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Nutritional, Bioactive and Sensory Properties of Dairy–Oat–Cinnamon Coated Dried Banana Slices

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Abstract: This study investigated the effects of dairy–oat–cinnamon coating formulations on the nutritional, bioactive, antioxidant, and sensory properties of dried banana slices. Ripe banana slices were divided into three different treatments and conditions: T₀, T₁ and T₂ which immersed in a coating solution containing milk powder, cinnamon powder and oat flour. All samples were dried in a hot-air oven at 50°C/16h and evaluated for proximate composition, potassium and calcium contents, total phenolic content (TPC), total flavonoid content (TFC), DPPH radical-scavenging activity, and sensory characteristics. The coating treatments significantly modified the nutritional and functional properties of the dried banana slices. Protein and calcium contents increased in T₂ (12.80% and 141.50 mg/100 g DW, respectively). Moreover, T₂ recorded the highest TFC, TPC and DPPH (34.50 mg QE/100 g, 80.00 mg GAE/100 g, and 60.00%, respectively), compared with others treatments. Sensory evaluation showed that T₂ achieved the highest overall acceptability (8.90 ± 0.32), whereas T₁ obtained the highest color score (9.60 ± 0.52). Overall, incorporation of the dairy–oat–cinnamon coating, particularly the T₂ formulation, enhanced several nutritional, bioactive, antioxidant, and sensory attributes of dried banana slices, supporting its potential for developing an enriched and acceptable dried banana product.

Key words: Banana snakes; Dairy–oat–cinnamon coating; Bioactive compounds; Antioxidant activity; Sensory evaluation.

1. Introduction

Bananas (*Musa* spp.) are widely consumed fruits owing to their nutritional value, palatability, accessibility, and versatility in food applications. They provide important nutrients, including carbohydrates, dietary fiber, potassium, and various bioactive compounds, which support their potential as a raw material for the development of value-added and functional food products. However, bananas are highly perishable climacteric fruits characterized by rapid ripening and substantial postharvest physiological and biochemical changes. Their high perishability therefore represents a major challenge

for postharvest handling and utilization (**Wang *et al.*, 2024 and Shinga *et al.*, 2025**). Drying is an important preservation method for extending the usability of bananas and producing convenient, shelf-stable snack products. However, drying conditions can substantially influence the nutritional, physicochemical, structural, and sensory properties of banana slices. Thermal drying may promote shrinkage, browning, structural changes, and alterations in bioactive compounds and antioxidant activity, making the selection of suitable pretreatment and drying conditions important for maintaining product quality (**Nadery Dehsheikh *et al.*, 2025; Atmaca and Büyükcan, 2025**).

Edible coatings are generally formulated from food-grade proteins, polysaccharides, lipids, or their combinations and form a thin protective layer on the food surface. Depending on their composition and structural properties, these coatings can regulate moisture transfer and gas exchange, reduce oxidative deterioration, delay quality losses, and provide a matrix for the incorporation of antioxidant or antimicrobial compounds. Composite coating systems are particularly attractive because combining different biopolymers and functional ingredients can provide complementary barrier and functional properties that may not be achieved using a single coating component (**Gammage and Marangoni, 2025; Pillai *et al.*, 2024; Gidado *et al.*, 2025**). The application of edible coatings to bananas has received increasing scientific attention because of the rapid postharvest deterioration of this fruit. Recent studies have shown that edible coatings can reduce weight loss, delay softening and ripening, modulate respiration and ethylene production, and contribute to the preservation of antioxidant systems and overall fruit quality. However, the effectiveness of a coating is strongly dependent on its composition, concentration, permeability, and interaction with the characteristics of the fruit matrix (**Shinga *et al.*, 2025**).

The incorporation of nutritionally and functionally active ingredients into coating systems provides an additional opportunity to develop value-added fruit products. Dairy-derived ingredients, particularly milk proteins, possess good film-forming and water-binding properties and can contribute to the nutritional value and structural characteristics of food matrices. In parallel, oats (*Avena sativa* L.) are recognized as a source of dietary fiber, particularly β -glucan, as well as several bioactive constituents (**Li *et al.*, 2024**). Cinnamon represents another potentially valuable functional component for incorporation into food systems. Cinnamon contains a range of phenolic compounds and flavonoids, in addition to characteristic compounds such as cinnamaldehyde. These constituents have been associated with substantial antioxidant activity and may contribute to the oxidative stability and functional properties of food formulations (**Lazaridis *et al.*, 2024**). Accordingly, combining dairy- and cereal-derived ingredients with cinnamon in a coating matrix may provide a multifunctional system in which nutritional enhancement, structural modification, and antioxidant functionality are integrated within a single food application. Such an approach is consistent with recent developments in composite edible coatings, which emphasize the potential advantages of combining proteins, polysaccharides, and bioactive compounds to obtain improved functional performance and tailored barrier properties (**Gammage and Marangoni, 2025; Kumar *et al.*, 2025**).

