

WATERMELON RIND TUTTI FRUTTI: A STEP TOWARDS ZERO-WASTE FOOD PROCESSING

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ABSTRACT

Watermelon rind, often discarded as waste, possesses significant nutritional and functional properties; this study explores the utilization of watermelon rind in the preparation of tutti frutti candy through osmotic dehydration, aiming to enhance sustainability in food processing. The process involves initial peeling, cuboid cutting, and treating the rind with a hypertonic solution, followed by steam blanching. Over three days, the rind is infused with sugar, citric acid, and sodium benzoate to improve flavor and preservation. After attaining the desired Total Soluble Solids (TSS) levels, the rind undergoes tray drying and is subsequently packaged. A comprehensive biochemical analysis was conducted, including ascorbic acid retention, moisture content, total soluble solids (TSS), and color value, to evaluate the nutritional quality of the final product. Microbial analysis ensured product safety, while sensory evaluation using a trained panel confirmed the candy's aroma, taste, texture, and overall acceptability. Response Surface Methodology (RSM) was applied to optimize processing parameters to determine the influence of blanching time, sugar concentration, and drying temperature on ascorbic acid retention and TSS. The quadratic model developed using RSM exhibited high predictive accuracy (Adjusted $R^2 = 0.9943$ for ascorbic acid retention and 0.9911 for TSS). Results indicated that higher blanching times and drying temperatures negatively impacted ascorbic acid retention. At the same time, sugar concentration played a dual role—enhancing TSS but contributing to some nutrient degradation at extreme levels. The optimized conditions for maximum ascorbic acid retention while preserving TSS were blanching for 10–15 minutes, sugar concentration at 75–80°Brix, and drying at 40–50°C. This study highlights the potential of watermelon rind as a functional ingredient in confectionery while employing scientific optimization techniques to enhance product quality and sustainability. The findings provide valuable insights for food industries looking to develop innovative, value-added products from agricultural waste.

Keywords: Watermelon Rind; Tutti frutti; Optimization; value-added product; fruit waste reuse

INTRODUCTION

Food waste is a growing global concern, posing significant environmental, economic, and social challenges. Among various strategies to tackle this issue, utilizing agricultural byproducts offers a sustainable approach to reduce waste and create value-added food products. One such underutilized byproduct is watermelon rind, which constitutes nearly one-third of the total fruit weight. Despite its rich nutritional composition — including carbohydrates, proteins, fibers, and essential minerals — watermelon rind is commonly discarded, leading to waste management issues and the loss of potentially valuable raw material for the food industry. Valorizing watermelon rind through innovative food processing can contribute significantly to sustainability efforts. Various studies have highlighted its potential in different food applications due to its bioactive compounds and functional properties (Raṭu *et al.*, 2023; Kumar Gupta *et al.*, 2024; Danya *et al.*, 2024; Kolawole *et al.*, 2024). However, large-scale adoption remains limited due to the lack of standardized processing techniques and product development approaches.

Tutti frutti, a popular candied fruit product, is traditionally prepared by osmotic dehydration (OD), a method where fruit or vegetable pieces are immersed in a hypertonic sugar solution. This process promotes controlled moisture removal and sugar infusion, improving shelf stability, texture, and flavor (Yadav and Singh, 2014). Using watermelon rind as a raw material for tutti frutti production presents an opportunity to convert waste into a high-value confectionery product while addressing environmental and economic sustainability (Wanapat *et al.*, 2024). Nevertheless, producing high-quality watermelon rind tutti frutti poses challenges in maintaining desirable texture, taste, and color throughout processing. Factors such as blanching time, sugar concentration, and drying temperature significantly affect the product's nutritional and sensory qualities. Improper control of these parameters can lead to nutrient loss, undesirable texture, and color degradation, limiting consumer acceptance (Dermesonlouglou *et al.*, 2020; Dubey *et al.*, 2023; Shourove *et al.*, 2025).

To address these challenges, advanced process optimization techniques like Response Surface Methodology (RSM) can be employed. RSM is a powerful statistical tool for modeling and analyzing problems where multiple variables influence the desired response. It enables researchers to evaluate interaction effects among variables and determine optimal conditions with fewer experimental trials compared to traditional methods (Cano-Lamadrid *et al.*, 2023; Vijayan *et al.*, 2024; Hasan *et al.*, 2024). In the context of watermelon rind tutti frutti, RSM helps identify the best combination of blanching time, sugar concentration, and drying temperature to maximize nutrient retention — particularly ascorbic acid — while achieving desirable Total Soluble Solids (TSS) and favorable sensory attributes. The present study was undertaken to develop a standardized and optimized process for producing watermelon rind tutti frutti using osmotic dehydration. Specifically, the objectives were to: (i) investigate the effect of key processing parameters on ascorbic acid retention and TSS, (ii) apply RSM to optimize these parameters for maximum nutritional and sensory quality, and (iii) evaluate the final product's biochemical, microbial, and sensory properties to ensure safety and consumer acceptability. By transforming watermelon rind — an often-discarded byproduct — into a commercially viable confectionery product, this research contributes to sustainable food processing and waste reduction, aligning with global circular economy principles. The findings aim to provide food industries and policymakers with practical insights for upscaling such zero-waste approaches and developing new, eco-friendly food innovations.

MATERIALS AND METHODS

Raw Material Description

Watermelon rind, the firm, and thick green outer layer, is often discarded despite its nutritional and culinary potential. The outermost surface of the rind is a dark green, often with lighter green stripes or patterns, and is smooth and tough. Beneath this lies a white or pale green layer that is crispier and less sweet than the red or

pink flesh of the fruit. Nutritionally, the rind is low in calories and rich in vitamins A, B6, and C and minerals like potassium, magnesium, and zinc. It also contains citrulline, an amino acid that improves blood flow and reduces muscle fatigue. The rind can be used in various culinary applications, such as pickling, stir-fries, salads, and smoothies, offering a crunchy texture and subtle flavor. Its high water and fiber content also contribute to hydration and digestive health. Utilizing watermelon rind in cooking enhances dietary diversity and promotes sustainability by reducing food waste. So, the watermelon rind is dehydrated and sold as tutti fruttii, a value-added product to watermelon waste. By doing so, the product's shelf life can be increased and used throughout the year, reducing food wastage (Rezagholizade-Shirvan et al., 2023; Du and Ramirez, 2022). Figure 1 shows the Sequential processing stages for the preparation of watermelon rind tutti fruttii.

