



ISSN Print: 2664-844X
 ISSN Online: 2664-8458
 NAAS Rating (2026): 4.97
 IJAFA 2026; 8(4): 89-98
www.agriculturaljournals.com
 Received: 15-01-2026
 Accepted: 17-02-2026

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Physico-chemical properties of Moroccan red dragon fruit rind powder in the production of natural food colorants

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DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i4b.1298>

Abstract

This study evaluated the potential of Moroccan red dragon fruit (*Hylocereus* spp.) rind powder as a natural colorant in soy milk. A true experimental design using a Completely Randomized Design (CRD) was applied with four treatments: 0 g, 2 g, 3 g, and 4 g rind powder added to 100 mL soy milk, each replicated three times. Parameters assessed included pH level, color intensity, solubility, and overall color effect. Results showed that increasing rind powder concentration enhanced color intensity, producing more visually appealing samples. Slight variations in pH were observed, indicating compatibility with soy milk. Solubility improved with proper mixing, though higher concentrations showed minimal sedimentation. Statistical analysis using ANOVA and Tukey's test confirmed significant differences among treatments. The findings suggest that dragon fruit rind powder is an effective, sustainable, and eco-friendly natural colorant for plant-based beverages.

Keywords: Dragon fruit rind, natural colorant, soy milk, betalains, sustainability

Introduction

Background of the Study

In recent years, the food industry has faced increasing pressure to replace synthetic additives with natural, safe, and sustainable alternatives, particularly in response to the growth in consumer awareness and stricter regulatory frameworks. Color is one of the most influential factors in food selection, significantly impacting consumers' perception, acceptability, and overall preference (Francis & Markakis, 2021) ^[10]. A visually appealing product is often associated with freshness, quality, and nutritional value, making color a critical attribute in the food industry.

To enhance or restore the appearance of food products, food manufacturers commonly add colorants, which could be either synthetic or natural. Synthetic colorants have been favored for decades due to their low cost, ease of production, and high stability under varying environmental conditions. However, numerous studies raised concerns about the safety of artificial dyes. Several synthetic colorants were associated with allergic reactions, hyperactivity in children, and potential carcinogenic effects, prompting regulatory authorities to limit or ban certain chemicals in food products (Clifford, 2020; FAO/WHO, 2019) ^[6].

In response to these concerns, there has been a growing demand for natural and safer alternatives derived from plant-based sources. Natural pigments are increasingly being investigated not only for their ability to provide color but also for additional functional benefits, such as antioxidant activity, health-promoting bioactive compounds, and environmental sustainability (Azeredo, 2019) ^[2]. Among these, tropical fruits, particularly those with vibrantly hued peels, have emerged as promising sources of natural pigments that can be safely used by humans.

Dragon fruit (*Hylocereus* spp.), also known as pitaya, is a climbing cactus species cultivated extensively in tropical and subtropical regions, including Southeast Asia, Central America, and the Philippines. The Moroccan red variety of dragon fruit is distinguished by its bright red rind and deep red flesh, which are rich in betalain pigments.

Betalains, including betacyanins and betaxanthins, are water-soluble pigments responsible for red-violet and yellow-orange coloration, respectively (Mahattanatawee *et al.*, 2021) [20]. These pigments are non-toxic, biodegradable, and exhibit significant antioxidant properties, making them suitable candidates for replacing synthetic colorants in food products.

Despite these promising properties, dragon fruit rinds are typically discarded as waste, representing approximately one-third of the total fruit mass (Kusumaningrum *et al.*, 2021) [16]. This not only contributes to environmental issues but also represents a missed opportunity to generate value-added products. By converting dragon fruit rind into powder for use as a natural food colorant, food processors can reduce agricultural waste, create economic opportunities for farmers, and promote environmentally sustainable practices (Lim *et al.*, 2020) [17].

The effectiveness of natural colorants, however, depends on several factors, including pH, solubility, and processing conditions. Betalains are highly sensitive to pH, showing maximum color stability under acidic conditions (pH 3-6), while their solubility and dispersibility in liquid matrices influence the uniformity of color (Herbach *et al.*, 2016; Pham *et al.*, 2023) [12, 35]. Processing methods, such as freeze-drying and oven-drying, affect pigment retention, particle size, and solubility, which in turn impact color intensity and stability in the final product.

Soy milk, a plant-based dairy alternative, is naturally pale in appearance and has a slightly acidic to neutral pH, typically ranging from 6.0 to 7.0 (Chan *et al.*, 2020) [5]. Its light color often requires additional coloring when used in beverages, desserts, or flavored milk products. Incorporating Moroccan red dragon fruit rind powder into soy milk could enhance its visual appeal, improve consumer perception, and potentially provide health benefits due to the antioxidant properties of betalains (Gengatharan *et al.*, 2020) [11]. Moreover, because betalains are most stable under slightly acidic conditions (pH 3-6), adjusting or maintaining the pH of soy milk is essential to maximize color stability and intensity when using the rind powder as a natural pigment.

Furthermore, the study contributes to local food innovation by exploring the use of an underutilized agricultural by-product in a practical application. By turning waste materials into value-added food ingredients, this research promotes sustainability, supports circular economy principles, and creates opportunities for farmers and small-scale food producers to participate in local and global markets. It also addresses a gap in research regarding the direct use of powdered dragon fruit rind in liquid food systems, providing insights into optimal concentrations and processing methods for maintaining color stability, solubility, and pH compatibility.

