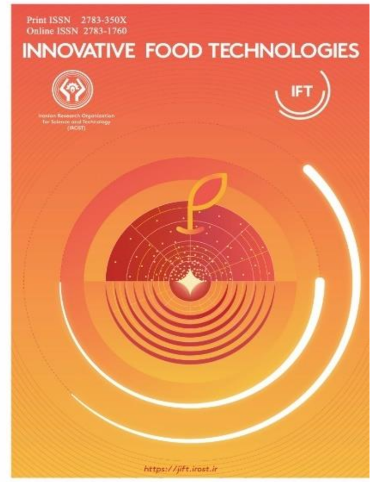
Journal Pre-proofs



Watermelon Outer Peel Powder as a Sustainable Functional Ingredient in Wafer Formulations: Proximate, Mineral, Antioxidant, and Sensory Evaluation

Aiza Qamar; Ayesha Khalid 1; Ayesha Sarfaraz; Ayesha Shoukat; Hifza Ali; Syed Abdul Wadood; Wahab Ali Khan

DOI: https://doi.org/ 10.22104/ift.2026.8354.2307

To appear in: Innovative Food Technologies (IFT)

Received Date: 19 June 2026
Revised Date: 23 July 2026
Accepted Date: 29 July 2026

Please cite this article as: Aiza Qamar; Ayesha Khalid 1; Ayesha Sarfaraz; Ayesha Shoukat; Hifza Ali; Syed Abdul Wadood; Wahab Ali Khan, Watermelon Outer Peel Powder as a Sustainable Functional Ingredient in Wafer Formulations: Proximate, Mineral, Antioxidant, and Sensory Evaluation, *Innovative Food Technologies (2026)*, doi: https://doi.org/ 10.22104/ift.2026.8354.2307

Watermelon Outer Peel Powder as a Sustainable Functional Ingredient in Wafer Formulations: Proximate, Mineral, Antioxidant, and Sensory Evaluation

Aiza Qamar* 1; Ayesha Khalid 1; Ayesha Sarfaraz 1; Ayesha Shoukat *2; Hifza Ali 1; Syed Abdul Wadood 1; Wahab Ali Khan 1

Author Affiliations:

1. Department of Nutrition & Health Promotion, University of Home Economics, Lahore, Pakistan
2. Department of Human Nutrition and Dietetics, Minhaj University, Lahore 54700, Pakistan

*** Corresponding Author:**

Primary Corresponding Author:

Aiza Qamar; Email: aizaqamar.uhe@gmail.com

Secondary *Corresponding Author:*

Ayesha Shoukat; Email: 2020F-mulbscn-015@mul.edu.pk

Abstract

This study explored the valorization of watermelon outer peel powder (WOPP) as a sustainable functional ingredient for nutritional fortification of wafer snacks. WOPP was characterized by low moisture, high ash, substantial crude fiber, moderate protein and fat, and a rich mineral profile dominated by phosphorus, calcium, potassium, and iron. Notably, WOPP exhibited exceptional antioxidant capacity, with high total phenolic content and strong DPPH radical scavenging activity. Wafers were formulated with 0%, 5%, 10%, and 15% WOPP substitution of wheat flour. Nutritional analysis revealed dose-dependent increases in moisture, ash, fiber, protein, fat, and minerals in fortified wafers, accompanied by a corresponding decrease in available carbohydrates. Antioxidant properties of wafers were markedly enhanced, with the 15% WOPP wafer showing the highest total phenolic content and radical scavenging activity. Sensory evaluation by trained panelists indicated that wafers with 10% WOPP substitution achieved the highest overall acceptability, balancing improved nutritional and antioxidant profiles with favorable taste, texture, and appearance. These findings demonstrate that WOPP is a viable, nutrient-dense, and antioxidant-rich ingredient that can be successfully incorporated into wafer snacks without compromising sensory quality. The study provides a practical model for converting agricultural waste into value-added functional foods, addressing both environmental sustainability and nutritional challenges in snack product development. Future work should focus on scaling production, shelf-life stability, and in vivo nutrient bioavailability assessment.

