Evaluation of Physicochemical Characteristics and Sensory Qualities of Fruit Roll Ups Made from Watermelon

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ABSTRACT

Watermelon biomass can be categorised into flesh, seed, and rind. Although discarded, the rind is edible and nutritious.

Objective: The study aimed to optimise watermelon fruit rolls-up formulation combining the flesh and rind purees. F1 (80:0), F2 (70:10), F3 (60:20), F4 (50:30), F5 (40:40), F6 (30:50), and F7 (20:60) were formulated from watermelon flesh-to-rind purees.

Methodology: Samples were prepared by pasteurising the watermelon flesh and rind purees with a predetermined amount of ingredients at 90 °C for 5 min, then dried at 60°C for 11 hours, cut, rolled and packed in an aluminium polyethene bag until evaluation.

Results: There were significant differences in pH, total soluble solids (TSS), moisture content (MC), water activity (A_w) and thickness of the samples. It showed that the increase of watermelon flesh puree in the formulations reduced the pH value and thickness of the samples. By contrast, the increase in watermelon rind puree decreases the samples' TSS, MC and A_w values. For sensory acceptance, the F2 sample had the highest mean scores for colour, texture (chewiness), sweetness, sourness and overall acceptability, indicating it was the most preferred formulation among panellists.

Conclusion: Thus, watermelon rind may be employed in watermelon fruit roll-up formulations to improve their physicochemical and sensory properties.

Keywords: Watermelon; fruit roll-up; physicochemical; sensory

1. INTRODUCTION

Watermelon (*Citrullus lanatus*) is a tropical fruit commonly grown in various regions across Africa and Southeast Asia [1] It is known for its high nutritional content, rich in vitamins C, A, B, amino acids, and lycopene, which contribute to overall health benefits, including enhanced immune function and improved skin health [2]. Watermelon biomass can be divided into three main components: the flesh, seeds, and rind. The flesh constitutes approximately 68% of the total weight, the rind makes up about 30%, and the seeds account for roughly 2% [3]. While the flesh is often consumed fresh or processed into juice, the rind, although edible, is usually discarded due to its bland and undesirable taste [4]. However, this part of the fruit contains important nutrients such as potassium, dietary fibre, and citrulline—an amino acid that promotes healthy blood circulation and helps relax blood vessels. This is particularly beneficial for heart health and may aid in preventing cardiovascular diseases. Research indicates that watermelon is particularly high in citrulline, with the rind containing more (24.7 mg/g) than the flesh (16.7 mg/g), based on dry weight [5].

In addition to these benefits, watermelon is also rich in antioxidants like lycopene and beta-carotene, which play a role in reducing oxidative stress and inflammation. This contributes to a lower risk of chronic diseases, including cancer and diabetes [6]. Despite these advantages, a significant portion of the fruit—especially the rind—is often underutilised, leading to food waste and a missed opportunity for creating value-added products. Given its high-water content (approximately 95%), watermelon is susceptible to spoilage, which limits its shelf life and makes it challenging to store and transport over time [7]. Therefore, reducing its moisture content to produce shelf-stable products, such as fruit roll-ups, is essential. Fruit roll-ups, or fruit leathers, are dried sheets of fruit puree known for their soft, chewy texture and sweet flavour [8][9]. They can be made from single fruits or a mixture of different fruits and are a popular snack choice among health-conscious consumers. These roll-ups are nutritious, naturally low in fat, and high in fibre and carbohydrates, making them an ideal snack for both children and adults. Their lightweight, compact nature makes them easy to store and carry, providing convenience for those with busy lifestyles [8][10].

Furthermore, fruit roll-ups represent an economical and convenient alternative to fresh fruits, especially in areas where access to fresh produce may be limited or seasonal [11]. They not only preserve the nutritional quality of the fruit but also add value to agricultural by-products like watermelon rind, which might otherwise be discarded. This aligns with the increasing focus on reducing food waste and developing sustainable snacks, making fruit roll-ups a timely product in today's market. In terms of consumer acceptance, fruit roll-ups are both healthy and well-received for their taste and texture. The production process involves dehydrating fruit puree into a flexible, rollable sheet. Typically, fruit pulps are combined with sugar, pectin, acid, and colouring before drying. The addition of sugar enhances the sweetness and boosts the solids content, while pectin thickens the puree, provides a desirable texture, and helps maintain the product's shape [8].