Incorporating natural pigments such as Moroccan red dragon fruit rind aligns with increasing consumer demand for health-conscious and environmentally responsible food products. It supports the development of safe, appealing, and innovative plant-based beverages, enhancing both the functional and aesthetic quality of soy milk while reinforcing sustainable agricultural practices and promoting locally sourced ingredients.

Objectives of the Study

This study aimed to determine the potential of Moroccan red dragon fruit rind powder as a natural food colorant in soy

milk using varying concentrations (2g, 3g, and 4g) combined with a fixed amount of soy milk (100mL).

Specifically, it sought:

1. To measure the pH level of soy milk samples incorporated with varying concentrations of Moroccan red dragon fruit rind powder;
2. To evaluate the physical characteristics (color intensity and solubility) of soy milk samples incorporated with varying concentration of Moroccan red dragon fruit rind powder; and
3. To assess the effect of different concentrations of Moroccan red dragon fruit rind powder on the color produced when mixed with a fixed amount of soy milk.

Materials and Methods

Materials

The materials used in this study included fresh Moroccan red dragon fruit rind, soybeans, distilled and purified water, a digital weighing scale, cutting board, knife, food dehydrator, grinder, blender, digital pH meter, strainer, filter net mesh, bowls, transparent cups, a standard color rating chart, airtight containers, and 800 mL beakers (See Appendix A, Page 58). The ingredients for preparing the experimental samples consisted of Moroccan red dragon fruit rind powder at concentrations of 2 g, 3 g, and 4 g per sample, combined with 100 mL of soy milk for each treatment.

Methods

Research Design

The study employed a true experimental research design using a Completely Randomized Design (CRD). A true experimental design is characterized by the manipulation of a treatment factor, the inclusion of a control group, and the random assignment of treatments to experimental units to establish a cause-and-effect relationship. In this study, the treatment factor involved varying concentrations of Moroccan red dragon fruit rind powder, while the response parameters measured included the pH level, color intensity, solubility, and the effect of different concentrations on the color produced in soy milk.

The Completely Randomized Design was implemented by randomly assigning homogeneous soy milk samples to four treatment groups, namely the control (0 g) and treatments containing 2 g, 3 g, and 4 g of Moroccan red dragon fruit rind powder per 100 mL of soy milk. Each treatment was replicated three times to enhance the reliability and precision of the results. Randomization ensured that each experimental unit had an equal probability of receiving any treatment, thereby minimizing bias, and reducing the influence of uncontrolled external factors.

This design was appropriate for the study because all experimental units were prepared under identical laboratory conditions and were considered uniform in composition. The CRD allowed a direct and unbiased comparison of the effects of different rind powder concentrations on the measured physico-chemical properties of soy milk. Through this approach, any observed differences in pH level, color intensity, solubility, and color development were attributed primarily to variation in the treatment levels, thereby strengthening the validity and reliability of the findings.

(Montgomery, 2017; Steel, *et al.*, 1997) [31, 32].

Table 1: Treatment

Treatment	Description
T ₁ (Control)	0g Moroccan red dragon fruit rind powder with 100 mL of soy milk
T ₂	2g Moroccan red dragon fruit rind powder with 100 mL of soy milk
T ₃	3g Moroccan red dragon fruit rind powder with 100 mL of soy milk
T ₄	4g Moroccan red dragon fruit rind powder with 100 mL of soy milk

Locale of the Study

The study was conducted at the Food Processing Laboratory, College of Agriculture, Mindanao State University (MSU) Main Campus, located in Marawi City, Lanao del Sur. This location was chosen because it provided access to the necessary laboratory facilities, equipment, and resources required for the preparation and analysis of the experimental samples. The College of Agriculture laboratories were equipped with essential tools such as digital weighing scales, food dehydrators, grinders, blenders, and digital pH meters, which allowed for accurate measurement, processing, and evaluation of the Moroccan red dragon fruit rind powder and soy milk mixtures. Additionally, the controlled environment minimized external factors, such as temperature fluctuations and contamination, ensuring the reliability and validity of the results. The accessibility of the campus also enabled the researchers to efficiently gather and monitor data throughout the study, making it an ideal setting for conducting the experimental research.

Data Gathering Procedure

Measurement of pH

The pH of each soy milk sample containing Moroccan red dragon fruit rind powder was measured using a digital pH meter to determine the acidity levels influenced by different powder concentrations. Before the analysis, the pH meter was carefully calibrated using standard buffer solutions at pH 4.01, 6.86, and 9.18 to ensure the accuracy and reliability of the measurements. For each treatment, which included soy milk mixed with 2 g, 3 g, and 4 g of powdered red dragon fruit rind per 100 mL of soy milk was poured into a clean, transparent cup to allow proper immersion of the electrode and clear visibility of the readings. The electrode was rinsed with distilled water and gently blotted dry before each measurement to prevent contamination and carry-over from previous samples. It was then immersed in the sample and left until the reading stabilized, ensuring that the displayed pH value reflected the true acidity of the mixture. The pH reading was recorded carefully, and the electrode was rinsed again between each measurement to maintain the integrity of subsequent samples. This procedure was repeated for all treatments and replications to obtain consistent and reliable data. The methodology followed AOAC Official Method 981.12 (AOAC International, 2019), ensuring standardized and widely accepted procedures for pH analysis in food systems.