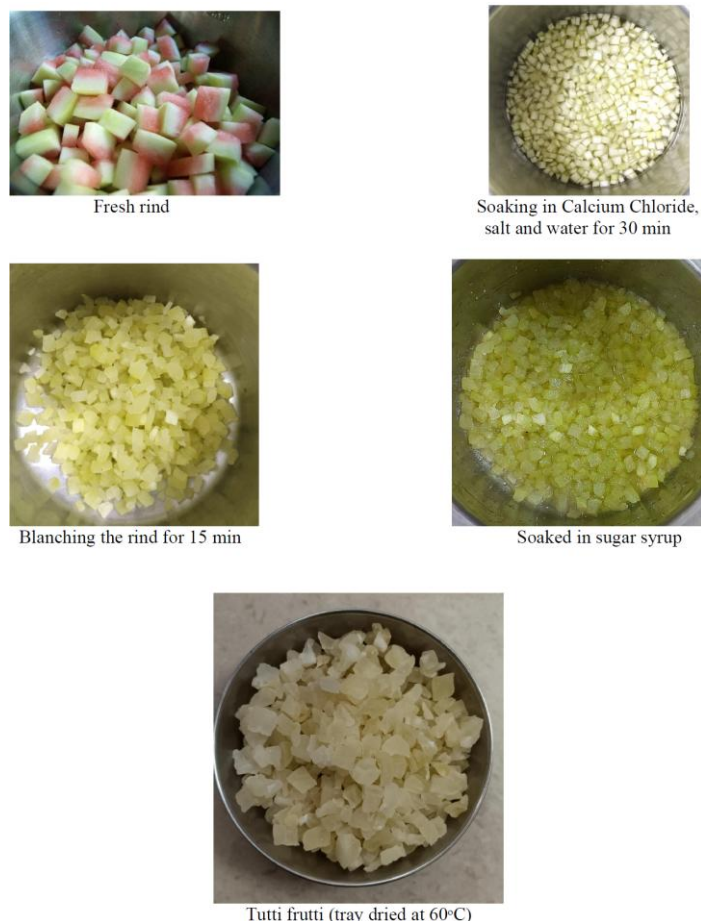


Figure 1 Sequential processing stages for the preparation of watermelon rind tutti fruttii

Design of Watermelon peeler

The Watermelon Automatic Peeler is a device engineered to streamline the peeling process of melons, including watermelons, pumpkins, and other cucurbits. The primary characteristic of the Cucurbit Peel is its exceptional strength and durability in peeling hard and thick-skinned fruits or vegetables. The Watermelon/Pumpkin Automatic Peeler expedites peeling, enhancing production efficiency (Tlevlessova et al., 2022).

The automatic watermelon peeler first transports watermelons to the peeling section using a feeding mechanism, such as a conveyor belt. Once positioned, the watermelon is secured by clamps or a vacuum system. Sensors, typically optical, ultrasonic, or laser-based, detect the watermelon's size, shape, and position, sending this data to a central control system. This control system calibrates the peeling mechanism, which consists of precision blades, knives, or rotating peeling heads to match the watermelon's contours. The blades then move around the surface of the watermelon, efficiently separating the rind from the flesh. The removed rind is collected and carried to the cutting section through the conveyor belt or suction mechanism. Safety features, including emergency stop buttons and protective covers, ensure safe operation. Finally, the peeled watermelon is released and transported out of the machine, ready for further processing or packaging (Schmilovitch et al., 2015).

The rind of the watermelon was collected and washed, and the outer green skin was peeled. The white peeled rind was cut into cuboids. Then, watermelon rind cuboids were soaked in water, rock salt, and calcium chlorite for 30 min. Then, drain the water out and steam blanch it for 15 min until the rind becomes glossy. The amount of sugar to be added equals the quantity of rind used. This total sugar amount is divided and added for three days. Citric acid and a pinch of sodium

benzoate are added on the first day of soaking. On the second day of soaking, the sugar designated for the second day is added to the sugar syrup obtained from the first day. This mixture is then heated and poured over the rind. The same is repeated on the third day. Then, the syrup is drained out, and the soaked rind is separated. The separated rind is then dried in a tray dryer at 60°C for 1hr. Then, the obtained final product is packaged in PET bottles. Principle steps used for tutti fruttii preparation are illustrated below (Chethan et al., 2018).

Biochemical Analysis

Estimation of Ascorbic Acid

Fruits and vegetables are significant sources of ascorbic acid. The most reliable chemical estimate methods involve reducing 2, 6-dichlorophenol indophenols by ascorbic acid and reducing dehydroascorbic acid using 2, 4-dinitrophenyl hydrazine. 10 g or ml of the sample is combined with a 4% oxalic acid solution and diluted to a final volume of 100 ml. Five milliliters of the sample were titrated against the dye (Eq. 1) (Sadasivam and Balasubramanian, 1987; Raman et al., 2023).

$$\text{Ascorbic acid} \left(\frac{\text{mg}}{100 \text{ g sample}} \right) = \frac{\text{Titre value (mL)} \times \text{Dye factor} \times \text{Volume made up (mL)}}{\text{Aliquot taken (mL)} \times \text{Weight/Volume of sample taken (mL)}} \times 100 \quad (\text{Eq.1})$$

Moisture Content (AOAC)

Moisture content is the percentage ratio of the mass of water in the pore spaces of soil to the solid mass of the particles in that substance. The sample was dried in an oven at 105°C for 3 hours and then transferred to a desiccator to cool (Eq.2) (Minor et al., 1984; Ahn et al., 2014).

$$\text{Moisture (\%)} = \frac{[W1 - W2]}{W1} \times 100 \quad (\text{Eq. 2})$$

W1 = weight (g) of the sample before drying, and W2 = weight (g) after drying.

Total Soluble Solids

Total soluble solids (TSS) refer to the concentration of dissolved substances in a liquid, commonly measured in degrees Brix (°Bx), where 1°Bx represents 1 gram of sucrose per 100 grams of solution. This metric is vital in the food and beverage industry, especially for assessing the quality and ripeness of fruits, juices, wines, and other beverages. TSS is measured using tools like refractometers, which evaluate the refractive index of a solution, or hydrometers, which determine specific gravity. Higher TSS values generally indicate greater sweetness and ripeness in fruits, making them more desirable in flavor. In juice and wine production, TSS is crucial for controlling the fermentation process and estimating potential alcohol content. Additionally, TSS is a critical quality control measure, ensuring consistency in taste and overall (Ball, 2006).

Color Value

The color index of the watermelon rind tutti fruttii was assessed using a chroma meter CR400 (Minolta Camera Co.) according to the L* a* b* color scheme. L* represents lightness on a scale from 0 to 100, ranging from black to white, while a* and b* signify the color axis, with a* indicating redness (+) or greenness (-) and b* indicating yellowness (+) or blueness (-). The apparatus was calibrated utilizing a white tile for the Y, x, and y values of 92.5, 0.3134, and 0.3194, respectively (Hunt, 1977; Moritsuka et al., 2019).

Microbial Analysis

Watermelon rind was evaluated for microbes' analysis using Yeast Growth Methods as per Martins et al. (2024) and Total Plate Count method to determine the presence of pathogenic or non-pathogenic microbes in food and fruits (Arifan et al., 2019).

Sensory Evaluation

The prepared candy was subjected to sensory evaluation by a panel of trained judges to assess attributes such as aroma, taste, color, and overall acceptability using standardized sensory evaluation techniques. The hedonic scale is a standard method used in sensory evaluation to measure a person's liking or preference for a particular product. It is typically a nine-point scale that ranges from "dislike extremely" to "like extremely." This scale is particularly useful in food science and consumer product testing to assess the overall acceptability of a product (Samakradhamrongthai et al., 2021).

Response Surface Methodology (RSM) Optimization

Response Surface Methodology (RSM) was employed to determine blanching time, sugar concentration, and drying temperature effects on ascorbic acid retention and total soluble solids (TSS). A central composite design (CCD) was used to analyze the interactions between these independent variables and their impact on the final product's nutritional and sensory quality. The optimization process was conducted using a three-factor, five-level CCD model, where the following independent variables were selected based on preliminary trials: Blanching time (A): 10–20 minutes, Sugar concentration (B): 70–80°Brix and Drying temperature (C): 40–60°C (Aravind et al., 2015; Cano-Lamadrid et al., 2023).