Despite the increasing application of edible coatings in fruit preservation, relatively limited information is available on the development of dried banana slices incorporating a dairy–cereal coating matrix enriched with cinnamon and on the simultaneous evaluation of their nutritional, physicochemical, and antioxidant characteristics. In particular, the potential contribution of combining milk powder, oat flour, and cinnamon to the quality characteristics of dried banana slices warrants further investigation. Therefore, developing such a composite system may provide a practical approach for improving the functional and technological characteristics of banana-based snack products while utilizing food-grade and nutritionally relevant ingredients. Therefore, the present study aimed to develop functional dried banana slices using a composite coating containing milk powder, oat flour, and cinnamon and to evaluate their proximate composition, selected physicochemical characteristics, bioactive compounds, antioxidant activity, and mineral composition. The study was designed to determine whether incorporation of these functional ingredients could improve the nutritional and functional characteristics of dried banana slices and provide a promising approach for the development of value-added functional snack products.

2. Materials and Methods

Fresh ripe bananas (*Musa* spp.) were obtained from a local market (Cairo, Egypt) and selected based on uniform maturity, peel color, and absence of visible physical damage. Full cream milk powder, oat flour, and ground cinnamon were used as coating ingredients. Bananas were peeled manually and sliced into uniform thickness (~3–5 mm) using a stainless-steel slicer to ensure homogeneity during drying (Doymaz, 2010; Krokida *et al.*, 2003). The experimental design consisted of three treatments: T₀: Untreated banana slices (Control); T₁: Banana slices coated with milk powder (5%, w/v) and cinnamon (1%, w/v); T₂: Banana slices coated with milk powder (5%, w/v), cinnamon (1%, w/v) and oat flour (5%, w/v). Each coating formulation was prepared using 100 mL of distilled water, and the banana slices (T₁ and T₂) were immersed for 10 min before drying. All samples were dried in a hot-air oven at 50°C/16h and effective incorporation of functional ingredients according to Shinga *et al.* (2025) and Zhang *et al.* (2024). All treatments conducted in triplicate (n=3) and drying in a hot-air oven (Thermo Scientific Heraeus) at 50°C/16 h until constant weight (Nadery Dehsheikh *et al.*, 2025; Doymaz, 2010). However, all chemicals and analytical reagents used throughout the study were of analytical grade.

2.1. Proximate Composition analysis

The proximate composition of dried banana slices, including crude protein, crude fat, crude fiber, and ash, was determined according to the standard methods of AOAC International (2019). Total carbohydrate content was calculated by difference using the AOAC equation. All analyses were performed in triplicate. Crude protein content was determined using the Kjeldahl method based on nitrogen determination, and protein values were calculated using a nitrogen conversion factor of 6.25, as well as crude fat was analyzed using Soxhlet extraction with petroleum ether as the extraction solvent. Crude fiber was determined using acid–alkali digestion method, while ash values were used to estimate the total mineral residue present in the samples. Total ash content was determined by incinerating the dried samples in a muffle furnace at 550°C until light gray ash was obtained. On the other hand, total carbohydrate content was calculated by the following equation:

$$\text{Carbohydrates (\%)} = 100 - \%(\text{Protein} + \text{Fat} + \text{Ash} + \text{Crude fiber})$$

Potassium (K) and calcium (Ca) contents were determined using Atomic Absorption Spectrophotometry (AAS) after wet digestion of the samples using nitric acid and perchloric acid mixtures. Mineral concentrations were expressed as mg/100 g dry weight according to standard analytical procedures. The results were expressed as mg/100 g dry weight (DW).

2.2. Determination of bioactive components and antioxidant activity

2.2.1. Total Phenolic Content (TPC)

Total phenolic content (TPC) was determined using the Folin–Ciocalteu colorimetric method according to Kugler *et al.* (2004). Briefly, 50 µL of dried banana extract was mixed with 2.5 mL of 95% ethanol and homogenized thoroughly. The mixture was centrifuged at 1000 rpm /10 min, after which 5 mL of deionized water and 1 mL of 95% ethanol were added. Subsequently, 500 µL of 50% Folin–Ciocalteu reagent was added and mixed thoroughly. After the addition of 1 mL of 5% sodium carbonate (Na₂CO₃), the reaction mixture was vortexed and incubated in the dark for 60 min at room temperature. The absorbance was measured at 725 nm using a UV–Vis spectrophotometer (UVD-3500, Labomed Inc., California, USA). A calibration curve was prepared using gallic acid as the reference standard, and the results were expressed as milligrams of gallic acid equivalents per 100 g dry weight (mg GAE/100 g DW).