Color Intensity Assessment

The visual color intensity of the samples was evaluated using a 5-point scoring method. Each treatment and replication were poured into a transparent cup and placed against a white background under natural white light to maintain consistent observation conditions. Samples were compared to a Standard Color Rating Chart, and scores were assigned as follows: 1 = very pale, 2 = pale, 3 = moderate, 4 = strong, and 5 = very intense. The assigned scores were

recorded for each replicate, providing quantitative data for color intensity. This method was adapted from the USDA Standard Color Classification Chart (Perez *et al.* (2021) ^[33].

Solubility Test

The solubility of red dragon fruit rind powder in soy milk was determined by adding 2 g, 3 g, and 4 g of the powder to the corresponding soy milk samples. Each mixture was stirred for 1 minute and allowed to stand for 5 minutes. Samples were then observed for sediments or undissolved powder, and solubility was rated using a 5-point scale: 1 = poor (heavy sedimentation), 2 = fair (visible clumps), 3 = moderate (partly dissolved), 4 = good (minimal sediment), and 5 = excellent (fully dissolved). The solubility scores were recorded for all treatments and replications, following the procedures of Jeyakumar and Kandasamy (2020) ^[13].

Effect of Different Concentrations Assessment

To assess the effect of different concentrations of Moroccan red dragon fruit rind powder on the color produced in soy milk, a fixed amount of soy milk (100mL) was used for each treatment. Samples were prepared by adding 2g, 3g, and 4g of rind powder, while a sample without powder served as the control. All samples were thoroughly mixed to ensure uniform dispersion of the pigment. The resulting color of each treatment was evaluated visually using 5-point color intensity scoring method. This method was adopted from USDA Standard Color Classification Chart and the procedure describe by Peres *et al.*. Each sample was poured into a transparent container and placed against a white background under natural white light to ensure consistent observation. Scores range from 1 (very pale) to 5 (very intense). The values were recorded and compared across treatments. This assessment provided the baseline data needed to determine the effect concentrations of rind powder influenced the color intensity and uniformity of soy milk.

Data Analysis

All data obtained from the pH measurement, color intensity, solubility tests and effect of different concentrations assessment were carefully recorded for each treatment and replication. Each treatment was conducted in three replications, and the results from these trials were averaged to determine the mean value for each treatment. This approach ensured that the measurements accurately reflected the effects of Moroccan red dragon fruit rind powder. The recorded data were encoded and processed using Microsoft Excel. These tools were used to organize, tabulate, and calculate the averages of the measurements, allowing for systematic and efficient handling of all experimental results. Once the data were tabulated, the treatment means were subjected to statistical analysis to determine significant differences among treatments. Analysis of Variance (ANOVA) was employed to compare the means of the treatment groups and to test whether the observed differences were statistically significant. Following

ANOVA, Tukey's multiple comparison test was performed to identify which specific treatment pairs differed significantly.

The application of ANOVA and Tukey's test ensured a rigorous evaluation of the data. The systematic recording, averaging, tabulation, and statistical analysis provided reliable evidence for interpreting the effects of different concentrations of Moroccan red dragon fruit rind powder on soy milk, thereby strengthening the validity and credibility of the study's findings.

Statistical Tools

The data gathered in this study were subjected to appropriate statistical analyses to determine significant differences among treatments and to interpret the effects of Moroccan red dragon fruit rind powder on the pH, color intensity, and solubility and effect of different concentration on the color produced in soy milk. The use of statistical tools allowed for an objective and systematic.

Analysis of Variance (ANOVA) was employed to compare

the means of the different treatment groups. The test was used to determine whether the observed differences among the treatments were statistically significant or simply due to random variation. By analyzing the variation within and between treatment groups, ANOVA provided a comprehensive assessment of the effects of the different concentrations of dragon fruit rind powder.

Following ANOVA, Tukey's multiple comparison test was performed to identify which specific treatment pairs differed significantly. This post-hoc test allowed for a more detailed understanding of the relationships among treatments and highlighted which concentrations of the powder had the greatest impact on the measured parameters.

The combinations of ANOVA and Tukey's test ensured that the data were analyzed in an objective. These statistical tools provided reliable evidence for interpreting the effects of Moroccan red dragon fruit rind powder in soy milk and strengthened the validity of the study's findings.