By incorporating both the flesh and rind of watermelon, this product can further enhance its nutritional profile, as the rind is rich in fibre. This study aims to develop a watermelon fruit roll-up that combines both watermelon flesh and rind to create a nutritious, shelf-stable snack. By doing so, it introduces a novel product to the market while promoting the sustainable use of agricultural resources, thus contributing to a reduction in food waste and encouraging healthier consumption habits.

2. MATERIAL AND METHODS

2.1 Preparation of watermelon fruit roll-up

Watermelons were purchased from Pasar Borong Selangor, Seri Kembangan, Selangor, Malaysia. Watermelons were washed thoroughly, and the outer green rind was peeled. The red flesh and rind were segregated. Then, the flesh and rind were blended until they became slurry-like purees. The flesh and rind puree were stored in the aluminium polyethene bags at freezing temperature (-18°C) until further use. Seven formulations of watermelon fruit roll-up were developed based on the proportion of watermelon flesh and rind purees, respectively: F1 (80:0), F2 (70:10), F3 (60:20), F4 (50:30), F5 (40:40), F6 (30:50), and F7 (20:60) (Table 1). Samples were prepared by pasteurising the watermelon flesh and rind purees with a predetermined amount of ingredients, namely sugar, glucose syrup, maltodextrin, citric acid, vegetable oil, pectin, water, flavour and potassium sorbates at 90 °C for 5 min, then dried at 60°C for 11 hours, cut, rolled and packed in an aluminium polyethene bag until evaluation.

Table 1. Formulations of watermelon roll-up

Sample	Flesh puree (%)	Rind puree (%)	Other ingredients (%)
F1	80	0	20
F2	70	10	20
F3	60	20	20
F4	50	30	20
F5	40	40	20
F6	30	50	20
F7	20	60	20

2.2 Determination of total soluble solids and pH

The total soluble solid (TSS) contents were measured using a pocket refractometer (Atago, Tokyo, Japan) with a scale of 0–53°Brix. The pH of the samples was measured using a pH meter (FE20, Mettler Toledo, Switzerland).

2.3 Determination of moisture content

The moisture content was determined using the air oven method. The samples were dried in the oven at 105 °C for 24 h. The moisture content was calculated from the weight difference between the original and dried sample and expressed in percentage. The observation was done in duplicates for each sample and the average was reported.

2.4 Determination of water activity

The water activity (Aw) of fruit-roll samples was determined using a Labswift-aw hygrometer (Novasina, Switzerland). The ~~dehydrated candies~~ watermelon fruit-roll samples were cut into small pieces, loaded into a sample dish, and put in the measurement chamber. The equilibrium of the air humidity over a sample (water-vapour pressure), which is proportional to the Aw value, was measured. For each sample, duplicates were obtained and the mean was reported.

2.5 Determination of colour intensity

The colour intensity of the fruit-roll samples was measured using Chroma Meter Minolta CR-400/410 (Minolta Co., Osaka, Japan) based on *L* a* b** colour system. *L** denotes the lightness on a 0 – 100 scale from black to white, while *a** and *b** denote the redness (+) or greenness (–) and yellowness (+) or blueness (–) hues, respectively.

2.6 Determination of thickness

Fruit-roll sample thickness was determined using a digital micrometre (Mitutoyo, Japan). Five readings were taken randomly and averaged.

2.7 Sensory acceptability test

The sensory evaluation was carried out at the Food Science and Technology Research Centre, MARDI Serdang Selangor, Malaysia by 40 untrained panellists. Sensory attributes were evaluated according to the degree of liking in sweetness, sourness, taste, colour and overall acceptability. All samples were served and coded with random three-digit numbers. The sensory attributes of the samples were evaluated using a 7-point category hedonic scale (1 = dislike very much; 4 = neither like nor dislike; 7 = like very much) as described by

Meilgaard *et al*. [13]. Samples with the mean scores of more than 5.00 for overall acceptability were considered acceptable.

2.8 Statistical analysis

All analyses were done in triplicate. Experimental data were subjected to the analysis of variance (ANOVA), and the significant differences among means were determined by the Least Significant Difference (LSD) at $p \leq 0.05$ using SAS software (Ver. 9.4., SAS Institute, Cary, NC, USA).