Keywords: Food waste valorization; Nutritional improvement; Snack fortification; Watermelon by-product

1. Introduction

The world food system is facing a serious challenge due to both food waste and food insecurity. Each year, approximately 1.3 billion tonnes of food is lost or wasted, which is equivalent to the loss of one-third of the total food production for human consumption, and has serious economic and environmental consequences, including contributions to methane emissions from landfills and significant water footprint impacts (Awasthi et al., 2022; FAOSTAT, 2023). The fruit and vegetable processing industry is a significant contributor, as by-products like peels, rinds, and seeds make up 25 - 30% of the total amount of fruit waste (Esparza et al., 2020; Goryńska-Goldmann et al., 2021). The disposal of these nutrient-rich materials in landfills leads to greenhouse gas emissions, pollution of the environment, and the loss of valuable biomass, highlighting the need for sustainable valorization strategies (Benmeziane & Derradji, 2023; Thiviya et al., 2022).

At the same time, dietary habits of consumers are becoming more linked to public health issues, especially in the snack segment. Many popular confectionery products such as wafers and biscuits are made using refined wheat flour, which contains little dietary fibre, vitamins, minerals and bioactive compounds but is rich in rapidly digestible carbohydrates (Aly et al., 2021; Mititelu et al., 2023). Eating these "empty calories" regularly has been associated with higher risk of obesity, cardiovascular diseases and other metabolic diseases (Burton-Freeman et al., 2021; Grahovac & Rončević, 2020). Thus, there is a critical need for innovative solutions to improve the nutritional quality of staple snacks without compromising their sensory appeal, in line with the increasing consumer demand for “clean-label” and functionally fortified foods (Fernandes et al., 2024; McClements & Grossmann, 2021).

Watermelon (*Citrullus lanatus L.*) is a popular fruit that is processed to produce a significant amount of waste, which is mainly the rind and outer peel (exocarp). Approximately hundreds of thousands of tonnes of watermelon by-products such as exocarp, albedo and seeds are wasted every year (Capossio et al., 2022; Zia et al., 2021). The green peel, which is traditionally discarded as waste, is now known to be a rich source of bioactive nutrients, such as dietary fiber, minerals (especially calcium and phosphorus), and powerful antioxidants like phenolic compounds and chlorophyll (Bhardwaj et al., 2022; Ilahy et al., 2019). Interestingly, the exocarp may have greater antioxidant activity than the edible pulp or rind, making it a potential source for functional food development (Tarahi et al., 2023; Zia et al., 2023). The valorization of this underutilized resource into a stable powder (Watermelon Outer Peel Powder, WOPP) offers an interesting solution to food waste management and the demand for nutritional food ingredients, thus helping to achieve a more circular bioeconomy (Merrylin et al., 2020; Raţu et al., 2023).

The recent studies have shown the successful application of fruit and vegetable by-product powders in bakery and confectionery matrices to enhance their nutritional and functional properties (Calderón-Oliver & López-Hernández, 2022; Usatiuk & Bozhko, 2023). The application of WOPP in wafer systems, however, is not well explored specifically in terms of the optimal substitution levels, processing methods, and sensory interactions that affect consumer acceptance, as it is a popular, shelf-stable snack food with global market. The nutritional enrichment must be techno-functional, but also maintain or enhance the critical sensory properties of texture, taste and color that are important for consumer acceptance (Arepally et al., 2020).

The objective of this study was to thoroughly assess the feasibility of WOPP as a new and sustainable functional ingredient for fortification of nutritional wafers. The specific objectives were as follows: to characterize the proximate composition, mineral profile and antioxidant capacity of WOPP; to develop wafers with partial substitution of wheat flour with WOPP (5%, 10% and 15%) and analyze the resulting nutritional, mineral and antioxidant properties; and to assess the sensory acceptability of the wafers enriched with WOPP to determine the optimal inclusion level that allows a balance between nutritional fortification and consumer acceptance. This work offers a viable model for converting agricultural waste into a value-added food ingredient, thereby contributing to environmental sustainability and human health by innovative food product development.