The dependent variables (responses) were ascorbic acid retention (%), a measure of vitamin C preservation in the final product. Total soluble solids (°Brix) indicate sugar concentration and product sweetness. The BBD model generated 17 experimental runs with different combinations of blanching time, sugar concentration, and drying temperature. The experimental data were analyzed using a quadratic regression model, expressed in Eq.3.

$$Y = \beta_0 + \beta_1A + \beta_2B + \beta_3C + \beta_4AB + \beta_5AC + \beta_6BC + \beta_7A^2 + \beta_8B^2 + \beta_9C^2 + E \quad (Eq.3)$$

Y represents the response variable (ascorbic acid retention or TSS), A, B, and C are the independent variables, β_0 is the intercept, β_1 to β_9 are regression coefficients, and E is the error term.

Analysis of variance (ANOVA) was performed to determine the statistical significance of the model. The Adjusted R² and Predicted R² values were used to evaluate the model's accuracy. A lack-of-fit test ensured the model's reliability. The optimal conditions were identified using contour plots and 3D surface response plots, showing the interactive effects of process variables on ascorbic acid retention and TSS. The numerical optimization function of RSM was used to determine the optimal blanching time, sugar concentration, and drying temperature that maximized ascorbic acid retention while maintaining a high TSS level. The optimal conditions were experimentally validated by preparing samples under the predicted settings and comparing the results with the model's predicted values (Dao et al., 2021).

RESULT AND DISCUSSION

The physico-chemical characteristics of freshwater melon fruits used for the preparation tutti fruttii are given in the table below. Results for physicochemical parameters are in line with the observations made published results in literature (Plabon et al., 2024).

Table 1 Physico-Chemical Characteristics of Watermelon and Its Rind

S. No	Parameters			
Physical parameters				
1.	Weight of fruit (kg)	04.00		
2.	Length (cm)	27.00		
3.	Breadth (cm)	24.50		
4.	Weight of pulp (kg)	03.50		
5.	Weight of rind (kg)	00.43		
	a. Edible white portion (g)	400.0		
	b. Green peel (g)	30.00		
Chemical parameters of rind				
1.	Moisture (%)	89.20		
2.	Ascorbic acid (mg/g)	0.846		
3.	Total soluble solids (°brix)	04.00		
4.	Color value (L*, a*, b*)	L-47.3	a*-4.1	b* -6.1

Physico-chemical characteristics of tutti fruity

Moisture-content

Drying is an essential procedure in producing a tutti frutti product. The optimal moisture content for tutti frutti should range from 12% to 21% to provide prolonged storage without deterioration from microbes. The drying duration of 2 hours in a tray dryer at 60° was sufficient to yield high-quality watermelon rind tutti frutti, which exhibited an elevated moisture content of 22.82%. An elevated moisture content led to products particularly susceptible to harm, notably mold proliferation, which poses a health risk to consumers due to foodborne contamination (Farah Hani et al., 2014; Plabon et al., 2024).

Ascorbic acid

The ascorbic acid (vitamin C) content in tutti frutti, a candied fruit, can vary significantly based on the type of fruit used and the processing methods. However, since tutti frutti is a processed and preserved food item, it typically has a much lower ascorbic acid content than fresh fruit. In the case of tutti frutti, where the ratio of sugar to rind concentration is 1:1, the ascorbic acid content is 5.41 mg/100g, lower than that found in fresh fruit. This occurs because making tutti frutti involves soaking sugar syrup and cooking the rind. This exposure to heat and prolonged processing typically leads to significant degradation of natural ascorbic acid. In contrast, in low sugar concentration tutti frutti, the ascorbic acid content is 7.2 mg/100g (Fenech et al., 2019; Sánchez et al., 2021).

Total Soluble Solids

The tutti frutti, with a 1:1 sugar-to-rind ratio, has a TSS of 78 degrees Brix, ensuring high sweetness, preservation, and ideal texture. In contrast, the Tutti Frutti with 2:3 has a TSS of 73 degrees Brix, offering a less sweet, potentially softer product with a shorter shelf life, catering to health-conscious consumers (Castillejo and Martínez-Zamora, 2024).

Color value

A notable reduction in brightness was detected with an elevation in sugar concentration. The recent sample exhibited a higher 'a' value, indicating a stronger greenish hue of the product. A minor reduction in the 'a' value was noted in osmotically treated samples, ascribed to the thermal degradation of color compounds during the osmotic treatment. An appreciable augmentation in 'b' was noted with the prolongation of cooking duration and elevation of sugar content. This may indicate an effect of the elevated sucrose concentration, resulting in more yellowish samples (Athmaselvi et al., 2012; Zhang et al., 2023). Various Physico-Chemical Characteristics of Watermelon and Its Rind are listed in Table 1. The effect of Sugar Concentration on the Color Characteristics of Watermelon Rind Tutti Frutti is listed in Table 2.

Table 2 Effect of Sugar Concentration on Color Characteristics of Watermelon Rind Tutti Frutti

Sample	°Brix	Lightness L*	Redness a*	Yellowness b*
Fresh rind	4	73.42	-7.53	32.43
High Conc	78	46.9	-4.1	13.7
Low Conc	73	47.3	-4.1	6.1

Microbial Analysis of tutti frutti

A microbial analysis of watermelon rind tutti frutti was conducted using Plate Count Agar (PCA), Yeast Extract Peptone Dextrose (YPD), and Potato Dextrose Agar (PDA) media. PCA was used to evaluate bacterial microorganisms, YPD was used to assess yeast count, and PDA was used to analyze fungal and mold growth. The results revealed that yeast had the highest microbial presence, with 14 CFU/ml and 1.4×10^{-4} CFU/ml, followed by bacteria at 3 CFU/ml and 3×10^{-5} CFU/ml, and fungi at 1.5×10^{-5} CFU/ml. Overall, yeast exhibited the highest Colony Forming Units among all microorganisms tested (Arifan et al., 2019). Various Microbial Load Analyses of Watermelon Rind Tutti Frutti on Different Media are listed in Table 3.

Table 3 Microbial Load Analysis of Watermelon Rind Tutti Frutti on Different Media

Microorganism	Media	Microbial Count		Mean value	CFU/ml
		R1	R2		
Bacteria	PCA	4	2	3	3×10^5
Yeast	YPD	7	21	14	1.4×10^4
Fungi	PDA	1	2	1.5	1.5×10^5

Sensory Evaluation

The evaluation of samples TF73 and TF74 by four panelists revealed that TF73 is generally more favorably received. TF73 consistently scored high in appearance (8), taste (7-9), smell (7-9), texture (7-9), sweetness (8-9), and overall acceptability (7-9). In contrast, TF74 received slightly lower but consistent scores across the same attributes, with appearance (7-9), taste (7-8), smell (7-8), texture (7), sweetness (7-8), and overall acceptability (7-8). TF73 is preferred over TF74, particularly in appearance, taste, texture, sweetness, and overall acceptability (Samakradhamrongthai et al., 2021). Sensory Evaluation of Watermelon Rind Tutti Frutti Based on Hedonic Scale Ratings in Table 4.