3. RESULTS AND DISCUSSION

3.1 Total soluble solid and pH

Significant differences were observed in the total soluble solids (TSS) content of the various watermelon roll-up formulations, as indicated in Table 2. Among the seven formulations tested, F1 exhibited the highest TSS value at 10.60 ± 0.17 °Brix, while F7 recorded the lowest at 8.13 ± 0.06 °Brix. This finding suggests that F1, with its specific ingredient composition, contributed to a higher concentration of sugars and soluble solids, which are key factors in determining the sweetness and overall quality of the product. The data further demonstrated a significant increase in TSS values in formulations containing a higher proportion of watermelon flesh puree. This could be attributed to the naturally higher sugar content present in the watermelon flesh, which is reflected by its TSS value of 5.10 ± 0.01 compared to the rind puree, which showed a slightly lower TSS of 5.27 ± 0.01 (Table 3). The flesh of the watermelon, being richer in sugars and flavour compounds, contributes more significantly to the sweetness and overall acceptability of the final product.

In terms of pH, the formulated watermelon roll-ups displayed values ranging between 3.41 and 4.01, categorising them as high-acid foods (pH < 4.6), according to the classification by Babajide et al. [14]. High-acid foods are known for their resistance to microbial spoilage, which enhances the shelf stability of the product, making it less prone to bacterial growth and deterioration. This property is particularly beneficial for fruit-based products like roll-ups, which are intended for long-term storage and consumption.

Table 2 further highlights significant differences in the pH levels across the different formulations. F1 was found to have the lowest pH at 3.41 ± 0.01, while F7 had the highest pH at 4.01 ± 0.01. The pH values of the samples decreased notably in formulations with a higher ratio of watermelon flesh puree. This result can be explained by the lower intrinsic pH of watermelon flesh puree (5.10 ± 0.01) compared to that of the rind puree (5.27 ± 0.01), as shown in Table 3. The acidic nature of the flesh puree, combined with its higher sugar content, not only affects the product's flavour profile but also plays a crucial role in the preservation and safety of the roll-up. The increased acidity may contribute to a sharper, more tangy taste, which could be a desirable characteristic for consumers seeking a balance between sweetness and sourness.

Table 2. Physicochemical properties of watermelon rolls-up formulations

Sample	pH	TSS (°brix)	MC (%)	A_W	Thickness (mm)
F1	3.41 ± 0.01d	10.60 ± 0.17a	16.90 ± 0.16c	0.54 ± 0.01e	0.58 ± 0.01e
F2	3.78 ± 0.01c	8.57 ± 0.23b	16.23 ± 0.06d	0.57 ± 0.01d	0.99 ± 0.09b
F3	3.83 ± 0.06c	8.70 ± 0.01b	21.63 ± 0.12a	0.67 ± 0.00a	0.70 ± 0.05d
F4	3.79 ± 0.04c	8.53 ± 1.27b	18.44 ± 0.49b	0.61 ± 0.01b	0.88 ± 0.05c
F5	4.00 ± 0.01a	8.77 ± 0.12b	14.67 ± 0.20e	0.53 ± 0.01e	0.95 ± 0.03b
F6	3.90 ± 0.01b	8.23 ± 1.79b	15.94 ± 0.20d	0.59 ± 0.01c	1.09 ± 0.08a
F7	4.01 ± 0.01a	8.13 ± 0.06b	12.90 ± 0.15f	0.52 ± 0.00f	1.06 ± 0.04a

Table 3. Physicochemical properties of watermelon flesh and rind purees

Sample	pH	TSS (°brix)	*L** (lightness)	*a** (redness)	*b** (yellowness)
Flesh puree	5.10 ± 0.01b	8.80 ± 0.01a	14.61 ± 0.07	6.91 ± 0.06	5.10 ± 0.05
Rind puree	5.27 ± 0.01a	4.40 ± 0.01b	22.69 ± 1.10	-0.88 ± 0.09	5.10 ± 0.41

3.2 Moisture content and water activity

Drying is a crucial process in the production of fruit roll-ups, as it involves the removal of moisture from the fruit mixture. High moisture content can lead to increased microbial activity, resulting in spoilage of the product. According to the Food and Agriculture Organization [15], the optimal moisture content for fruit leather or fruit roll-ups should fall within the range of 15-25%. Maintaining moisture levels within this range is essential for ensuring the product can be stored for extended periods without deterioration caused by microorganisms.