Experimental Procedure Flow

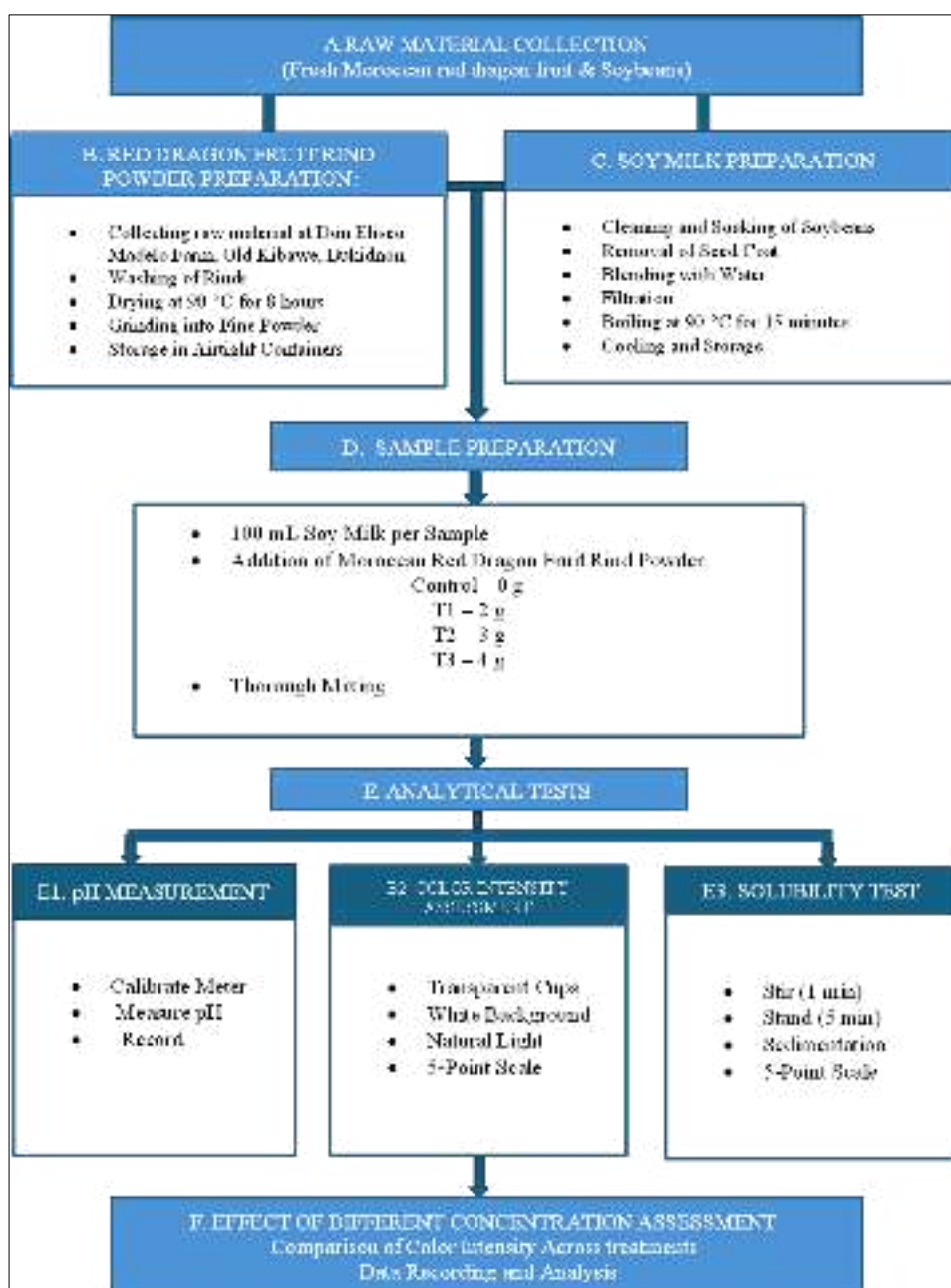


Fig 1: Experimental Procedure Flow

The experimental procedure began with the collection of raw materials, specifically fresh Moroccan red dragon fruit and soybeans. The red dragon fruit rinds were washed, dried at 90 °C for eight hours, ground into a fine powder, and stored in airtight containers. Simultaneously, soy milk was prepared by cleaning and soaking the soybeans, removing the seed coat, blending with water, filtering, boiling at 90 °C for 15 minutes, and allowing the mixture to cool before storage. Sample preparation was then conducted using 100 mL of soy milk per sample, to which varying concentrations of Moroccan red dragon fruit rind powder were added: 0g for the control, 2g for Treatment 1, 3g for Treatment 2, and 4g for Treatment 3, followed by thorough mixing.

After preparation, the sample were subjected to analytical tests to evaluate their characteristics. The pH of each sample was measured using a calibrated pH meter and recorded

accordingly. Color intensity was assessed using transparent cups placed using a 5-point scale. Solubility was evaluated by stirring the samples for one minute, allowing them to stand for five minutes, and assessing sedimentation using a 5-point scale. Finally, the results were compared to determine the effect of different concentrations of red dragon fruit rind powder, and the data were systematically recorded and analyzed.

Results and Discussions

pH Level of Soy Milk

This section analyzed the pH level of soy milk incorporated with varying concentrations of Moroccan red dragon fruit rind powder. The parameter determined whether the addition of rind powder altered acidity, which was important for color stability and beverage quality.

Table 2: Mean pH Level of Soy milk

Treatment	Replication 1	Replication 2	Replication 3	Mean
Treatment 1 (Control)	5.75	5.79	5.76	5.77
Treatment 2 (2g)	5.44	5.42	5.44	5.43
Treatment 3 (3g)	5.36	5.35	5.37	5.36
Treatment 4 (4g)	5.22	5.23	5.22	5.22

ANOVA Test Result: $F = 914.08$; $p\text{-value} = 0.000 < 0.05$ (significant)

Table 2 shows the mean pH level ($\bar{x}$) of the four groups, namely, the control group, Treatment 1, Treatment 2, and Treatment 3. The mean pH level of the control group is 5.77, the highest among the groups. Treatment 2 has a mean pH level of 5.43, while Treatment 3 has a mean pH level of 5.36, and Treatment 4 has a mean pH level of 5.22. The values observed indicated that as the grams increased, there is a decrease in the pH level.