2.2.2. Total flavonoid content (TFC)

Total flavonoid content (TFC) was determined using the aluminum chloride colorimetric assay according to Zhishen *et al.* (1999). Briefly, 0.5 mL of the sample extract was mixed with 2.5 mL distilled water, followed by addition of 0.15 mL of 5% sodium nitrite (NaNO₂). After 5 min, 0.15 mL of 10% aluminum chloride (AlCl₃) was added and the mixture was incubated for 6 min. Subsequently, 1.0 mL of 1 M sodium hydroxide (NaOH) was added, and the final volume was adjusted to 5 mL with

distilled water. The solution was mixed thoroughly, and absorbance was measured at 510 nm using a UV–Vis spectrophotometer. Quercetin was used as the calibration standard, and results were expressed as mg QE/100 g.

2.2.3. Antioxidant Activity (DPPH Assay)

Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay according to the method described by **Brand-Williams *et al.* (1995)**. The decrease in absorbance was measured spectrophotometrically, and antioxidant activity was expressed as percentage inhibition of DPPH radicals. The radical scavenging activity was calculated using the following equation:

$$\text{DPPH scavenging activity (\%)} = \frac{A_0 - A_1}{A_0} \times 100$$

Where: A_0 = absorbance of the control, A_1 = absorbance of the sample

2.3. Sensory Evaluation

Sensory evaluation was conducted using a panel of 30 panelists. Samples were evaluated for taste, color, flavor, texture and overall acceptability using a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely). Samples were coded and presented in randomized order under controlled conditions. Sensory evaluation is essential for assessing consumer acceptance and correlating physicochemical attributes with perceived quality (**Stone and Sidel, 2004**).

2.4. Statistical Analysis

Statistical analysis was carried out using IBM SPSS Statistics version 25.0 (**IBM Corp., 2017**). To assess differences between the sample groups, a one-way ANOVA was conducted. Where statistically significant differences were found ($P \leq 0.05$), Duncan's multiple range tests was used for post hoc comparisons to identify which means differed. All results are presented as means $\pm$ standard deviation (SD), with significance accepted at the 5% level (**Kramer, 1956**).

3. Result and Discussion

3.1. Effect of Dairy–Oat–Cinnamon Coating on Nutritional Composition

The nutritional composition of dried banana slices plays a critical role in determining their functionality and consumer value. As shown in Table 1, the incorporation of dairy–oat–cinnamon composite coating significantly ($P \leq 0.05$) modified the proximate composition and mineral profile, reflecting the nutritional contribution of the coating ingredients.

A significant increase ($P \leq 0.05$) in crude protein was observed following coating application, increasing from 3.05% in the untreated control (T_0) to 9.55% and 12.80% in T_1 and T_2 treatments, respectively. Likewise, crude fat content increased from 0.45% to 3.30%, while ash content increased from 2.70% to 4.85%. In contrast, total carbohydrate content decreased progressively from 78.85% in the control to 68.60% in T_2 treatment. Crude fiber remained statistically insignificant changes ($P \geq 0.05$) between T_0 and T_1 but increased significantly in T_2 , reaching 10.75%. In addition, the coated samples T_2 exhibited marked increases in potassium and calcium contents (460.00 mg/100 g DW and 141.50 mg/100 g DW, respectively) followed by T_1 (422.50 and 111.00 mg/100 g DW, respectively) comparing with control (T_0).

The significant changes in the proximate and mineral composition of the dried banana slices demonstrate that the nutritional profile of the final product was strongly influenced by the composition of the applied coating matrix. The progressive differences among T_0 , T_1 , and T_2 can be rationally related to the incorporation of milk powder, oat flour, and cinnamon, although their relative contribution differs according to the concentration and inherent composition of each ingredient. This interpretation is consistent with the current understanding of edible coatings as multifunctional systems that can act not only as protective barriers but also as carriers of functional and nutritionally relevant compounds (**Alemu *et al.*, 2025 and Gidado *et al.*, 2025**).

The pronounced protein observed in the present study can be attributed primarily to the incorporation of full-fat milk powder, which provides high-quality proteins (casein and whey proteins), as well as oat flour further in T₂ may further reflect the contributes proteins addition to dietary fiber and lipids. Milk proteins are known to form cohesive protein networks that enhance coating integrity and facilitate the retention of coating materials on banana surfaces. The increase in crude fat is also compatible with the composition of the coating ingredients, particularly full-fat milk powder, with oat flour providing an additional lipid contribution in T₂. These result was in the same trends with **Shinga *et al.*, (2025)** and **Weng *et al.*, (2026)** whose highlighted dairy proteins as highly effective coating constituents due to their excellent film-forming ability, water-binding capacity, and nutritional contribution of incorporating milk proteins into banana coating systems. On the other side, the previous results confirming that milk powder can provide a concentrated source of both protein and lipid to formulated food systems (**El-Said *et al.*, 2021**).

The further enhancement of protein and fiber in T₂ is consistent with the addition of oat flour. **Gu *et al.* (2022)** reported that oat flour contains substantial protein, dietary fiber, lipids, and unsaturated fatty acids, with their distribution depending on flour characteristics. Therefore, the additional nutritional enrichment observed in T₂ is reasonably attributable to the oat component added to the milk–cinnamon formulation.

