durability of food products, such as pastilles, can be predicted by monitoring their water activity levels, which directly influence the growth of bacteria, yeast, and fungi.

Table 6 shows a significant difference ($p<0.05$) in the water activity levels of both the control and F3 formulations over six weeks. Water activity levels increased as storage time progressed, with the highest readings occurring on the sixth week. This gradual rise in water activity can be attributed to the use of glucose syrup in the pastille formulations, as glucose syrup is hygroscopic and functions as a humectant. Humectants are molecules containing hydroxyl groups, which have a strong affinity for binding water molecules via hydrogen bonds (Poçan et al., 2022). This property allows glucose syrup to trap water from the surrounding environment throughout the storage period, leading to increased water activity over time.

Table 6. Water activity of the control and the best formulation pastilles during the storage period

Formulation	Week			
	Week 0	Week 2	Week 4	Week 6
Control	0.737 ± 0.003^{a}	0.743 ± 0.001^{b}	0.746 ± 0.003^{c}	0.752 ± 0.002^{d}
Best Formulation	0.743 ± 0.002^{a}	0.753 ± 0.001^{b}	0.760 ± 0.004^{b}	0.769 ± 0.002^{c}

Note: Mean values ± standard deviations with different alphabets in the same row indicate a significant difference ($p<0.05$) between the formulations.

As water activity rises, it can affect the quality and safety of the product. Although the pastilles may initially have water activity levels within the safe range to inhibit microbial growth. However, the upward trend during storage suggests that the product could become more vulnerable to spoilage if water activity exceeds critical thresholds. Therefore, controlling water activity throughout the storage period is essential to maintain the pastille's shelf life and ensure its safety for consumption.

3.6.3 Bacterial Growth

Table 7 presents the bacterial growth rates in both the control and the best formulation pastille over a six-week storage period. Initially, at week 0, no bacterial growth was observed in any pastille formulation. This is likely due to the low water activity levels recorded at the beginning of the study—0.737 for the control pastille and 0.743 for the best formulation. Low water activity is a key factor in preventing bacterial proliferation, as bacteria typically require a water activity level of at least 0.91 to sustain growth (Allen, 2018).

However, starting from week 2 until week 6, the bacterial growth in both formulations increased progressively. By the sixth week, bacterial counts reached 1.03×10^4 CFU/g for the control pastille and 3.4×10^3 CFU/g for the best formulation. Despite this rise, both formulations remained within the safe limits as stipulated by the Malaysian Food Act (1983) and Malaysian Food Regulations 1985, which set allowable bacterial colony counts between 10^3 and 10^4 CFU/g. Any bacterial growth exceeding 10^5 CFU/g would render the product unsafe for consumption.

Table 7: The growth rate of bacteria on the control and the best formulation pastilles over the storage period

Week	Bacteria growth (CFU/g)	
	Control	Best formulation
0	0	0
2	3.2×10^3	1.1×10^3
4	6.9×10^3	2.8×10^3
6	1.03×10^4	3.4×10^3

Interestingly, although the best formulation pastille exhibited higher water activity and pH values over time, its bacterial growth rate remained lower than that of the control pastille. It is due to the antimicrobial properties of pomelo pith, which, according to Suklampoo et al. (2014), contains bioactive compounds capable of inhibiting the growth of harmful microorganisms, such as bacteria, yeast, and fungi. These antimicrobial properties help prolong the shelf life and safety of the pastille product, making the best formulation a superior choice for microbial stability.

3.6.4 Yeast and Fungi Growth

Table 8 presents the growth rates of yeast and fungi in both the control and best formulation pastilles over a six-week storage period. At week 0, no yeast or fungal growth was detected in either the control or best formulation pastille. However, yeast and fungal growth in the control pastille started appearing after week 2 and progressively increased, reaching 2.3×10^3 CFU/g by week 6. In contrast, the best formulation showed no yeast or fungal growth until week 4, with a much lower growth rate of 2.0×10^2 CFU/g recorded by week 6.

According to Ng et al. (2022), the maximum allowable limit for yeast and fungal colonies is 10^2 CFU/g. Therefore, the yeast and fungal growth observed in the control pastille exceeded the acceptable limit, making it unsafe by the end of the storage period. On the other hand, the best formulation remained within the safe threshold, demonstrating better resistance to yeast and fungal contamination.