The ANOVA test showed that there was a significant difference in the pH level of the different treatment groups. By Tukey's multiple comparison test, each pair of treatment groups had a significant difference in pH level as follows: (1) Control Group vs. Treatment 2 had a difference of 0.33 in pH level ($t = -30.86$; $p\text{-value} = 0.000$; significant); (2) Control Group vs. Treatment 3 had a difference of 0.41 in pH level ($t = -37.65$; $p\text{-value} = 0.000$; significant); (3) Control Group vs. Treatment 4 had a difference of 0.54 in pH level ($t = -50.30$; $p\text{-value} = 0.000$; significant); (4) Treatment 2 vs. Treatment 3 had a difference of 0.07 in pH level ($t = -6.79$; $p\text{-value} = 0.001$; significant); (5) Treatment 2 vs. Treatment 4 had a difference of 0.21 in pH level ($t = -19.44$; $p\text{-value} = 0.000$; significant); and (6) Treatment 3 vs. Treatment 4 had a difference of 0.14 in pH level ($t = -12.65$; $p\text{-value} = 0.000$; significant).

According to Herbach *et al.* (2016) [12], who investigated betalain-containing plant materials, betalains were weakly acidic compounds composed of betacyanins and betaxanthins that naturally reduced the pH of aqueous systems. They explained that betalains carried ionizable acidic groups that released hydrogen ions into the solution, resulting in increased acidity. Their study further revealed that betalain pigments were highly sensitive to alkaline environments, where rapid degradation, discoloration, and structural breakdown occurred due to hydrolysis and oxidation reactions. They also emphasized that betalains exhibited maximum stability in slightly acidic conditions and that acidification helped maintain their chromophore structure, thereby preserving their red-violet color. This finding strongly supported the present study because the addition of moroccan red dragon fruit rind powder led to a

progressive decrease in pH, resulting in an acidic environment that favored the stability of betalain pigments present in the soy milk formulation.

Priatni and Pradita (2015) [23] conducted a stability assessment of betacyanin pigments extracted from red dragon fruit peel under different pH, temperature, and storage conditions. They reported that as the concentration of red dragon fruit peel extract increased in beverages, there was a corresponding decline in pH due to organic acids such as citric acid, malic acid, and ascorbic acid present in the peel. Their study further showed that pigment stability was significantly higher under acidic conditions, whereas neutral and alkaline environments triggered pigment degradation, causing a reduction in redness and the formation of brown degradation products. They concluded that betacyanin pigments behaved as both natural acidifiers and natural colorants in beverages. These findings reinforced the observations in the present research, where higher concentrations of Moroccan red dragon fruit rind powder resulted in lower pH values in soy milk, demonstrating that rind powder not only provided color but also contributed to acidification that supported pigment stability.

Kujala *et al.* (2020) [15] examined betalain stability across different acidity levels and confirmed that betalains maintained their molecular structure and antioxidant activity more efficiently within pH 4.0-6.0. They also found that when pH values shifted toward neutrality or alkalinity, betalains underwent irreversible structural rearrangements that caused rapid color fading. In their study, betalain-rich extracts displayed stronger color retention and higher solubility in acidic systems compared with neutral ones. The authors emphasized that food developers must control pH to protect betalain-based pigments during product processing and storage. This aligned closely with the present study, where the pH levels of soy milk after the addition of rind powder remained within mildly acidic conditions, indicating a favorable environment for pigment stability and supporting the conclusion that Moroccan red dragon fruit rind powder was suitable for use as a natural food colorant.

Color Intensity of Soy Milk

This section analyzes the color intensity of soy milk beverages added with Moroccan red dragon fruit rind powder. Color intensity reflected pigment concentration and

consumer visual acceptance. Color was measured using a 5-point visual scoring scale. In addition to numeric scores, verbal color description was added.

Table 3: Mean Color Intensity of Soy milk

Treatment	Replication 1	Replication 2	Replication 3	Mean
Treatment 1 (Control)	1	1	1	1
Treatment 2 (2g)	3	3	3	3
Treatment 3 (3g)	4	4	4	4
Treatment 4 (4g)	5	5	5	5

ANOVA Result: $F = 8.75 / 0$ (undefined)

Table 3 shows the mean color intensity of the four groups, namely, the control group, Treatment 1, Treatment 2, and Treatment 3. The mean color intensity of the control group is 1 (Very Pale), the lowest among the groups. Treatment 2 has a mean color intensity of 3 (Moderate), while Treatment 3 has a mean color intensity of 4 (Strong), and Treatment 4 has a mean color intensity of 5 (Very Intense). The values observed indicated that as the grams increased, there is an increase in the color intensity. Due to no variation in the replicates per treatment group, the F-value of the ANOVA has a zero-residual denominator ($F\text{-value} = 8.75 / 0$).

Mahattanatawee *et al.* (2021) [20] evaluated different cultivars of dragon fruit and reported that the rind contained significantly higher concentrations of betacyanins than the flesh, making the peel an excellent source of natural red pigment. They observed that when higher amounts of rind extract or powder were added to food systems, the intensity of red coloration increased correspondingly because of increased chromophore density. Their research demonstrated that betalains in dragon fruit had strong tinctorial strength, meaning even small increases in concentration yielded noticeable changes in the perception of redness. This directly supported the present findings, where increasing Moroccan red dragon fruit rind powder levels from 2 g to 4 g resulted in stronger color intensity in soy milk samples, confirming that rind powder acted as an efficient natural pigment source.