Table 4 Sensory Evaluation of Watermelon Rind Tutti Frutti Based on Hedonic Scale Ratings

Panelist	Sample code	Appearance	Taste	Smell	Texture	Sweetness	Overall acceptability
1	TF73	8	9	9	9	8	9
	TF74	8	7	8	7	8	8
2	TF73	8	7	7	8	8	7
	TF74	9	8	8	8	7	8
3	TF73	8	7	8	7	8	8
	TF74	7	7	8	7	7	7
4	TF73	8	8	8	9	9	8
	TF74	7	7	7	7	8	7

Notably, the sensory scores for TF73 were comparable to or slightly higher than typical scores reported for commercially available tutti frutti products (average scores of 7–8 for appearance, taste, and overall acceptability). This indicates that the developed watermelon rind tutti frutti meets or exceeds consumer expectations for texture, sweetness, and visual appeal, highlighting its potential for market acceptance.

Optimization of process parameter via response surface methodology

Food processing techniques significantly influence food products' nutritional quality and physicochemical properties. Among the key nutrients, ascorbic acid (Vitamin C) retention is critical due to its high sensitivity to heat, oxygen, and moisture content during processing. Similarly, total soluble solids (TSS) are crucial in determining food products' texture, flavor, and shelf stability. Optimizing processing parameters is essential to maintain product quality while minimizing nutrient loss. Blanching, sugar concentration, and drying temperature are critical factors affecting ascorbic acid retention and TSS. Blanching time influences

enzymatic activity and nutrient leaching, and sugar concentration affects osmotic balance and preservation, while drying temperature determines moisture removal and thermal degradation of bioactive compounds. Finding the right combination of these factors is necessary to balance nutrient preservation and desirable sensory attributes. Response Surface Methodology (RSM) is a widely used statistical tool for modeling and optimizing complex processes involving multiple variables. RSM helps understand the interactive effects of process parameters while reducing the number of experimental trials needed compared to traditional one-factor-at-a-time approaches. In this study, RSM was applied to investigate and optimize the effects of blanching time, sugar concentration, and drying temperature on ascorbic acid retention and total soluble solids in food products (Dao et al., 2021; Cano-Lamadrid et al., 2023). By employing statistical modeling through RSM, this study provides a scientific basis for optimizing food processing techniques to enhance processed food products' nutritional and quality attributes. The findings can be valuable for food industries, researchers, and quality control professionals aiming to improve product stability and consumer acceptability (Table 5).

Table 5 RSM design and response

Run	Factor 1 A: Blanching time (Min)	Factor 2 B: Sugar concentration (°Brix)	Factor 3 C: Drying temperature (°C)	Response 1 Ascorbic acid retention	Response 2 Total Soluble Solids
1	10	80	50	9.11	4.54
2	15	75	50	7.22	3.68
3	10	75	40	9	4.28
4	20	75	40	7.1	3.55
5	15	75	50	7.22	3.68
6	20	75	60	5.96	2.92
7	15	70	60	6.11	2.9
8	15	75	50	7.22	3.68
9	15	75	50	7.31	3.68
10	20	80	50	7.81	3.66
11	10	70	50	8.45	3.93
12	15	75	50	7.28	3.68
13	15	80	40	8.3	4.07
14	15	80	60	7.51	3.51
15	10	75	60	7.84	3.38
16	15	70	40	7.78	3.71
17	20	70	50	6.19	3.4

Table 6 ANOVA for Quadratic model for Ascorbic acid retention output of RSM design

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	13.14	9	1.46	313.04	< 0.0001	significant
A-Blanching time	6.73	1	6.73	1443.83	< 0.0001	
B-Sugar concentration	2.21	1	2.21	472.74	< 0.0001	
C-Drying temperature	2.83	1	2.83	607.21	< 0.0001	
AB	0.2304	1	0.2304	49.40	0.0002	
AC	0.0001	1	0.0001	0.0214	0.8877	
BC	0.1936	1	0.1936	41.51	0.0004	
A ²	0.5012	1	0.5012	107.45	< 0.0001	
B ²	0.3664	1	0.3664	78.56	< 0.0001	
C ²	0.0606	1	0.0606	13.00	0.0087	
Lack of Fit	0.0255	3	0.0085	4.71	0.0842	not significant

The **Model F-value** of 313.04 implies the model is significant. **P-values** less than 0.0500 indicate model terms are essential. In this case, A, B, C, AB, BC, A², B², C² are significant model terms. Values greater than 0.1000 indicate the model terms are insignificant (Table 6).

Final Equation in Terms of Coded Factors:

$$\text{Ascorbic acid retention} = 98.96 - 1.32 * A - 2.03 * B - 0.27 * C + 0.009 * AB + 0.0001 * AC + 0.004 * BC + 0.014 * A^2 + 0.012 * B^2 - 0.001 * C^2$$

----- (Eq.4)

Equation 4 represents the quadratic regression model derived from Response Surface Methodology (RSM), used to predict ascorbic acid retention in watermelon rind tutti frutti as a function of blanching time (A), sugar concentration (B), and drying temperature (C). The equation includes linear, interaction, and quadratic terms, capturing these processing parameters' direct, combined, and nonlinear effects. The negative coefficients of A (-1.32), B (-2.03), and C (-0.27) indicate that higher blanching time, sugar concentration, and drying temperature reduce ascorbic acid retention, primarily due to heat-induced degradation and oxidative losses. The interaction terms (AB, AC, BC) suggest that combinations of process variables have a marginal effect on retention, with the highest impact observed for blanching time and sugar concentration (AB = 0.009). The quadratic terms (A², B², C²) highlight the system's nonlinear behavior, where moderate values of blanching time and sugar concentration help preserve vitamin C, but excessive levels lead to further losses. This model helps predict optimal processing conditions that maximize ascorbic acid retention, ensuring a nutritionally superior final product (Dao et al., 2021; Cano-Lamadrid et al., 2023).

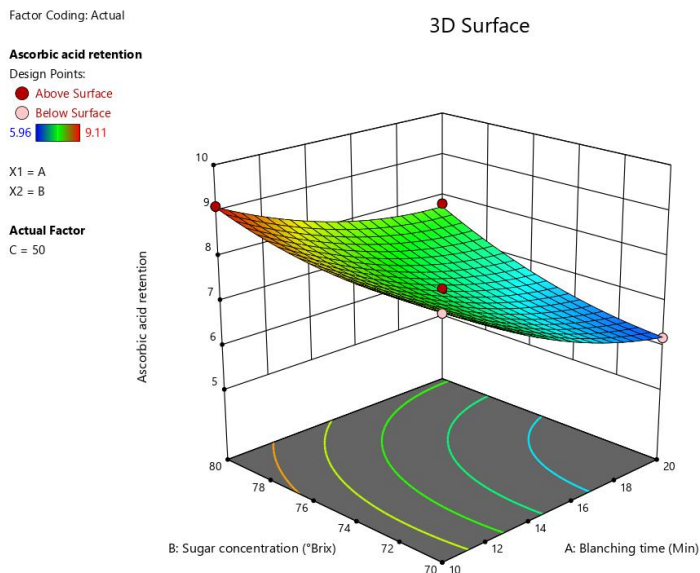


Figure 2a 3D contour plot of Blanching time vs. Sugar concentration on Ascorbic acid