The increases in ash, potassium, and calcium indicate an overall enrichment of the mineral fraction. The pronounced calcium increase in T₁ is consistent with the mineral contribution expected from the dairy component, whereas the further increase in T₂ may reflect the additional contribution of oat flour. Cinnamon also contains appreciable potassium, calcium, and other minerals (**Gul and Safdar, 2009**); however, because cinnamon was incorporated at the same relatively low concentration in T₁ and T₂, it is unlikely to explain the additional mineral increase observed specifically in T₂. Thus, its contribution should be considered complementary rather than the principal determinant of the treatment differences.

The lower carbohydrate proportion in the coated samples therefore does not necessarily indicate carbohydrate degradation; rather, incorporation of protein, lipid, fiber, and mineral-containing coating solids changes the relative distribution of the proximate components. The present interpretation is consistent with recent studies on coated dried banana slices. **Nadery Dehsheikh *et al.* (2025)** demonstrated that pre-drying CMC (Carboxymethyl Cellulose) coating combined with ultrasound significantly modified several quality characteristics of dried banana slices. However, their coating was primarily a hydrocolloid-based barrier system, whereas the present formulation contains nutritionally active ingredients.

Overall, the results suggest that milk powder was the major contributor to protein, fat, and calcium enrichment; oat flour provided the additional contribution to protein, fiber, and minerals; while cinnamon likely played a relatively minor role in proximate composition but a potentially more important role in the bioactive profile. The superior nutritional profile of T₂ therefore reflects the combined formulation rather than the action of a single ingredient. Because the experiment did not include separate milk-only, oat-only, or cinnamon-only treatments, these interpretations should be regarded as formulation-based contributions rather than definitive quantitative effects of each individual ingredient.

Table (1). Chemical composition of dried dairy–oat–cinnamon coating banana slices

Treatments	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	Potassium (mg/100g DW)	Calcium (mg/100g DW)
T ₀	3.05±0.05 ^c	0.45±0.05 ^c	7.35±0.15 ^b	2.70±0.20 ^c	78.85±0.35 ^a	355.00±5.00 ^c	5.25±0.25 ^c
T ₁	9.55±0.35 ^b	3.00±0.20 ^b	7.15±0.15 ^b	3.65±0.05 ^b	72.75±0.75 ^b	422.50±2.50 ^b	111.00±1.00 ^b
T ₂	12.80±0.30 ^a	3.30±0.10 ^a	10.75±0.25 ^a	4.85±0.05 ^a	68.60±0.60 ^c	460.00±10.0 ^a	141.50±1.50 ^a

T₀: Untreated banana slices (control); T₁: Banana slices coated with milk powder (5%, w/v) and cinnamon (1%, w/v); T₂: Banana slices coated with milk powder (5%, w/v), cinnamon (1%, w/v) and oat flour (5%, w/v), mean ±SD (n = 3) Different lowercase letters within the same column indicate significant differences among treatments ($P \leq 0.05$). **DW**: dry weight; **SD**: standard deviation.

3.2. Effect of Dairy–Oat–Cinnamon Coating on Bioactive Compounds and Antioxidant Activity

The bioactive profile of dried banana slices is an important indicator of their functional quality, particularly because drying and coating treatments can influence the retention and/or incorporation of phenolic and flavonoid compounds and consequently affect antioxidant activity. Table (2) the dairy–oat–cinnamon coating samples markedly influenced the bioactive profile and antioxidant activity of the dried banana slices ($P \leq 0.05$).

The results showed a clear increase in total flavonoid and phenolic contents with the application of the coatings. Total flavonoid content increased from 18.00 ± 1.00 mg QE/100 g in the control (T_0) to 27.50 ± 0.50 mg QE/100 g in T_1 and 34.50 ± 0.50 mg QE /100 g in T_2 . Similarly, total phenolic content increased from 46.00 ± 7.19 mg GAE/100 g in T_0 to 65.00 ± 2.00 and 80.00 ± 1.00 mg GAE/100 g in T_1 and T_2 , respectively. DPPH radical-scavenging activity also increased from $35.00 \pm 1.00\%$ in T_0 to $48.00 \pm 1.00\%$ in T_1 and $60.00 \pm 1.00\%$ in T_2 . The different lowercase letters indicate significant differences among treatments ($P \leq 0.05$). Overall, T_2 treatment showed the highest values for all measured parameters, followed by T_1 , while T_0 recorded the lowest values.

The progressive increase in total flavonoid content (TFC), total phenolic content (TPC), and DPPH radical-scavenging activity from T_0 to T_1 and T_2 indicates an improvement in the functional properties of the coated dried banana slices. The particularly higher values observed in T_2 may be associated with the additional incorporation of oat flour into the milk–cinnamon coating. This finding is consistent with the study of **Nadery Dehsheikh *et al.* (2025)**, who reported that coating combined with ultrasound pretreatment improved the antioxidant properties of dried banana slices, supporting the potential of pretreatment and coating systems to enhance the functional quality of dried fruit products.