Widyasanti *et al.* (2020) [28] explored the application of dragon fruit peel pigments as natural colorants in beverages and confectionery systems. They found that higher pigment concentration not only enhanced redness but also improved product attractiveness and perceived freshness. Their study

further reported that dragon fruit peel pigments remained visually stable in acidic beverage environments but showed fading under prolonged light or heat exposure. Importantly, they emphasized that consumers showed strong preference for food products with visibly intense natural color compared with synthetic dyes. The present study supported these findings because higher concentrations of rind powder yielded very intense red coloration, suggesting that Moroccan red dragon fruit rind powder could significantly improve product appeal in soy milk-based beverages. Francis and Markakis (2021) [10] focused on the role of food colorants in influencing consumer perception and buying behavior. They stated that color intensity was one of the most important sensory attributes because consumers associated deep, uniform color with freshness, sweetness, quality, and nutritional value. Their research highlighted that natural colorants such as betalains did not only provide pigmentation but also added functional properties such as antioxidant capacity. They further emphasized that increasing concentration of natural pigments generally improved color strength up to a certain saturation point. The present study reflected this pattern, as the soy milk samples treated with higher concentrations of dragon fruit rind powder exhibited stronger color intensity scores, indicating that rind powder could serve both aesthetic and functional purposes in food product development.

Solubility of Soy Milk

This section analyzes solubility, referring to how well the rind powder dissolved in soy milk without sediment formation. Solubility was important for uniform color and consumer acceptability.

Table 4: Mean Solubility of Soy Milk

Treatment	Replication 1	Replication 2	Replication 3	Mean
Treatment 1 (Control)	0	0	0	0
Treatment 2 (2g)	3	4	4	3.67
Treatment 3 (3g)	3	3	3	3
Treatment 4 (4g)	2	2	2	2

ANOVA Test Result: $F = 92.0$; $p\text{-value} = 0.0025 < 0.05$ (significant);

Mean: 1 (Poor); 2 (Fair Visible slumps); 3 (Moderate-Partly dissolved); 4 (Good - Minimal Sediment); 5 (Excellent-Fully dissolved)

Table 4 shows the mean solubility of the four groups, namely the control group, Treatment 1, Treatment 2, and Treatment 3. The mean solubility of the control group is 0, the lowest among the groups. Treatment 2 has a mean solubility of 3.67 (Moderate to Good). This is described as partly dissolved with minimal sediment. Treatment 3 has a mean solubility of 3 (Moderate - partly dissolved), and

Treatment 4 have a mean solubility of 2 (Visible clumps). The values observed indicates that as the grams increased, there is a decrease in mean solubility. The ANOVA test shows that there is a significant difference in the solubility of the different treatment groups ($F = 92.0$; $p\text{-value} = 0.0025$; significant). By Tukey's multiple comparison test, each pair of treatment groups has a significant difference in mean solubility except between Treatment 2 and Treatment 3, which have no significant difference in their solubility. By pairwise comparison: (1) Control Group vs. Treatment 2

has a difference of 3.67 in mean solubility ($t = 15.56$; p -value = 0.000; significant); (2) Control Group vs. Treatment 3 has a difference of 3.0 in mean solubility ($t = 12.73$; p -value = 0.000; significant); (3) Control Group vs. Treatment 4 has a difference of 2.0 in mean solubility ($t = 8.49$; p -value = 0.000; significant); (4) Treatment 2 vs. Treatment 3 has a difference of 0.67 in mean solubility ($t = -2.83$; p -value = 0.085; not significant); (5) Treatment 2 vs. Treatment 4 has a difference of 1.67 in mean solubility ($t = -7.07$; p -value = 0.000; significant); and (6) Treatment 3 vs. Treatment 4 has a difference of 1.0 in mean solubility ($t = -4.24$; p -value = 0.012; significant).

Jeyakumar and Kandasamy (2020) [13] analyzed the solubility characteristics of natural pigments in dairy and non-dairy liquid systems. They found that solubility depended greatly on pigment concentration, particle size, and the composition of the liquid medium. Their results showed that increasing pigment concentration beyond solubility capacity led to particle aggregation, sedimentation, and visible clumping because undissolved solids settled at the bottom of the container. They further noted that plant-based beverages such as soy milk contained proteins that interacted with pigment particles, changing dispersion behavior. These findings closely paralleled those obtained in the present study, where solubility was good at moderate concentrations but decreased at the highest concentration level of 4 g rind powder.

Wong and Siow (2021) [30] examined the solubility and dispersion of natural pigments in plant-based beverages including almond milk and soy milk. They observed that pigment powders first underwent hydration and then dispersion, and insufficient hydration led to insoluble aggregates that appeared as clumps in solution. Their study also reported that soy proteins formed complexes with pigments, reducing solubility and causing sediments. They concluded that lower pigment dosages favored dissolution, while excessively high amounts exceeded solvent capacity. These results directly supported the outcome of this study, where 2 g and 3 g of Moroccan red dragon fruit rind powder dissolved better than 4 g, which showed visible clumping and reduced solubility.

Ma *et al.* (2022) [19] investigated factors improving solubility of natural pigment powders and found that encapsulation, fine milling, and reduction of particle size significantly enhanced dispersion in beverages. They stated that coarse powders dissolved slowly and tended to sediment, while fine powders dissolved more quickly due to greater surface area contact with water. They further emphasized that solubility decreased at high concentrations because the liquid medium became saturated, leaving excess solids undissolved. This observation supported the present study, where higher concentrations of Moroccan red dragon fruit rind powder showed decreased solubility, indicating that both particle size and concentration played key roles in dispersion in soy milk systems.