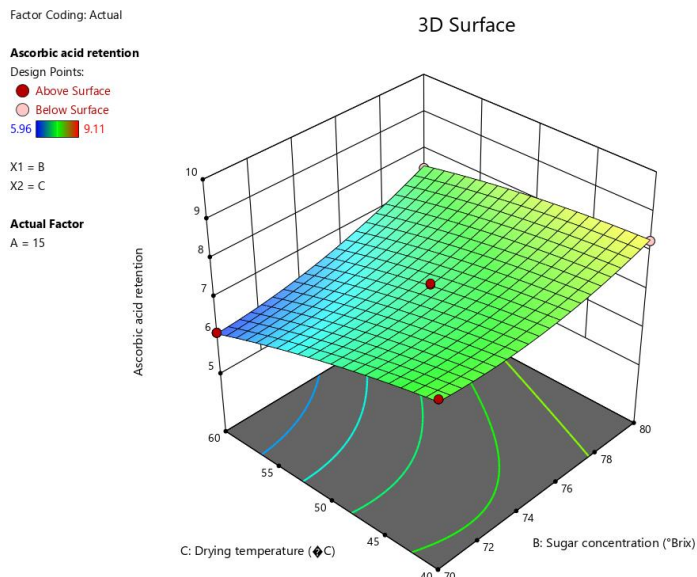


Figure 2c 3D contour plot of drying temperature vs. Sugar concentration on Ascorbic acid

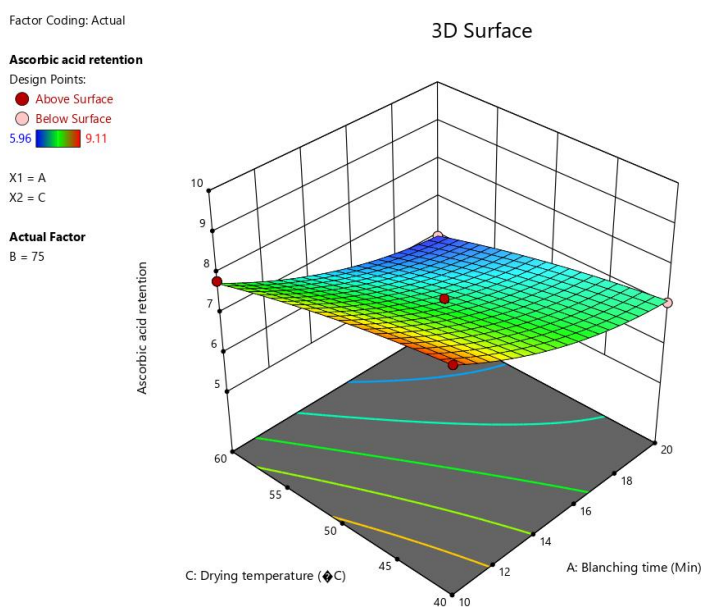


Figure 2b 3D contour plot of Blanching time vs. drying temperature on Ascorbic acid

The present study employed Response Surface Methodology (RSM) to optimize the processing conditions to maximize the product's ascorbic acid retention and total soluble solids (TSS). The factors examined were blanching time (A), sugar concentration (B), and drying temperature (C), and their effects were evaluated using a quadratic model. The high adjusted R^2 and predicted R^2 values for both responses confirm the strong reliability of the models. The retention of ascorbic acid is crucial for maintaining the nutritional quality of the product. The quadratic model was the most suitable for this response, as indicated by the high adjusted R^2 (0.9943) and predicted R^2 (0.9682), confirming the model's robustness. The ANOVA results demonstrated that all three main factors (A, B, and C) significantly influenced ascorbic acid retention ($p < 0.0001$), with blanching time (A) contributing the most variance ($F = 1443.83$).

Among the interaction effects, the AB (blanching time \times sugar concentration) and BC (sugar concentration \times drying temperature) interactions were statistically significant ($p = 0.0002$ and $p = 0.0004$, respectively). In contrast, the AC interaction was insignificant ($p = 0.8877$). This indicates that blanching time and sugar concentration interactively impact ascorbic acid retention, likely due to sugar's potential role in reducing oxidative degradation. The quadratic terms of A^2 , B^2 , and C^2 were also significant, highlighting the nonlinear effects of processing conditions on ascorbic acid retention.

The negative coefficients for blanching time (A: -1.32), sugar concentration (B: -2.03), and drying temperature (C: -0.27) indicate that increasing these parameters beyond optimal levels leads to a reduction in ascorbic acid retention. This could be due to excessive thermal exposure and leaching of ascorbic acid during prolonged blanching and drying at high temperatures. The 3D response surface plots (Figure 2 a, b, c) illustrate the interactive effects of blanching time, sugar concentration, and drying temperature on ascorbic acid retention. The contour plots reveal optimal regions where ascorbic acid retention is maximized.

Effect of Blanching Time and Sugar Concentration: The interaction between blanching time (A) and sugar concentration (B) shows a downward trend in ascorbic acid retention at higher blanching times and sugar concentrations. This aligns with the negative coefficients in the quadratic model (-1.32 for A and -2.03 for B), indicating that prolonged blanching and high sugar concentrations accelerate degradation. **Optimal Region:** Higher ascorbic acid retention is observed at lower blanching times (~10 min) and moderate sugar concentrations (~75 °Brix).

Effect of Blanching Time and Drying Temperature: The response surface plot highlights that increasing drying temperature (C) reduces ascorbic acid retention, with a more substantial effect at longer blanching times. The steep gradient in the surface plot suggests that drying temperature is a critical factor. **Optimal Region:** A blanching time of 10–15 minutes and drying temperature of ~40–50°C maintains higher ascorbic acid levels. **Effect of Sugar Concentration and Drying Temperature:** A concave curvature is observed in the plot, confirming the significance of quadratic effects (B^2 and C^2 , $p < 0.0001$). While moderate sugar concentrations may provide some protection against oxidative degradation, excessive sugar levels combined with high drying temperatures result in ascorbic acid loss.

Table 7 ANOVA output for response Total Soluble Solids (TSS)

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.70	9	0.2999	199.97	< 0.0001	significant
A-Blanching time	0.8450	1	0.8450	563.33	< 0.0001	
B-Sugar concentration	0.4232	1	0.4232	282.13	< 0.0001	
C-Drying temperature	1.05	1	1.05	700.83	< 0.0001	
AB	0.0306	1	0.0306	20.42	0.0027	
AC	0.0182	1	0.0182	12.15	0.0102	
BC	0.0156	1	0.0156	10.42	0.0145	
A ²	0.0370	1	0.0370	24.67	0.0016	
B ²	0.0498	1	0.0498	33.20	0.0007	
C ²	0.2451	1	0.2451	163.37	< 0.0001	
Lack of Fit	0.0105	3	0.0065	4.11	0.0782	Not significant

The **Model F-value** of 199.97 implies the model is significant. **P-values** less than 0.0500 indicate model terms are essential. In this case, A, B, C, AB, AC, BC, A², B², and C² are significant model terms. Values greater than 0.1000 indicate the model terms are insignificant (Table 7).

Final Equation in Terms of Coded Factors:

$$\text{Total Soluble Solids (TSS)} = +3.68 - 0.33 *A + 0.23 *B - 0.36 *C - 0.0875 *AB + 0.0675 *AC + 0.0625 *BC + 0.0937 *A^2 + 0.1087 *B^2 - 0.2413 C^2$$

----- (Eq. 5)

Equation 5 represents the quadratic regression model derived from Response Surface Methodology (RSM) to predict Total Soluble Solids (TSS) in watermelon rind tutti frutti as a function of blanching time (A), sugar concentration (B), and drying temperature (C). The equation accounts for linear, interaction, and quadratic effects, ensuring a precise estimation of TSS under different processing conditions. The negative coefficients of A (-0.33) and C (-0.36) indicate that higher blanching time and drying temperature decrease TSS, likely due to excessive moisture loss and thermal degradation of soluble sugars. The positive coefficient of B (0.23) suggests that increasing sugar concentration enhances TSS, as expected due to the osmosis-driven infusion of sugars into the rind. The interaction terms (AB, AC, BC) show that combined variations in blanching time, sugar concentration, and drying temperature have a moderate impact on TSS levels, with AB (-0.0875) indicating a slight reduction in TSS retention when blanching time and sugar concentration increase together. The quadratic terms (A², B², C²) illustrate the nonlinear influence of process parameters, with B² (0.1087) contributing positively, affirming that controlled sugar concentration optimizes TSS, whereas C² (-0.2413) highlights that excessive drying temperature negatively affects TSS due to excessive sugar degradation.