Table 8. The growth rate of yeast and fungi on the control and the best formulation pastilles over the storage period

Week	Yeast and fungi growth (CFU/g)	
	Control	Best formulation
0	0	0
2	1.0×10^2	0
4	4.0×10^2	1.0×10^2
6	2.3×10^3	2.0×10^2

Yeast and fungi can thrive in environments with a wide pH range (pH 2 to above pH 9), and the high sugar content in pastilles provides an ideal environment for their growth (Ng et al., 2022; Kong et al., 2020). However, the reduced yeast and fungal growth in the best formulation can be attributed to the antimicrobial properties of the pomelo pith, which has been shown to inhibit the reproduction of microorganisms, including yeast and fungi (Suklampoo et al., 2014). This demonstrates the efficacy of pomelo pith in improving the microbiological stability of the pastille, resulting in a safer and more durable product over time.

4. Conclusion

The percentage of pomelo pith puree that increased from 10% to 20% improved the pastille's colour, texture, water activity, and total soluble solid content without changing its aroma. Formulation F3, with 20% pomelo pith puree, was brighter and yellower than other samples. Panellists also liked its texture. Thus, F3 was the best formulation. This pastille formulation featured a slightly higher moisture content, resulting in a shorter shelf life than commercial pastilles. F3 has more ash, protein, and crude fibre, indicating a healthy profile. F3 had a longer shelf life than the control formulation and might last over six weeks.

It should also be mentioned that even the best formulation had a rather average consumer acceptability score (6.52 out of 9) and a relatively low concentration of vitamin C. To overcome these limitations, it is suggested that future formulations could incorporate other citrus fruits that are naturally rich in vitamin C, such as orange, lemon, or calamansi. Non-thermal preparation methods may also help to prevent vitamin-C degradation throughout the preparation process. The combination of pomelo pith with these citrus fruits may significantly enhance the vitamin C content of the pastille, improving its nutritional profile. Moreover, the strong citric flavour and refreshing aroma of these fruits may help to mask the inherent bitterness caused by the incorporation of pomelo pith. This flavour enhancement could potentially improve the overall sensory acceptance of the product, leading to higher consumer acceptability.

Pomelo pith contains considerable amounts of pectin, which makes it useful in food. This study found that pomelo pith may have antibacterial properties that extend the shelf life of food. Food made from pomelo pith showed promise in sustainability. However, the bitter taste of pomelo pith remains a major drawback of its utilisation. Future studies should reduce or eliminate pomelo pith's bitter flavour and explore value-added food products with pomelo pith as the main ingredient.

Acknowledgement

Special thanks to the Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, for providing the laboratory facilities essential for conducting this research.

References

Allen, L. V. 2018. Quality Control: Water Activity Considerations for Beyond-use Dates. PubMed, 22(4), 288–293. https://pubmed.ncbi.nlm.nih.gov/30021184/

Anmol, R. J., Marium, S., Hiew, F. T., Han, W. C., Kwan, L. K., Wong, A. K. Y., Khan, F., Sarker, M. M. R., Chan, S., Kifli, N., & Ming, L. C. 2021. Phytochemical and Therapeutic Potential of Citrus grandis (L.) Osbeck: A Review. Journal of Evidence-Based Integrative Medicine, 26, 2515690X2110437. https://pmc.ncbi.nlm.nih.gov/articles/PMC8527587/

Azim, M. L., Farahain, M., Siti Fairus, M. Y., Ishak, A., & Adil, H. 2013. Synthesis and Characterization of pH Sensitive Hydrogel Using Extracted Pectin from Dragon Fruit Peel. Malaysian Journal of Analytical Sciences, 17(3), 481–489. https://mjas.analis.com.my/wp-content/uploads/2018/10/17_3_16.html

Basiri, S. 2020. Assessment of Sensory, Texture and Colour Properties of Functional Pastilles Containing Licorice (*Glycyrrhiza glabra* L.). Nutrition and Food Sciences Research, 7(4), 27–32. https://doi.10.29252/nfsr.7.4.27

Blanco-Pérez, F., Steigerwald, H., Schülke, S., Vieths, S., Toda, M., & Scheurer, S. 2021. The Dietary Fiber Pectin: Health Benefits and Potential For The Treatment of Allergies by Modulation of Gut Microbiota. Current Allergy and Asthma Reports, 21(10). https://doi.10.1007/s11882-021-01020-z

Boontongkong, Y., Yaemsiri, J., & Methacanon, P. 2018. Characteristics and Flavour Retention of Structured Emulsion from Pomelo (*Citrus maxima*) Residue. Chiang Mai Journal of Science, 45(2):949-960. https://cmudc.library.cmu.ac.th/frontend/Info/item/dc:48392

Bortnowska, G. 2018. Characteristics of Aroma Compounds and Selected Factors Shaping Their Stability In Food With Reduced Fat Content. Nauki Inżynierskie I Technologie, 3(30), 9–19. https://doi.10.15611/nit.2018.3.01