2. Materials and methods

2.1. Raw materials and reagents

Sugar Baby watermelons were bought from a local market in Lahore, Pakistan. Local procurement of standard baking ingredients for wafer preparation such as wheat flour (refined wheat flour, commercially available, Pakistan Standards and Quality Control Authority, PSQCA certified), vegetable oil, milk, sugar, baking powder, baking soda and salt was also done following standard food-grade quality specifications (PSQCA, 2020). Unless otherwise indicated, all chemicals and reagents used in the analytical procedures were of analytical grade and purchased from Sigma-Aldrich (St. Louis, MO, USA).

2.2. Preparation of Watermelon Outer Peel Powder (WOPP)

Watermelons were thoroughly washed with potable water. The outer green peel (exocarp) was hand peeled with a stainless-steel peeler (Carrillo-López & Yahia, 2019). The peels were harvested and placed in a thin even layer on stainless steel trays and dried in a cabinet dryer (Memmert, Schwabach, Germany) at 60 °C with an airflow rate of about 2.0 m/s until a constant weight was obtained (Pires et al., 2023). During the drying process, the relative humidity was kept between 15 – 20% to obtain uniform drying rate. The hot-air drying method was chosen because it is an inexpensive, readily available method, and it can be used to obtain dried material with hygienic and uniform characteristics in a controlled environment (Calín-Sánchez et al., 2020). The dried peels were ground to a fine powder in an industrial grinder and passed through a 250 µm mesh size sieve to ensure uniformity of the peels. The particle size was not reported, but rather controlled by the mesh. The WOPP had a relatively coarse texture, however, and was not as soft as typical wheat flour, so the texture of the wafer may be affected and needs to be optimized for wafer production. The outer peel of the watermelon was then dried, resulting in Watermelon Outer Peel Powder (WOPP), which was stored in airtight polyethylene bags at 4 °C for further analysis and product development (Pires et al., 2023).

2.3. Production of WOPP-enriched wafers

The basic wafer batter formulation was used (Arepally et al., 2020). Wheat flour was partially replaced with WOPP at 0% (Control, T0), 5% (T1), 10% (T2) and 15% (T3) substitution level to produce nutritionally enriched wafers (Olaitan et al., 2017) as indicated in Figure.1. Dry ingredients (wheat flour, WOPP, sugar, baking powder and salt) were thoroughly mixed for each batch. Then liquid ingredients (milk, oil/butter, water) were added and mixed to make a homogeneous batter. Portions of the batter (approx. 30 g) were placed in a preheated electric waffle maker and baked for 30 seconds. The relatively short baking time of 30 seconds was selected to ensure a partially cooked product with a moisture content of around 30 – 35% followed by a final convection drying process to give the desired crispy texture. The two-step process enabled more control of the final moisture content and texture of the wafers. The formed wafers were then cut into pieces, rolled into cylindrical shapes and further dried in a convection oven at 100 °C for 15 min to give a characteristic crispy texture. The wafers were then allowed to cool to room temperature before being placed in hermetic containers for further analysis (Arepally et al., 2020; Olaitan et al., 2017).

INSERT FIGURE 1 HERE

2.4. Compositional analysis of WOPP and wafers

2.4.1. Proximate composition

The proximate composition of WOPP and all the wafer treatments was assessed according to standard AOAC methods with slight modifications as described by Rațu et al. (2023).

The moisture content was determined by oven drying for 60 minutes at 130 °C, which is a shorter time than the standard drying time of 3 – 5 hours in the AOAC 930.15 method, but was validated in preliminary tests to ensure complete removal of bound moisture (Md Noh et al., 2020).

The ash content was determined gravimetrically by incineration in a muffle furnace at 570 °C (Rațu et al., 2023).

The crude protein content was determined by Kjeldahl method (Kjeltec 8400, Foss, Denmark). The nitrogen to protein conversion factor of 6.25 was used (Adegunwa et al., 2019; Ahamad et al., 2022).

Continuous solvent extraction with hexane in a Soxhlet extractor was employed to extract crude fat (Ajiboye et al., 2020; Aly et al., 2021).