The improvement observed in T_1 compared with the untreated control may be partly attributed to the incorporation of cinnamon, which is a recognized source of phenolic compounds and flavonoids with antioxidant properties. The additional increase in T_2 compared with T_1 is particularly relevant because both treatments contained the same concentrations of milk powder and cinnamon, whereas T_2 additionally contained oat flour. Oat flour contains phenolic acids, flavonoids, and avenanthramides, which contribute to its antioxidant potential; therefore, their incorporation into the coating may have contributed to the higher TFC and TPC observed in T_2 (**Nikolić *et al.*, 2024**). Recent research has likewise demonstrated a positive association between phenolic compounds in oats and their radical-scavenging activity (**Huang *et al.*, 2025**; **Živković *et al.*, 2025**).

The concurrent increase in TPC and DPPH radical-scavenging activity suggests that the enhanced phenolic profile of the coated samples may have contributed to their greater antioxidant activity. Similar associations between phenolic content and antioxidant activity have been reported in processed banana products and other plant-based matrices. However, this relationship should be interpreted cautiously because DPPH activity reflects the combined contribution of different antioxidant compounds rather than phenolics alone. The present findings differ from some reports in which drying reduced phenolic content and antioxidant activity. **Guiné *et al.* (2015)** observed reductions in phenolic compounds and antioxidant activity in bananas subjected to hot-air drying, while **Milani *et al.* (2020)** reported changes in the phenolic profile of banana slices following drying and pretreatment. These differences can be explained by the different experimental comparisons and processing conditions. The present study compared coated and untreated dried banana slices, whereas several previous studies compared fresh and dried fruit. In addition, differences in drying temperature, pretreatment, cultivar, maturity, extraction procedure, and the presence of phenolic-rich coating ingredients can substantially affect the measured TPC, TFC, and DPPH activity.

Overall, the present results demonstrate that the dairy–oat–cinnamon coating, particularly the formulation containing oat flour (T_2), was associated with an enhanced bioactive and antioxidant profile of dried banana slices. Nevertheless, because milk-only, cinnamon-only, and oat-only treatments were not included, the individual contribution of each coating component cannot be quantitatively separated.

Table (2). Effect of Dairy–Oat–Cinnamon Coating on Bioactive Compounds and Antioxidant Activity of Dried Banana Slices

Treatments	Total flavonoids content (mg QE/100 g).	Total phenols content (mg GAE/100 g)	DPPH radical-scavenging activity (%)
T ₀	18.00±1.00 ^c	46.00±7.19 ^c	35.00±1.00 ^c
T ₁	27.50±0.50 ^b	65.00±2.00 ^b	48.00±1.00 ^b
T ₂	34.50±0.50 ^a	80.00±1.00 ^a	60.00±1.00 ^a

T₀: Untreated banana slices (control); T₁: Banana slices coated with milk powder (5%, w/v) and cinnamon (1%, w/v); T₂: Banana slices coated with milk powder (5%, w/v), cinnamon (1%, w/v) and oat flour (5%, w/v), mean values (n = 3) different lowercase letters within the same column indicate significant differences among treatments ($P \leq 0.05$); SD: standard deviation; GAE: Gallic acid equivalent; QE: quercetin equivalents, DPPH: 2,2-diphenyl-1-picrylhydrazyl radical (%).

3.3. Sensory Evaluation and Overall Acceptability of Dried Banana Slices

Sensory evaluation is an essential component of food product development, as nutritional and functional improvements must be accompanied by desirable sensory characteristics and consumer acceptance. Evaluation of attributes such as taste, color, odor, and texture provides an integrated measure of the perceived quality and acceptability of a food product and helps identify formulations with greater consumer appeal (Shariati *et al.*, 2025; de Almeida Costa *et al.*, 2024). Therefore, the sensory evaluation results presented in Table 3 showed significant differences among the treatments ($P \leq 0.05$) for several sensory attributes of the dried banana slices.

Taste scores increased from 8.00 ± 0.67 in the control (T₀) to 8.50 ± 0.53 in T₁ and 9.00 ± 0.00 in T₂. However, the difference between T₁ and T₂ was not statistically significant. Moreover, color scores were significantly higher in T₁ (9.60 ± 0.52) than in the control (8.10 ± 0.57), whereas T₂ (8.80 ± 0.42) showed an intermediate value and did not differ significantly from either treatment. Odor scores increased from 8.20 ± 0.63 in T₀ to 8.50 ± 0.63 in T₁ and 8.70 ± 0.48 in T₂, with T₂ showing a significantly higher score than the control, while T₁ was intermediate. On the other hand, a significant improvement in texture was also observed following coating application. texture scores increased from 8.00 ± 0.67 in T₀ to 8.70 ± 0.48 in T₁ and 9.00 ± 0.00 in T₂, with T₁ and T₂ showing significantly higher scores than the untreated control. Additionally, overall acceptability increased from 7.90 ± 0.57 in T₀ to 8.00 ± 0.53 in T₁ and 8.90 ± 0.32 in T₂. The highest overall acceptability was therefore recorded for T₂, which differed significantly from both T₀ and T₁. Overall, T₂ achieved the highest scores for taste, odor, texture, and overall acceptability, whereas T₁ showed the highest color score.