In the current study, significant variations were observed in the moisture content of the watermelon fruit roll-up samples, with values ranging from 12.90% to 21.63% (refer to Table 2). Notably, the F7 sample exhibited the lowest moisture content, while the F3 sample had the highest moisture content after being dried for 11 hours in the cabinet dryer. It was evident that the moisture content of the samples decreased as the proportion of rind puree increased in the formulations. This may be attributed to the fact that watermelon rind puree contains a greater amount of pulp compared to flesh puree, thereby facilitating a more efficient drying process. The fibrous nature of the rind may enhance moisture removal during drying, contributing to a more stable product.

Another important factor to consider in the preservation of fruit roll-ups is water activity (Aw), which measures the amount of free water available in food materials that microorganisms can utilise for their growth. A decrease in water activity is typically associated with a reduction in moisture content, indicating less free water available for microbial activity [16]. In this study, significant differences in the water activity of the samples were noted, with values ranging from

0.52 to 0.67. The F7 sample recorded the lowest Aw value, whereas the F3 sample displayed the highest Aw value (see Table 2).

According to Jangam et al. [17], food items with water activity levels between 0.4 and 0.6 are classified as dry products, while those with water activity levels ranging from 0.65 to 0.75 are considered intermediate moisture-content foods (IMF). All samples in this study were within the IMF range since their Aw values were below 0.75. Reducing water activity not only enhances the stability of the food product but also improves its safety by minimising the potential for microbial growth. Consequently, achieving optimal moisture content and water activity levels is critical for the shelf life and overall quality of the watermelon fruit roll-ups, ensuring they remain safe and enjoyable for consumers.

3.3 Thickness

There were notable differences in the thickness of the watermelon roll-up samples after the drying process. The thickness measurements varied between 0.58 mm and 1.06 mm, as illustrated in Table 2. The results indicate that both watermelon flesh and rind purees significantly influenced the thickness of the samples in the formulations. Specifically, an increase in the proportion of rind puree within the formulations led to a corresponding increase in the thickness of the samples after drying. Conversely, a higher ratio of flesh puree resulted in thinner samples.

This variation in thickness can be attributed to the composition of the purees. Watermelon rind puree tends to contain more pulp compared to the flesh puree, which is typically more watery due to its higher juice content. The pulp from the rind not only adds body to the roll-up but also affects its overall texture and thickness. As the rind puree contributes a denser, more fibrous structure, it allows for a thicker product after the moisture has been removed. Additionally, the thickness of the roll-ups may have implications for consumer perception and acceptance. Thicker roll-ups could be perceived as more substantial and satisfying, potentially enhancing the overall eating experience. On the other hand, thinner roll-ups may be viewed as less desirable if they lack the expected chewiness and texture associated with fruit leathers.

Furthermore, the thickness may also impact the drying time and efficiency during production. Thicker samples could require longer drying periods to ensure that adequate moisture is removed, which might affect the production schedule and increase energy costs. The interaction between the flesh and rind purees is crucial in determining the final texture of the watermelon roll-ups, as it influences their sensory qualities and consumer acceptance.

3.4 Colour intensity

Colour is an essential aspect of product presentation, significantly influencing consumers' acceptance and preference for food products [18]. In this study, notable differences were observed among the roll-up samples in terms of their *L**, *a**, and *b** values, as indicated in Table 4. Specifically, the F7 sample demonstrated the highest *L** value (reflecting lightness), the highest *b** value (indicating yellowness), and the lowest *a** value (indicating redness) in comparison to the other samples.

The increase in *L** and *b** values, coupled with the decrease in *a** value, was attributed to the higher proportion of watermelon rind puree in the formulations. This is because the rind puree possesses a higher *L** value and a lower *a** value than the flesh puree, as illustrated in Table 3. The implications of these findings suggest that by increasing the concentration of rind puree, the resulting watermelon roll-ups exhibit a lighter colour, reduced redness, and enhanced yellowness.