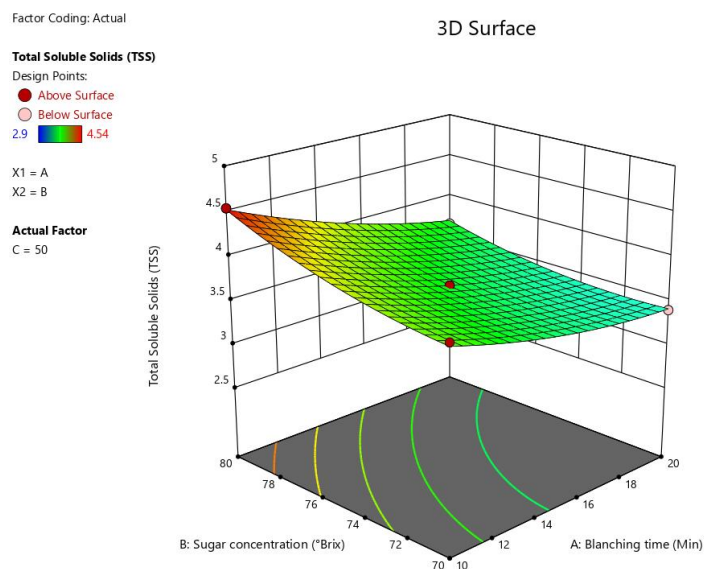


Figure 3a. 3D contour plot of Blanching time vs. Sugar concentration on TSS

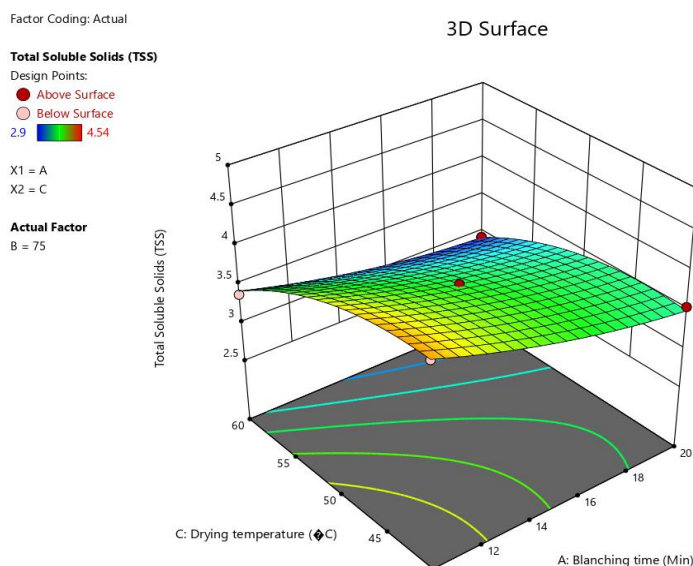


Figure 3b 3D contour plot of Blanching time vs. Drying temperature on TSS

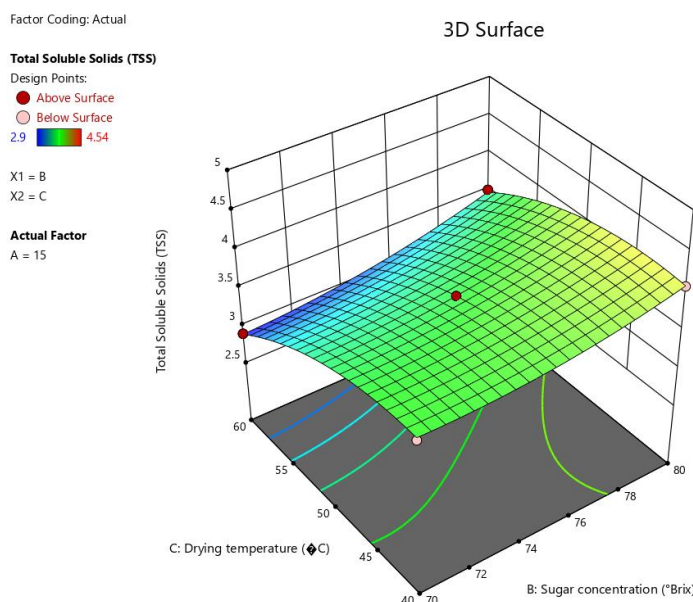


Figure 3c 3D contour plot of Drying temperature vs. Sugar concentration on TSS

Total Soluble Solids (TSS) is a key quality parameter influencing the taste and texture of the product. The quadratic model was also the best fit for TSS, with an **adjusted R² of 0.9911 and a predicted R² of 0.9380**, indicating high predictive accuracy. The ANOVA results revealed that the **main effects of blanching time (A), sugar concentration (B), and drying temperature (C) were highly significant (p < 0.0001)**, with drying temperature (C) showing the highest impact (F = 700.83). Interaction terms AB (p = 0.0027), AC (p = 0.0102), and BC (p = 0.0145) were also significant, suggesting that the combined effects of these factors influence TSS retention. The quadratic terms A², B², and C² were also significant (p < 0.05), indicating a curvilinear response. The **final regression equation** shows that **blanching time (A) and drying temperature (C) negatively affect TSS (-0.33 and -0.36, respectively)**, while sugar concentration (B) has a positive effect (+0.23). The strong negative quadratic effect of drying temperature (-0.2413 C²) suggests that excessively high drying temperatures reduce TSS due to excessive moisture loss and degradation of sugar molecules.

The response surface plots for TSS (Figure 3 a, b, c) reveal how **blanching time, sugar concentration, and drying temperature** influence soluble solid content. **Effect of Blanching Time and Sugar Concentration:** As expected, **higher sugar concentrations lead to an increase in TSS** due to enhanced sugar infusion. However, **prolonged blanching reduces TSS**, as evident from the negative coefficient for A (-0.33). The interaction plot (AB) suggests that blanching time has a more pronounced effect at **lower sugar concentrations**. **Effect of Blanching Time and Drying Temperature:** A **strong negative effect of drying temperature on TSS** is evident from the surface plot, which corroborates the quadratic term C² (-0.2413, p < 0.0001) in the

regression equation. Excessively high drying temperatures increase moisture loss, concentrating TSS in the early drying phase but potentially degrading soluble sugars at prolonged exposure. **Effect of Sugar Concentration and Drying Temperature:** The response surface plot indicates that TSS increases with sugar concentration but declines at higher drying temperatures, reinforcing the significant BC interaction ($p = 0.0145$). This suggests that higher sugar concentrations can compensate for some TSS loss due to drying, but only up to a threshold.