The sensory results indicate that the dairy–oat–cinnamon coating positively influenced the sensory quality of the dried banana slices, particularly in T₂, which achieved the highest overall acceptability as well as the highest taste, odor, and texture scores, whereas T₁ showed the highest color score. This pattern suggests that the combined formulation provided a more favorable sensory balance than the control and the milk–cinnamon formulation. The present findings are consistent with those of Milani *et al.* (2020), who reported that pretreatment of banana slices before freeze-drying significantly affected their sensory characteristics, with selected pretreatments improving overall acceptance, supporting the importance of modifying the product matrix before drying. Similarly, Abd El-Wahhab *et al.* (2023) demonstrated that pretreatment and drying conditions significantly influenced the color, odor, taste, texture, and overall acceptability of dried banana slices, indicating that processing conditions can substantially determine the final sensory quality.

On the other hand, the favorable texture and overall acceptability observed in the coated samples are consistent with the findings of Macedo *et al.* (2025), who reported that pretreatment of banana slices before convective drying influenced their textural properties and sensory quality, with the optimized treatment achieving satisfactory sensory acceptance. These findings support the potential of suitable pretreatment formulations to improve the sensory quality of dried banana products. In contrast, Alagbe *et al.* (2020) reported that the sensory response of pretreated dried banana varied according to treatment and storage conditions, indicating that sensory improvement is not an inherent consequence of pretreatment and may depend on the formulation and processing conditions.

Taken together, the present results suggest that T₂ provided the most favorable overall sensory profile; however, this improvement should be attributed to the combined dairy–oat–cinnamon formulation rather than to any individual ingredient, since the experimental design did not include separate milk, cinnamon, or oat treatments.

Table (3). Sensory attribute and overall acceptability of dried banana slices as affected by dairy–oat–cinnamon formulations

Treatments	Taste	Color	Flavor	Texture	Overall acceptability
T ₀	8.00±0.67 ^b	8.10±0.57 ^b	8.20±0.63 ^b	8.00±0.67 ^b	7.90±0.57 ^b
T ₁	8.50±0.53 ^{ab}	9.60±0.52 ^a	8.50±0.63 ^{ab}	8.70±0.48 ^a	8.00±0.53 ^b
T ₂	9.00±0.11 ^a	8.80±0.42 ^{ab}	8.70±0.48 ^a	9.00±0.12 ^a	8.90±0.32 ^a

T₀: Untreated banana slices (control); T₁: Banana slices coated with milk powder (5%, w/v) and cinnamon (1%, w/v); T₂: Banana slices coated with milk powder (5%, w/v), cinnamon (1%, w/v) and oat flour (5%, w/v), mean values (n = 3) different lowercase letters within the same column indicate significant differences among treatments (P ≤ 0.05); SD: standard deviation.

4. Conclusion

The present study demonstrated that incorporation of a dairy–oat–cinnamon formulation into dried banana slices substantially modified their nutritional, bioactive, antioxidant, and sensory characteristics. Compared with the untreated control (T₀), the coated treatments (T₁) showed higher protein, fat, ash, potassium, and calcium contents, while the formulation containing oat flour (T₂) produced the greatest enhancement in dietary fiber. The addition of the coating system was also associated with progressive increases in total phenolic content, total flavonoid content, and DPPH radical-scavenging activity, with T₂ exhibiting the highest values among the evaluated treatments. Sensory evaluation further indicated that T₂ provided the most favorable overall acceptability, together with superior taste, odor, and texture scores, whereas T₁ achieved the highest color score.

The enhanced characteristics observed in T₂ may be attributed to the combined contribution of the milk, oat, and cinnamon components, which provided additional protein, minerals, fiber, and antioxidant-related constituents to the final dried product. However, because the experimental design did not include separate milk-, oat-, or cinnamon-only treatments, the individual contribution of each ingredient cannot be quantitatively distinguished. Therefore, the observed improvements should be interpreted as formulation-level effects rather than as definitive effects of individual coating components. Overall, the dairy–oat–cinnamon formulation, particularly T₂, showed promising potential for producing a nutritionally enriched and sensory-acceptable dried banana product. Further studies should investigate coating uptake and retention, textural and physicochemical properties, storage stability, microbial quality, and the individual contribution of each coating ingredient using an expanded factorial experimental design. Such investigations would provide a stronger basis for optimizing the formulation and confirming its technological and functional potential.