Table 4. Colour intensity of watermelon rolls-up formulations

Sample	*L** (lightness)	*a** (redness)	*b** (yellowness)
F1	31.86 ± 0.04d	6.19 ± 0.04b	8.92 ± 0.02e
F2	31.12 ± 0.62d	5.99 ± 0.22b	10.24 ± 0.42d
F3	33.48 ± 1.49c	8.41 ± 1.18a	12.23 ± 1.30c
F4	33.19 ± 0.88c	3.24 ± 0.13c	16.81 ± 1.52a
F5	25.23 ± 0.51e	3.42 ± 0.05c	9.14 ± 0.12de
F6	38.96 ± 1.20b	8.04 ± 0.34a	15.55 ± 0.92b
F7	43.77 ± 0.30a	3.19 ± 0.05c	17.50 ± 0.06a

3.5 Sensory acceptance

The mean scores assigned by the panellists for the sensory attributes of the watermelon roll-up samples are summarised in Table 5. Significant differences were evident across all assessed attributes, including colour, aroma, texture (chewiness), sweetness, sourness, and overall acceptance. Notably, the F6 sample received the lowest mean scores for nearly all attributes, which indicates a lack of preference among panellists and suggests potential areas for improvement in its formulation.

In contrast, the F2 sample stood out as the most preferred formulation, achieving significantly higher scores for colour (6.37), texture (5.74), sweetness (5.86), sourness (5.57), and overall acceptability (5.80) compared to the other samples. These results reflect the panellists' favourable perception of F2, highlighting its balanced flavour profile and appealing texture, which are crucial for consumer satisfaction. A minimum sensory score of 5.0 for all attributes is considered essential for establishing an acceptable formulation of the watermelon roll-up, indicating that products meeting this threshold are likely to be well-received in the market. Given that the F2 formulation surpassed this benchmark in all categories, it was obviously chosen as the best formulation for watermelon roll-up.

Table 5. Mean score for colour, aroma, texture, sweetness, sourness and overall acceptability of watermelon roll-up formulations

Sample	Colour	Aroma	Texture	Sweetness	Sourness	Overall acceptance
F1	6.09 ± 1.29a	5.43 ± 1.20a	5.06 ± 1.33b	5.74 ± 1.09ab	5.57 ± 1.29ab	5.54 ± 1.15ab
F2	6.37 ± 0.88a	5.37 ± 1.35a	5.74 ± 1.34a	5.86 ± 1.24a	5.77 ± 1.14a	5.80 ± 1.13a
F3	5.91 ± 1.42a	5.37 ± 1.19a	5.80 ± 1.13a	5.77 ± 0.97ab	5.54 ± 1.12ab	5.77 ± 1.06ab
F4	5.91 ± 0.92a	5.14 ± 1.31ab	5.06 ±1.11b	5.37 ± 1.11ab	5.26 ± 1.17ab	5.23 ± 1.06bc
F5	4.77 ± 1.14b	5.03 ±1.01ab	5.34 ± 1.08ab	5.46 ± 1.01ab	5.23 ± 1.19ab	5.23 ± 1.00bc
F6	4.57 ± 1.36b	4.66 ± 1.33b	4.20 ± 1.51c	4.69 ± 1.39c	4.43 ± 1.44c	4.51 ± 1.44d
F7	4.23 ± 1.46b	4.60 ± 1.31b	4.77 ± 1.37bc	5.29 ± 1.18b	5.00 ± 1.14cb	4.94 ± 1.21cd

4. CONCLUSION

The physicochemical properties and sensory evaluation of watermelon roll-ups made from combinations of flesh and rind purees were assessed. The results indicated that varying the ratios of flesh and rind purees in the formulations significantly influenced the total soluble solids, pH, moisture content, water activity, colour intensity, and sensory acceptance of the samples. Increasing the flesh puree in the formulations notably lowered the pH and reduced the thickness of the samples after drying. Conversely, higher proportions of rind puree led to a significant reduction in total soluble solids, moisture content, and water activity. Panellists rated the F2 formulation highest for sensory acceptance, receiving the highest mean scores across all evaluated attributes compared to the other samples. Therefore, it can be concluded that the F2 formulation was the best option for producing watermelon roll-ups.

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