Chen, J., Luo, W., Cheng, L., Wu, J., Yu, Y., Li, L., & Xu, Y. 2023. Influence of Cultivar and Turbidity on Physicochemical Properties, Functional Characteristics and Volatile Flavour Substances of Pomelo Juices. Foods, 12(5), 1028. https://doi.org/10.3390/foods12051028

Delgado, P., & Bañón, S. 2014. Determining The Minimum Drying Time of Gummy Confections Based on Their Mechanical Properties. Cyta-journal of Food, 13(3), 329–335. https://doi.10.1080/19476337.2014.974676

Din, S., Mubarak, A., Lani, M. N., Yahaya, M., & Abdullah, W. Z. W. 2022. Development of Pastilles From Flesh and Rind of Watermelon. Food Research, 6(3), 288–297. https://doi.10.26656/fr.2017.6(3).248

Efe, N., & Dawson, P. 2022. A Review: Sugar-Based Confectionery and the Importance of Ingredients. European of Agriculture and Food Sciences, 4(5), 1–8. https://doi.10.24018/ejfood.2022.4.5.552

Ergun, R., Lietha, R., & Hartel, R. W. 2010. Moisture and Shelf Life in Sugar Confections. Critical Reviews in Food Science and Nutrition, 50(2), 162–192. https://doi.10.1080/10408390802248833

Essodolom, P., Chantal, B. E., Mélila, M., & Amouzou, K. 2020. Effect Of Temperature On The Degradation of Ascorbic Acid (Vitamin C) Contained in Infant Supplement Flours During The Preparation of Porridges. International Journal of Advanced Research, 8(3), 116–121. https://doi.10.21474/IJAR01/10605

Gous, A. G. S., Almli, V. L., Coetzee, V., & De Kock, H. L. 2019. Effects of Varying The Colour, Aroma, Bitter, and Sweet Levels of A Grapefruit-Like Model Beverage on The Sensory Properties and Liking of The Consumer. Nutrients, 11(2), 464. https://doi.10.3390/nu11020464

Gupta, A., Dhua, S., Sahu, P. P., Abate, G., Mishra, P., & Mastinu, A. 2021. Variation in Phytochemical, Antioxidant and Volatile Composition of Pomelo Fruit (*Citrus grandis* (L.) Osbeck) during Seasonal Growth and Development. Plants, 10(9), 1941. https://doi.10.3390/plants10091941.

Harris, G. K., & Marshall, M. R. 2017. ASH analysis. In Food Science Text Series (pp. 287–297). https://doi.10.1007/978-3-319-45776-5_16

Hashim, N. A., Zin, Z. M., Zamri, A. I., Rusli, N. D., Smedley, K., & Zainol, M. 2021. Physicochemical Properties and Sensory Characteristics of Ciku Fruit (*Manilkara Zapota*) Pastilles. Food Research, 5(2), 164–172. https://doi.10.26656/fr.2017.5(2).510

Hemilä, H. 2017. Vitamin C and Infections. Nutrients, 9(4), 339. https://doi.10.3390/nu9040339

Ismail, B. 2017. ASH content determination. In Food Science Text Series (pp. 117– 119). https://doi.10.1007/978-3-319-44127-6_11

Kareem, M. A. 2020. Experiment-9 Estimation of Vitamin C. In BBCCL-102 Molecules of Life Lab (pp. 64–68). Indira Gandhi National Open University, New Delhi. http://egyankosh.ac.in//handle/123456789/68531

Khan, A. A., Butt, M. S., Randhawa, M. A., Karim, R., Sultan, M. T., & Ahmed, W. 2014. Extraction and Characterization of Pectin From Grapefruit (*Duncan Cultivar*) and Its Utilization as Gelling Agent. International Food Research Journal, 21(6), 2195–2199. http://webagris.upm.edu.my/id/eprint/21923

Kim, A. N., Lee, K. Y., Rahman, M. S., Kim, H. J., Chun, J., Heo, H. J., ... & Choi, S. G. 2020. Effect of Water Blanching on Phenolic Compounds, Antioxidant Activities, Enzyme Inactivation, Microbial Reduction, and Surface Structure of Samnamul (*Aruncus Dioicus* Var Kamtschaticus). International Journal of Food Science and Technology, 55(4), 1754-1762. https://doi.10.1111/ijfs.14424

Kong, T. Y., Hasnan, N. Z. N., A., N. D., I.M., N.-Z., Basha, R. K., Abdul Ghani, N. H., & Aziz, N. A. 2020. Effect of Different Pasteurisation Temperature on Physicochemical Properties, Bioactive Compounds, Antioxidant Activity and Microbiological Qualities of Reconstituted Pomegranate Juice (RPJ). Food Research, 4(S5), 157–164. https://doi.10.26656/fr.2017.4(S6).057