This study employed Response Surface Methodology (RSM) to optimize the processing conditions affecting food products' ascorbic acid retention and total soluble solids (TSS). The independent variables considered were blanching time (A), sugar concentration (B), and drying temperature (C), and their influence on the responses was analyzed using a quadratic regression model. The ANOVA results demonstrated that all three factors significantly impacted both responses ($p < 0.0001$), with blanching time having the most pronounced effect on ascorbic acid retention, while drying temperature exhibited the highest influence on TSS. Significant interaction effects were observed for AB (blanching time \times sugar concentration) and BC (sugar concentration \times drying temperature) for ascorbic acid retention, whereas all interaction terms were significant for TSS. The final regression equations provided predictive models to estimate both responses under varying process conditions. The findings suggest that a moderate blanching time, drying temperature, and a controlled sugar concentration maximize ascorbic acid retention while preserving total soluble solids. The study provides a scientific basis for optimizing food processing techniques to enhance food products' nutritional and sensory quality.

The findings of this study highlight the critical role of blanching time, sugar concentration, and drying temperature in determining ascorbic acid retention and total soluble solids (TSS) in food products. The quadratic model developed using RSM effectively captured the nonlinear relationships and interaction effects among the processing parameters, providing a statistically robust predictive tool. The ANOVA results confirmed the significance of all main factors, while interaction effects and quadratic terms demonstrated the complexity of optimizing these variables. Higher blanching times and drying temperatures reduced ascorbic acid retention, while sugar concentration showed a dual effect, enhancing TSS but contributing to some nutrient loss at extreme levels. To validate the accuracy of the developed RSM model, additional experiments were conducted under the predicted optimal conditions. The experimentally observed values for ascorbic acid retention and total soluble solids closely matched the predicted values, with deviations within $\pm 1\%$, confirming the reliability and practical applicability of the quadratic model.

This study underscores the importance of optimizing food processing techniques to minimize nutrient degradation while maintaining desirable sensory attributes. The findings provide valuable insights for food industries and researchers aiming to enhance product stability, quality, and consumer acceptability. Future research could explore additional factors such as airflow rate, relative humidity, and alternative drying methods to refine the optimization process further (Dao et al., 2021; Cano-Lamadrid et al., 2023). The study's results provide a scientific basis for improving processing techniques to retain nutritional and sensory qualities in food products. Future studies could explore the effects of other process parameters, such as airflow rate and relative humidity during drying, for further optimization.

CONCLUSION

This study successfully demonstrated the feasibility of utilizing watermelon rind — an often-discarded agricultural byproduct — to produce high-quality tutti frutti through an optimized osmotic dehydration process. The optimized process parameters, determined using Response Surface Methodology, were blanching for 10–15 minutes, sugar concentration of 75–80 °Brix, and drying at 40–50 °C, which ensured maximum ascorbic acid retention and desirable total soluble solids while maintaining favorable sensory characteristics. Biochemical and microbial analyses confirmed that the final product meets nutritional standards and microbial safety requirements, while sensory evaluation by trained panelists indicated high acceptability in terms of appearance, taste, texture, and overall appeal. These findings emphasize the dual benefit of waste reduction and value addition, offering a sustainable solution aligned with circular economy principles. Commercially, this approach provides a viable opportunity for farmers, small-scale processors, and the confectionery industry to generate additional income streams by converting watermelon rind into a marketable candied product. However, this research also has certain limitations. Long-term storage stability, shelf-life behavior under varying packaging conditions, and large-scale production feasibility need further investigation. Future studies should address these aspects through extended shelf-life trials, pilot plant validations, and the exploration of natural preservatives and alternative drying methods to enhance product quality and sustainability. Overall, this study sets a scientific foundation for valorizing watermelon rind and encourages broader adoption of zero-waste processing techniques, contributing to environmental sustainability and economic resilience in the food industry.

REFERENCES

- Ahn, J. Y., Kil, D. Y., Kong, C., & Kim, B. G. (2014). Comparison of Oven-drying Methods for Determination of Moisture Content in Feed Ingredients. *Asian-Australasian journal of animal sciences*, 27(11), 1615–1622. <https://doi.org/10.5713/ajas.2014.14305>
- Aravind, J., Lenin, C., Nancyflavia, C., Rashika, P., & Saravanan, S. (2015). Response surface methodology optimization of nickel (II) removal using pigeon pea pod biosorbent. *International Journal of Environmental Science and Technology*, 12, 105–114. <https://doi.org/10.1007/s13762-013-0391-0>
- Arifan, F., Winami, S., Wahyuningsih, W., Pudjihastuti, I., & Broto, R. W. (2019, October). Total plate count (TPC) analysis of processed ginger on Tlogowungu Village. In *International Conference on Maritime and Archipelago (ICoMA 2018)* (pp. 377–379). Atlantis Press. <http://dx.doi.org/10.2991/icoma-18.2019.80>
- Athmaselvi, K. A., Alagusundaram, K., Kavitha, C. V., & Arumuganathan, T. (2012). Impact of pretreatment on colour and texture of watermelon rind. *International Agrophysics*, 26(3)
- Ball, D. W. (2006). Concentration scales for sugar solutions. *Journal of Chemical Education*, 83(10), 1489. <https://doi.org/10.1021/ed083p1489>
- Cano-Lamadrid, M., Martínez-Zamora, L., Mozafari, L., Bueso, M. C., Kessler, M., & Artés-Hernández, F. (2023). Response Surface Methodology to Optimize the Extraction of Carotenoids from Horticultural Byproducts—A Systematic Review. *Foods*, 12(24), 4456. <https://doi.org/10.3390/foods12244456>
- Castillejo, N., & Martínez-Zamora, L. (2024). Bioactive Compounds from Fruit and Vegetable Waste: Extraction and Possible Utilization. *Foods*, 13(5), 775. <https://doi.org/10.2478/v10247-012-0035-5>
- Chethan, H. P., Raj, D., Vaghashiya, J. M., Kumar, S., & Thumar, V. M. (2018). Evaluation of osmotic treatments for preparation of water melon (Citrullus lanatus) rind candy. *IJCS*, 6(4), 1705–1714. <https://doi.org/10.1016/j.matpr.2018.06.292>
- Danya, U., Kamaraj, M., Babu, P. S., & Aravind, J. (2024). Bibliometric analysis and review of food waste management via sustainable approaches. *Global Journal of Environmental Science & Management (GJESM)*, 10(4). <https://doi.org/10.22034/gjesm.2024.04.38>
- Dao, T. A. T., Webb, H. K., & Malherbe, F. (2021). Optimization of pectin extraction from fruit peels by response surface method: Conventional versus microwave-assisted heating. *Food Hydrocolloids*, 113, 106475. <https://doi.org/10.1016/j.foodhyd.2020.106475>
- Dermesonlouoglou, E., Paraskevopoulou, E., Andreou, V., & Taoukis, P. (2020). Osmotic dehydration for the production of novel pumpkin cut products of enhanced nutritional value and sustainability. *Applied Sciences*, 10(18), 6225. <https://doi.org/10.3390/app10186225>
- Du, X., & Ramirez, J. (2022). Watermelon rind and flesh volatile profiles and cultivar difference. *Horticulturae*, 8(2), 99. <https://doi.org/10.3390/horticulturae8020099>
- Dubey, S., Rajput, H., & Batta, K. (2021). Utilization of watermelon rind (Citrullus lanatus) in various food preparations: a review. *J. Agr. Sci. Food Res*, 14, 1–3.
- Farah Hani, M. N., Nur Zahidah, W. Z. W., Saniah, K., & Mohd. Irwani, H. S. (2014). Effects of drying on the physical characteristics of dehydrated watermelon rind candies. *International Journal of Science and Engineering* 8(1). <http://dx.doi.org/10.12777/ijse.8.1.6-9>
- Fenech, M., Amaya, I., Valpuesta, V., & Botella, M. A. (2019). Vitamin C Content in Fruits: Biosynthesis and Regulation. *Frontiers in plant science*, 9, 2006. <https://doi.org/10.3389/fpls.2018.02006>
- Hasan, M. M., Islam, M. R., Haque, A. R., Kabir, M. R., Khushie, K. J., & Hasan, S. K. (2024). Trends and challenges of fruit byproducts utilization: Insights into safety, sensory, and benefits of the use for the development of innovative healthy food: A review. *Bioresources and Bioprocessing*, 11(1), 10. <https://doi.org/10.1186/s40643-023-00722-8>
- Hunt, R. W. G. (1977). The specification of colour appearance. I. Concepts and terms. *Color Research & Application*, 2(2), 55–68. <https://doi.org/10.1002/col.5080020202>
- Kolawole, I. D., Kolawole, G. O., Sanni-manuel, B. A., Kolawole, S. K., Ewansiha, J. U., Kolawole, V. A., & Kolawole, F. O. (2024). Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review. *Discover Environment*, 2(1), 51. <https://doi.org/10.1007/s44274-024-00086-6>
- Kumar Gupta, R., Ae Ali, E., Abd El Gawad, F., Mecheal Daood, V., Sabry, H., Karunanithi, S., & Prakash Srivastav, P. (2024). Valorization of fruits and vegetables waste byproducts for development of sustainable food packaging applications. *Waste Manag. Bull*, 2, 21–40. <https://doi.org/10.1016/j.wmb.2024.08.005>
- Martins, C. T., Jacobus, A. P., Conceição Jr, R., Barbin, D. F., Bolini, H., & Gombert, A. K. (2024). Simultaneous enumeration of yeast and bacterial cells in the context of industrial bioprocesses. *Journal of Industrial Microbiology and Biotechnology*, 51, kuae029. <https://doi.org/10.1093/jimb/kuae029>
- Minor, B. A., Sims, K. A., Bassette, R., & Fung, D. Y. C. (1984). Comparison of infra-dry and AOAC methods for moisture in food products. *Journal of food protection*, 47(8), 611–614. <https://doi.org/10.4315/0362-028X-47.8.611>
- Moritsuka, N., Kawamura, K., Tsujimoto, Y., Rabenarivo, M., Andriamananjara, A., Rakotoson, T., & Razafimbelo, T. (2019). Comparison of visual and