References

- Abd El-Wahhab, G. G., Sayed, H. A. A., Abdelhamid, M. A., Zaghlool, A., Nasr, A., Nagib, A., Bourouah, M., Abd-ElGawad, A. M., Rashad, Y. M., Hafez, M. E. S., and Taha, I. M. (2023). Effect of pre-treatments on the qualities of banana dried by two different drying methods. *Sustainability*, 15(20), 15112. <https://doi.org/10.3390/su152015112>
- Alagbe, E. E., Daniel, E. O., and Oyeniyi, E. A. (2020). Dataset on the effect of different pretreatment on the proximate analysis, microbial and sensory evaluation of dried banana during its storage. *Data in Brief*, 31, 105678. <https://doi.org/10.1016/j.dib.2020.105678>
- Alemu, T. T., Intipunya, P., and Gebeyo, B. A. (2025). A comprehensive review of edible coatings for postharvest management of fruits and vegetables: enhancing food and nutrition security. *Discover Agriculture*, 3(1), 190.
- AOAC. (2019). *Official methods of analysis* (21st ed.). AOAC International.

- Atmaca, M., and Büyükcan, M. B. (2025).** Infrared drying of banana slices: Quality evaluation using spectral and microstructural analysis. *Applied Sciences*, 15(17), 9632.
- Brand-Williams, W., Cuvelier, M. E., and Berset, C. (1995).** Use of a free radical method to evaluate antioxidant activity. *LWT – Food Science and Technology*, 28(1), 25–30. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5).
- de Almeida Costa, A. I., Monteiro, M. J. P., and Lamy, E. (Eds.). (2024).** Sensory evaluation and consumer acceptance of new food products: Principles and applications (Vol. 43). Royal Society of Chemistry. <https://doi.org/10.1039/9781839166655>.
- Doymaz, I. (2010).** Evaluation of mathematical models for drying kinetics of banana slices. *Journal of Food Engineering*, 98(1), 47–52. <https://doi.org/10.1016/j.jfoodeng.2009.12.012>
- El-Said, M. M., El-Messery, T. M., and Salama, H. H. (2021).** Functional properties and in vitro bio-accessibility attributes of light ice cream incorporated with purple rice bran. *International Journal of Dairy Science*, 16(1), 1–10. <https://doi.org/10.3923/ijds.2021.1.10>.
- Gammage, S., and Marangoni, A. G. (2025).** Safety of edible coatings on fruits and vegetables. *Comprehensive Reviews in Food Science and Food Safety*, 24, e70108. <https://doi.org/10.1111/1541-4337.70108>.
- Gidado, M. J., Gunny, A. A. N., Gopinath, S. C. B., Devi, M., Jayavalli, R., and Ilyas, R. A. (2025).** Challenges in selecting edible coating materials for fruit postharvest preservation and recent advances in edible coating techniques: A review. *Journal of Food Science and Technology*, 62(4), 612–622. <https://doi.org/10.1007/s13197-025-06214-1>
- Gu, Y., Qian, X., Sun, B., Ma, S., Tian, X., and Wang, X. (2022).** Nutritional composition and physicochemical properties of oat flour sieving fractions with different particle size. *LWT – Food Science and Technology*, 154, 112757. <https://doi.org/10.1016/j.lwt.2021.112757>
- Guiné, R. P. F., Barroca, M. J., Gonçalves, F. J., Alves, M., Oliveira, S., and Mendes, M. (2015).** Artificial neural network modelling of the antioxidant activity and phenolic compounds of bananas submitted to different drying treatments. *Food Chemistry*, 168, 454–459. <https://doi.org/10.1016/j.foodchem.2014.07.094>
- Gul, S., and Safdar, M. (2009).** Proximate composition and mineral analysis of cinnamon. *Pakistan Journal of Nutrition*, 8(9), 1456–1460. <https://doi.org/10.3923/pjn.2009.1456.1460>.
- Huang, M., Chen, Q., Li, S., He, J., Su, Y., and Wang, M. (2025).** Germination-driven dynamic changes of phenolic compounds in oats and the underlying mechanisms for antioxidation enhancement. *Food Chemistry*, 495, 146344. <https://doi.org/10.1016/j.foodchem.2025.146344>
- IBM Corp. (2017).** IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.
- Kramer, C. Y. (1956).** Extension of multiple range tests to group means with unequal numbers of replications. *Biometrics*, 12(3), 307–310. <https://doi.org/10.2307/3001469>
- Krokida, M. K., Maroulis, Z. B., and Saravacos, G. D. (2003).** The effect of drying methods on the quality of dehydrated products. *Journal of Food Engineering*, 59(4), 391–403. [https://doi.org/10.1016/S0260-8774\(02\)00426-9](https://doi.org/10.1016/S0260-8774(02)00426-9).
- Kugler, F., Stintzing, F. C., and Carle, R. (2004).** Identification of betalains from petioles of differently coloured Swiss chard (*Beta vulgaris* L. ssp. *cicla* Alef. cv. Bright Lights) by high-performance liquid chromatography–electrospray ionization mass spectrometry. *Journal of Agricultural and Food Chemistry*, 52(10), 2975–2981. <https://doi.org/10.1021/jf035491d>.
- Kumar, S., and Prasad, S. (2025).** Recent advances in edible coating of food products and its legislations. *Journal of Agriculture and Food Research*, 12, 100623. <https://doi.org/10.1016/j.jafr.2023.100623>.
- Lazaridis, D. G., Kitsios, A.-P., Koutoulis, A. S., Malisova, O., and Karabagias, I. K. (2024).** Fruits, spices and honey phenolic compounds: A comprehensive review on their origin, methods of extraction and beneficial health properties. *Antioxidants*, 13(11), 1335. <https://doi.org/10.3390/antiox13111335>.