Kusumiyati, K., Hadiwijaya, Y., Putri, I. E., Mubarok, S., & Hamdani, J. S. 2020. Rapid and Non-Destructive Prediction of Total Soluble Solids of Guava Fruits at Various Storage Periods Using Handheld Near-Infrared Instrument. IOP Conference Series: Earth and Environmental Science, 458(1), 012022. https://doi.10.1088/1755-1315/458/1/012022

Kurzyna-Szklarek, M., Cybulska, J & Zdunek, A. 2022. Analysis of The Chemical Composition of Natural Carbohydrates – An Overview of Methods, Food Chemistry, 394, 133466. https://doi.org/10.1016/j.foodchem.2022.133466

Lane, D. J., & Richardson, D. R. 2014. The Active Role of Vitamin C In Mammalian Iron Metabolism: Much More Than Just Enhanced Iron Absorption! Free Radical Biology and Medicine*,* 75, 69-83. https://doi.10.1016/j.freeradbiomed.2014.07.007

Lara-Espinoza, C., Carvajal-Millan, E., Balandrán-Quintana, R. R., López-Franco, Y. L., & Rascón-Chu, A. 2018. Pectin and Pectin-Based Composite Materials: Beyond Food Texture. Molecules, 23(4), 942. https://doi.10.3390/molecules23040942

Lee, S., Choi, Y., Jeong, H. S., & Sung, J. 2017. Effect of Different Cooking Methods on The Content of Vitamins and True Retention in Selected Vegetables. Food Science and Biotechnology. https://doi.10.1007/s10068-017-0281-1

Leong, S. Y., Duque, S. M. M., Abduh, S. B. M., & Oey, I. 2019. Carbohydrates. In Elsevier eBooks (pp. 171–206). https://doi.10.21776/ub.industria.2023.012.02.1

Mohos, F. 2016, Water Activity, Shelf Life and Storage. Confectionery and Chocolate Engineering. John Wiley & Sons, pp 579-603. https://doi.10.1016/B978-0-12-814174-8.00006-8

Mudgil, D. 2017. The Interaction Between Insoluble and Soluble Fiber. In Elsevier eBooks (pp. 35–59). https://doi.10.1016/B978-0-12-805130-6.00003-3

Ng, A. Q., Noor Hasnan, N. Z., Kadir Basha, R., Alyas, N. D., & Mohd Zulkifli, N. I. 2022. Physicochemical Properties, Bioactive Compounds Degradation Kinetics, and Microbiological Counts of Fortified Pomegranate Gummy Candy (GC) during Ambient Storage. Jurnal Teknologi Dan Manajemen Agroindustri, 12(2), 103–117. https://doi.10.21776/ub.industria.2023.012.02.1

Pichaiyongvongdee, S., & Rattanapun, B. 2015. Effect of Chemical Treatments to Reduce the Bitterness and Drying on Chemical Physical and Functional Properties of Dietary Fiber Pomelo Powder from *Citrus grandis* (L.) Osbeck Albedo. Agriculture and Natural Resources, 49(1), 122–132. https://li01.tci-thaijo.org/index.php/anres/article/view/243524

Poçan, P., Grunin, L., & Öztop, M. H. 2022. Effect of Different Syrup Types on Turkish Delights (Lokum): A TD-NMR Relaxometry Study. ACS Food Science & Technology, 2(12), 1819–1831. https://doi.10.1021/acsfoodscitech.2c00222

Pullar, J. M., Carr, A. C., & Vissers, M. C. 2017. The Roles of Vitamin C in Skin Health. Nutrients, 9(8), 866. https://doi.10.3390/nu9080866

Rahman, M. S., Khan, S., Ahmed, M. W., Jony, M. E., Das, P. C., & Uddin, M. J. 2023. Extraction of Pectin From Elephant Apple and Pomelo Fruit Peels: Valorisation of Fruit Waste Towards Circular Economy. Food Chemistry Advances, 3, 100544. https://doi.10.1016/j.focha.2023.100544

Rahman, N. F. A., Shamsudin, R., Ismail, A., Shah, N. N. a. K., & Varith, J. 2019. Physicochemical Properties of Pomelo (*Citrus grandis* L. Osbeck) Byproducts. Konvensyen Kebangsaan Kejuruteraan Pertanian Dan Makanan, 126–129. https://doi.10.1016/j.focha.2023.100544