The Assessment on the Effect of Different Concentrations on the Color Produced in Soy Milk

The effect of varying concentrations of Moroccan red dragon fruit rind powder on the color produced in soy milk was clearly evaluated by integrating the results of pH level, color intensity, and solubility analyses. Together, these parameters explained not only how color intensity changed with concentration, but also why these changes occurred and

how stable and uniform the resulting color appeared in the beverage.

Widyasanti *et al.* (2020) [28] and Jaafar *et al.* (2021) [29] reported that red dragon fruit peel contained high concentrations of betalains, especially betacyanins, which were water-soluble pigments responsible for red coloration in food and beverages. Nurliyana *et al.* found that the peel, often discarded during processing, contained higher pigment concentrations than the flesh, making it an underutilized but valuable source of natural colorants. Sari *et al.*, (2018) [26] observed that betalains were not only visually impactful but also possessed antioxidant and anti-inflammatory properties, making them functional ingredients for food systems. These studies supported the integration of parameters such as pH, pigment concentration, and solubility in assessing the visual appearance and stability of soy milk when supplemented with Moroccan red dragon fruit rind powder.

Influence of Concentration and pH on Color Formation

Results from Table 2 demonstrated that increasing the concentration of rind powder from 0 g (control) to 4 g caused a progressive decrease in soy milk pH from 5.77 to 5.22. This acidification played a critical role in color production because betalain pigments responsible for the red coloration were known to be more stable and visually intense in mildly acidic environments. As rind powder concentration increased, the release of organic acids and ionizable groups from the betalains enhanced acidity, creating conditions that favored pigment stability and chromophore preservation. Consequently, the increasingly acidic environment supported stronger and more stable red coloration in the soy milk.

Herbach *et al.* (2016) [12] and Kujala *et al.* (2020) [15] reported that betalains, including betacyanins from red dragon fruit, remained most stable and visually vibrant in mildly acidic conditions, typically between pH 3 and 6. Liu and Chang (2016) [18] and Yoon *et al.*, found that unfermented soy milk had a near-neutral pH (6.7-6.9), which limited pigment stability when incorporated directly. In the present study, increasing the powder concentration lowered the pH, creating a favorable acidic environment for pigment preservation. These observations aligned with previous research showing that slight acidification enhanced betalain stability, maintained color intensity, and preserved antioxidant properties in plant-based beverages (Azeredo, 2019; Strack & Vogt, 2021) [2].

Effect on Color Intensity

Color intensity results in Table 3 showed a direct and proportional relationship between rind powder concentration and visual color strength. The control sample remained very pale (mean score = 1), indicating the absence of pigment contribution. At 2 g, the soy milk exhibited moderate red coloration (mean = 3), which intensified to strong (mean = 4) at 3 g and reached very intense coloration (mean = 5) at 4 g. This clear gradient confirmed that higher concentrations introduced greater amounts of betalain pigments, increasing chromophore density and enhancing visual redness. The lack of variation among replicates further suggested that color formation was consistent and reproducible within each treatment level.

Naderi *et al.* (2010) [21] and Rebecca *et al.* observed that higher concentrations of red dragon fruit peel extract in beverages resulted in proportional increases in color

intensity due to increased availability of betacyanins. Jaafar *et al.* (2021)^[29] found that freeze-dried powders-maintained pigment integrity and produced strong coloration even at higher dosages, while high-temperature drying caused degradation. Lim *et al.* (2020)^[17] and Esatbeyoglu *et al.* highlighted that pigment concentration and particle size significantly influenced visual color strength, with finer powders producing deeper, more uniform coloration. These studies supported the present findings that increasing powder concentration produced progressively stronger red color in soy milk, and consistent replicate results indicated effective dissolution and dispersion of pigments.

Role of Solubility in Color Uniformity

While higher concentrations improved color intensity, solubility results (Table 4) revealed an important limitation. Moderate concentrations (2 g and 3 g) showed better dispersion and more uniform coloration, described as moderate to good solubility. In contrast, the highest concentration (4 g) exhibited visible clumps and reduced solubility, indicating pigment saturation and aggregation. Although this treatment produced the most intense color, incomplete dissolution may have compromised color uniformity and visual quality, potentially leading to sedimentation during storage. Thus, optimal color production depended not only on pigment quantity but also on how well the powder dispersed in the soy milk matrix. Jeyakumar and Kandasamy (2020)^[13] reported that solubility of natural pigments depended on concentration, particle size, and interactions with the liquid matrix. Excessive pigment concentrations exceeded the solubility limit, leading to aggregation, clumping, and sedimentation. Wong and Siow (2021)^[30] noted that protein-pigment interactions in soy milk reduced solubility, causing uneven color distribution. Ma *et al.* (2022)^[19] emphasized that fine milling and encapsulation improved solubility and dispersion by increasing surface area contact with water. These studies validated the observation that moderate concentrations (2-3 g) dissolved properly, producing uniform color, whereas the highest concentration (4 g) exceeded solubility capacity, resulting in reduced visual quality.