- Li, X., Wu, Y., Duan, R., et al. (2024).** Research progress in the extraction, structural characteristics, bioactivity, and commercial applications of oat β -glucan: A review. *Foods*, 13(24), 4160. <https://doi.org/10.3390/foods13244160>.
- Macedo, L. L., Araújo, C. da S., Cruz, M. de S., Pereira, G. L. de L., and Saraiva, S. H. (2025).** Applying vacuum pulse during ethanol pretreatment to enhance the drying rate and quality of fresh and osmo-dehydrated banana slices using coconut sugar. *Food Research International*, 208, 116115. <https://doi.org/10.1016/j.foodres.2025.116115>
- Milani, A., Jouki, M., and Rabbani, M. (2020).** Production and characterization of freeze-dried banana slices pretreated with ascorbic acid and quince seed mucilage: Physical and functional properties. *Food Science and Nutrition*, 8(7), 3768–3776. <https://doi.org/10.1002/fsn3.1666>
- Nadery Dehsheikh, F., Taghian Dinani, S., Koczón, P., Bryś, J., Niemiec, T., and Kouřimská, L. (2025).** Quality properties of dried banana slices with carboxymethyl cellulose coating ultrasonic pretreatments. *Foods*, 14(22), 3904. <https://doi.org/10.3390/foods14223904>
- Nikolić, V., Žilić, S., Simić, M., Šavikin, K., Stević, T., Živković, J., Sarić, B., Milovanović, D., and Kandić Raftery, V. (2024).** Characterization and potential food applications of oat flour and husks from differently colored genotypes as novel nutritional sources of bioactive compounds. *Foods*, 13(23), 3853. <https://doi.org/10.3390/foods13233853>
- Pillai, A. R. S., Eapen, A. S., Zhang, W., and Roy, S. (2024).** Polysaccharide-based edible biopolymer-based coatings for fruit preservation: A review. *Foods*, 13(10), 1529. <https://doi.org/10.3390/foods13101529>.
- Shariati, M., Asadi Touranlou, F., and Rezaie, M. (2025).** Sensory evaluation methods for food products targeting different age groups: A review. *Food Research International*, 221, 117608. <https://doi.org/10.1016/j.foodres.2025.117608>.
- Shinga, M. H., Silue, Y., and Fawole, O. A. (2025).** Recent advancements and trends in postharvest application of edible coatings on bananas: A comprehensive review. *Plants*, 14(4), 581. <https://doi.org/10.3390/plants14040581>.
- Stone, H., and Sidel, J. L. (2004).** Sensory evaluation practices (3rd ed.). Academic Press.
- Wang, T., Song, Y., Lai, L., Fang, D., Li, W., Cao, F., and Su, E. (2024).** Sustaining freshness: Critical review of physiological and biochemical transformations and storage techniques in postharvest bananas. *Food Packaging and Shelf Life*, 46, 101386. <https://doi.org/10.1016/j.fpsl.2024.101386>
- Weng, Y., Zhu, Y., Ren, Y., Oguzlu, H., Shewan, H., and Baldelli, A. (2026).** Transparent and water-resistant edible coatings for sustainable post-harvest preservation of banana. *Sustainable Food Technology*, 4, 1953–1966. <https://doi.org/10.1039/D5FB00804B>
- Zhang, X., Liu, X., and Wang, Y. (2024).** Edible coating for fresh-cut fruit and vegetable preservation: Biomaterials, functional ingredients, and joint non-thermal technology. *Foods*, 13(23), 3937. <https://doi.org/10.3390/foods13233937>
- Zhishen, J., Mengcheng, T., and Jianming, W. (1999).** Colorimetric method for determination of total flavonoids in plants. *Food Chemistry*, 64(4), 555–559. [https://doi.org/10.1016/S0308-8146\(98\)00064-6](https://doi.org/10.1016/S0308-8146(98)00064-6)
- Živković, A., Cigić, B., Polak, T., and Požrl, T. (2025).** Hulled oat (*Avena sativa* var. Noni) and naked oat (*Avena nuda* var. Kamil): Distribution of selected secondary metabolites during germination. *Food Chemistry*, 492(3), 145505. <https://doi.org/10.1016/j.foodchem.2025.145505>.