Ross, A., & Willson, V. L. 2017. Basic and Advanced Statistical Tests. In SensePublishers eBooks (1st ed., Vol. 5). SensePublishers Rotterdam. https://doi.10.1007/978-94-6351-086-8

Said, N. S., Olawuyi, I. F., & Lee, W. Y. 2023. Pectin Hydrogels: Gel-Forming Behaviors, Mechanisms, and food Applications. Gels, 9(9), 732. https://doi.10.3390/gels9090732

Sowmya, A., & Lakshmi, M. B. 2023. Value-addition of Pummelo (*Citrus grandis*) Peel- A Review. Pharma Innovation, 12(2), 40–45. https://doi.10.22271/tpi.2023.v12.i2a.18645

Suklampoo, L., Thawai, C., Weethong, R., Champathong, W., & Wongwongsee, W. 2014. Antimicrobial Activities of Crude Extracts from Pomelo Peel of Khao-nahm-peung and Khao-paen Varieties. KMITL-Science and Technology Journal, 12(1). https://li01.tci-thaijo.org/index.php/cast/article/view/136380

Sumonsiri, N., Phalaithong, P., Mukprasirt, A., & Jumnongpon, R. 2021. Value Added Gummy Jelly from Palmyra Palm (*Borassus flabellifer* Linn.). E3S Web of Conferences, 302, 02002. https://doi.10.1051/e3sconf/202130202002

Teixeira-Lemos, E., Almeida, A. M., Vouga, B., Morais, C. I. M., Correia, I., Pereira, P., & Guiné, R. 2021. Development and Characterization of Healthy Gummy Jellies Containing Natural Fruits. Open Agriculture, 6(1), 466–478. https://doi.10.1515/opag-2021-0029

Tien, N. N. T., Le, N. L., Khôi, T. T., & Richel, A. 2022. Characterisation of Dragon Fruit Peel Pectin Extracted With Natural Deep Eutectic Solvent and Sequential Microwave-Ultrasound-Assisted Approach. International Journal of Food Science & Technology, 57(6), 3735–3749. https://doi.10.1111/ijfs.15699

Tua, S. M., Sitohang, A., Restuana, S. D., Rosa, T., Pandiangan, M., Sibuea, P., Panjaitan, D., Sisilia, Y., & Oktavia, T. D. 2018. Effect of Citric Acid and Sucrose Concentration on The Quality of Passion Fruit Jelly With Dutch Eggplant. IOP Conference Series: Earth and Environmental Science, 205, 012050. https://doi.10.1088/1755-1315/205/1/012050

Wang, X., Xu, R., Wang, Y., Ma, L., Nie, S., Xie, M., & Yin, J. 2020. Physicochemical and Rheological Properties of Pomelo Albedo Pectin and Its Interaction With Konjac Glucomannan. International Journal of Biological Macromolecules, 151, 1205–1212. https://doi.10.1016/j.ijbiomac.2019.10.167

Wanjiru M., J. 2018. Analysis of The Factors That Determine Food Acceptability. The Pharma Innovation Journal, 7(5), 253–257. https://doi.10.1088/1755-1315/205/1/012050

Wichchukit, S., & O'Mahony, M. 2015. The 9-Point Hedonic Scale and Hedonic Ranking In Food Science: Some Reappraisals and Alternatives. Journal of the Science of Food and Agriculture, 95(11), 2167–2178. https://doi.10.1002/jsfa.6993

Zain, N. R. M., Yusop, S. M., & Ahmad, I. 2014. Preparation and Characterization of Cellulose and Nanocellulose from Pomelo (*Citrus grandis*) Albedo. Journal of Nutrition and Food Sciences, 05(01). https://doi.10.4172/2155-9600.1000334

Zainol, M., Che-Esa, N., Azlin-Hasim, S., Zamri, A. I., Zin, Z. M., & Majid, H. M. A. 2019. The Ramification of Arabic Gum and Gelatine Incorporation on The Physicochemical Properties of Belimbing Buluh (Averhoa *belimbi*) Fruits Pastilles. Food Research, 4(2), 532–538. https://doi.10.26656/fr.2017.4(2).319

Zhang, L., Sun, D.-W. and Zhang, Z. 2015. Methods for Measuring Water Activity (Aw) of Foods And Its Applications to Moisture Sorption Isotherm Studies. Critical Reviews in Food Science and Nutrition, 57(5), 1052–1058. https://doi.10.1080/10408398.2015.1108282

Zion Market Research 2023. Candy Market Size, Share, Growth Report 2030. In Zion Market Research (ZMR-7168). Retrieved June 3, 2023, from https://www.zionmarketresearch.com/report/candy-market