Overall Assessment

Overall, increasing the concentrations of Moroccan red dragon fruit rind powder significantly enhanced the red color intensity of soy milk by lowering pH and increasing betalain pigment availability. The most visually balanced outcome appeared at moderate concentrations (2-3 g), where strong coloration was achieved alongside acceptable solubility and uniform appearance. At higher concentrations (4 g), color intensity was maximized but at the expense of solubility and homogeneity. These findings indicated that Moroccan red dragon fruit rind powder was an effective natural colorant for soy milk, with concentration optimization being essential to balance color strength, stability, and product quality.

Pham *et al.* (2025)^[34] demonstrated that optimized processing methods, such as freeze-drying and ultrasonic-assisted extraction, preserved both pigment stability and solubility for application in beverages. Priatni and Pradita (2015)^[23] reported that moderate pigment concentrations under mildly acidic conditions produced the best balance between color intensity, solubility, and storage stability. Sari

et al., (2018)^[26] emphasized that while water-soluble betalains could be incorporated into soy milk effectively, excessive concentrations reduced dispersion and resulted in uneven coloration. These findings confirmed that 2-3 g of Moroccan red dragon fruit rind powder produced visually balanced, stable, and uniform red color, whereas higher concentrations, despite maximum intensity, reduced overall product quality due to solubility limitations.

Conclusion

Based on the results of this study, it was concluded that Moroccan red dragon fruit rind powder had significant potential as a natural colorant in soy milk, and its effects were directly influenced by the concentration used. The study revealed that the addition of the rind powder significantly lowered the pH of soy milk, with higher concentrations producing a more acidic environment. This acidification was attributed to the presence of organic acids and betalain compounds in the rind powder, which released hydrogen ions into the solution. The mildly acidic condition created by the powder supported the stability of betalain pigments, preserving their red coloration and preventing rapid degradation that typically occurs in neutral or alkaline environments.

The study also demonstrated that color intensity increased progressively with higher concentrations of Moroccan red dragon fruit rind powder. Soy milk samples with 2 g of powder produced moderate red coloration, 3 g produced strong red, and 4 g produced very intense red color. The increasing pigment concentration supplied more betalains, enhancing chromophore density and visual redness. The results indicated that higher concentrations of rind powder were effective in improving the aesthetic appeal of soy milk, confirming the functional role of the powder as a natural food colorant.

However, the solubility of the powder in soy milk was affected by concentration. Moderate concentrations (2-3 g per 100 mL) dissolved effectively, resulting in a uniform and visually acceptable color. In contrast, the 4 g treatment showed visible clumping and reduced solubility, which led to uneven dispersion and could compromise the homogeneity of the beverage. These findings indicated that although higher concentrations produced the most intense color, excessive powder could exceed the solubility capacity of soy milk, negatively affecting overall quality.

The study further showed that the effect of powder concentration on color formation was a combination of pH reduction, pigment availability, and solubility. Moderate concentrations of 2-3 g per 100 mL were found to provide the most balanced outcome, achieving strong coloration while maintaining good solubility and uniform appearance. Therefore, the study confirmed that Moroccan red dragon fruit rind powder was capable of producing stable, attractive, and functional color in soy milk, with optimal results achieved at moderate concentrations.

Recommendations

- **Dragon fruit Farmers:** They should be encouraged to use red dragon fruit rinds to produce value-added products such as natural food colorants. This could increase income, reduce waste, and promote sustainable farming, especially during periods of oversupply.
- **Food Manufacturers:** They may consider adopting dragon fruit rind powder as a natural and sustainable

alternative to synthetic colorants. Its use could enhance clean-label appeal across beverages, dairy alternatives, confectionery, and baked goods, while supporting eco-friendly innovation and meeting growing consumer demand for chemical-free products.

- **Food Industry:** Food manufacturers are advised to explore the use of dragon fruit rind powder as a natural alternative to synthetic colorants in beverages, dairy substitutes, confectioneries, and baked goods. Incorporating natural pigments may help companies meet consumer demand for clean-label and chemical-free products, while also promoting sustainability. Further research into processing stability, shelf-life, and sensory appeal of products using dragon fruit rind powder is encouraged.
- **Consumers:** They are encouraged to choose food products that utilize natural pigments such as dragon fruit rind powder. Awareness campaigns highlighting the health benefits of betalains, including antioxidant properties, may help consumers make informed and safer food choices, particularly for children, the elderly, and health-conscious individuals.
- **Local Economy:** Local entrepreneurs and community-based industries are recommended to explore business opportunities involving the processing and commercialization of dragon fruit rind. Investment in value-added products could generate employment, promote innovation, and strengthen agricultural value chains, ultimately contributing to sustainable economic growth in rural areas.
- **Researchers:** Are encourage to further investigate the potential applications and improvements of dragon fruit rind powder as a natural food colorant and functional ingredient.
 - a) Future researchers may apply dragon fruit rind powder in different food systems such as plant-based beverages, dairy alternative, baked goods, and confectionery products to evaluate its effectiveness and performance as a natural colorant across various food matrices.
 - b) They may examine the effects of different processing techniques, including drying methods, particle size reduction, and encapsulation, on the color intensity, solubility, and stability of dragon fruit rind powder.
 - c) Further studies may assess the sensory acceptability, shelf-life, and consumer perception of food products formulated with dragon fruit rind powder under actual storage and market conditions.
 - d) Future researchers may also explore the functional and bioactive properties of dragon fruit rind powder, such as antioxidant activity, and evaluate its potential applications in nutraceutical, cosmetic, and pharmaceutical products to support sustainable and green product development.

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