- instrumental measurements of soil color with different low-cost colorimeters. *Soil Science and Plant Nutrition*, 65(6), 605-615. <https://doi.org/10.1080/00380768.2019.1676624>
- Plabon, M. E. A., Akhtaruzzaman, M., Mondal, M. H. T., Islam, M. R., Hasan, S. K., & Sarker, M. S. H. (2024). Comprehensive assessment of drying performance, physical characteristics, bioactive compounds, and antioxidant capacity of mallow (*Malva verticillata*) vegetables: A comparative study of a modified tray dryer and conventional drying methods. *Applied Food Research*, 4(1), 100423. <https://doi.org/10.1016/j.afres.2024.100423>
- Raman, S., Sehrawat, A., Upadhyay, R., Singh, S., Verma, A., Aarushi, S. J., ... & Aggarwal, A. (2023). Different Methods Used For Determination of Vitamin C: A Review. *International Journal of Current Microbiology and Applied Sciences*, 12(9), 56-66. <https://doi.org/10.20546/ijcmas.2023.1209.006>
- Rațu, R. N., Veleșcu, I. D., Stoica, F., Usturoi, A., Arsenoia, V. N., Crivei, I. C., ... & Brumă, I. S. (2023). Application of agri-food byproducts in the food industry. *Agriculture*, 13(8), 1559. <https://doi.org/10.3390/agriculture13081559>
- Rezagholizade-Shirvan, A., Shokri, S., Dadpour, S. M., & Amiryousefi, M. R. (2023). Evaluation of physicochemical, antioxidant, antibacterial activity, and sensory properties of watermelon rind candy. *Heliyon*, 9(6), e17300. <https://doi.org/10.1016/j.heliyon.2023.e17300>
- Sadasivam, S., & Balasubramanian, T. (1987). Practical manual in biochemistry. *Tamil Nadu Agricultural University, Coimbatore, India*, 14, 15.
- Samakradhamrongthai, R. S., Jannu, T., & Renaldi, G. (2021). Physicochemical properties and sensory evaluation of high energy cereal bar and its consumer acceptability. *Heliyon*, 7(8). <https://doi.org/10.1016/j.heliyon.2021.e07776>
- Sánchez, M., Laca, A., Laca, A., & Díaz, M. (2021). Value-added products from fruit and vegetable wastes: a review. *CLEAN–Soil, Air, Water*, 49(8), 2000376. <https://doi.org/10.1002/clen.202000376>
- Schmilovitch, Z. E., Alchanatis, V., Ignat, T., Hoffman, A., Egozi, H., Ronen, B., ... & Rodov, V. (2015). Machinery for fresh cut watermelon and melon. *Chemical engineering transactions*, 44, 277-282. <https://doi.org/10.3303/CET1544047>
- Shourove, J. H., Jon, P. H., Samadder, M., Chy, M. W. R., Miah, M. S., Fahim, R. H., & Islam, G. R. (2025). Extraction of pectin from watermelon rinds using sequential ultrasound-microwave technique: Optimization using RSM and ANN modeling and characterization. *International Journal of Biological Macromolecules*, 307, 141905. <https://doi.org/10.1016/j.ijbiomac.2025.141905>
- Tlevlessova, D., Medvedkov, Y., Kairbayeva, A., & Nazymbekova, A. (2022). Mechanisation of the primary processing of watermelons without destroying the rind. *Food Science and Technology*, 43, e86622. <http://dx.doi.org/10.1590/fst.86622>
- Vijayan, L., Arumugam, M., Palaniyappan, S., Jayaraman, S., Brown, P. B., Kari, Z. A., ... & Ramasamy, T. (2024). Utilization of sustainable agri-waste watermelon rind for fishmeal in *Labeo rohita* diets: Effects on nutritional indices, hemato-biochemical properties, histoarchitectural traits, amino acid and fatty acid profiles. *Aquaculture Reports*, 36, 102045. <https://doi.org/10.1016/j.aqrep.2024.102045>
- Wanapat, M., Suriyapha, C., Dagaew, G., Prachumchai, R., Phupaboon, S., Sommai, S., & Matra, M. (2024). The recycling of tropical fruit peel waste-products applied in feed additive for ruminants: Food manufacturing industries, phytonutrient properties, mechanisms, and future applications. *Journal of Agriculture and Food Research*, 101234. <https://doi.org/10.1016/j.jafr.2024.101234>
- Yadav, A. K., & Singh, S. V. (2014). Osmotic dehydration of fruits and vegetables: a review. *Journal of food science and technology*, 51(9), 1654–1673. <https://doi.org/10.1007/s13197-012-0659-2>
- Zhang, M., Wang, H., Bao, S., Peng, W., Li, X., Sun, X., & Ma, T. (2023). Using multi-criteria decision-making method to select the optimal color fixative for cloudy kiwi juice during thermal sterilization processing. *LWT*, 187, 115266. <https://doi.org/10.1016/j.lwt.2023.115266>