Sequential acid and alkali digestion (Imoisi et al., 2020) was used to determine crude fibre.

Available carbohydrates (NFE) were calculated as per Maoto et al., 2019: NFE = 100 - (Moisture % + Ash % + Crude Protein % + Crude Fat % + Crude Fibre %).

2.4.2. Mineral analysis

Samples were dry-ashed at 550 °C for mineral analysis. The ash obtained was dissolved in 20% (v/v) hydrochloric acid, boiled, filtered and then made up to volume with distilled water (Pp et al., 2022). The concentrations of Fe and P in solution were measured using a UV-VIS spectrophotometer (UV-1800, Shimadzu, Japan) at the appropriate wavelengths (Pp et al., 2022). The Flame Photometer (Pp et al., 2022) (Jenway, UK) was used to quantify sodium (Na), calcium (Ca) and potassium (K).

2.4.3. Antioxidant activity analysis

Total Phenolic Content (TPC): The TPC of methanolic extracts (70% v/v) was determined using the Folin-Ciocalteu method (Zia et al., 2023). Briefly, an aliquot of the extract was mixed with Folin-Ciocalteu reagent and sodium carbonate solution. After incubation, absorbance was measured at 760 nm. The results were presented as mg Gallic Acid Equivalents (GAE) per gram of sample (mg GAE/g) based on a standard curve of Gallic Acid (Zia et al., 2021).

Free Radical Scavenging Activity: The free radical scavenging activity was determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay (Gulcin & Alwasel, 2023). The methanolic extracts were added to the methanolic DPPH solution (0.1 mM). The decrease in absorbance at 517 nm after 30 min of incubation in the dark was measured. The scavenging activity was expressed as percentage inhibition of a methanol blank.

2.5. Sensory evaluation

The sensory attributes of the wafer treatments were evaluated by a panel of 20 trained descriptive assessors. The samples were evaluated for appearance, color, crispiness, taste, texture, sweetness and overall acceptability using a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely) (Zia et al., 2022a; Zia et al., 2023). The panelists were given water to rinse their palate between samples to reduce carry-over.

2.6. Statistical analysis

Each experiment and analysis was repeated three times. Data are reported as mean ± SD. SPSS software (Version 26, IBM Corp., USA) was used for statistical analysis. One-way analysis of variance (ANOVA) was used to identify significant differences between the means and Tukey's post-hoc test was used to perform multiple comparisons at $p<0.05$ (Zia et al., 2023).

3. Results and discussion

3.1. Ingredient characterization

3.1.1. Compositional analysis of WOPP

The proximate composition of WOPP is given in Table 1. The moisture content of WOPP was 7.83±0.11%, which is similar to the moisture content of other dried watermelon by-products (Adegunwa et al., 2019) and falls within the range of moisture content of fruit peel powders (Pp et al., 2022). The ash content recorded was 12.38±0.01%, which is very high, as is a typical characteristic of watermelon processing waste, (Adegunwa et al., 2019; Benmeziane & Derradji, 2023). The crude fiber content was high (17.57±0.01%). The use of this high-fiber ingredient has the potential to contribute to dietary fiber intake, a deficiency that is essential for gastrointestinal health and chronic disease prevention (Bhardwaj et al., 2022). The crude protein (6.72±0.03%) and crude fat (4.49±0.01%) contents were moderate which was in agreement with other studies and cultivars on watermelon peel (Amin et al., 2014; Manivannan et al., 2020). The nitrogen-free extract (NFE) was 51.01±0.14%, which is mainly carbohydrates available. Overall, the nutritional profile indicates that WOPP is a nutrient-rich material, and the variations in composition may be due to the different cultivars of the 'Sugar Baby' variety, growing conditions, and drying methods used (Pp et al., 2022; Zia et al., 2021).

3.1.2. Mineral composition of WOPP

WOPP was determined to be an important source of essential minerals. It contained high levels of phosphorus (166.95±0.05 mg/100g) and calcium (76.85±0.05 mg/100g). The amount of phosphorus is consistent with the literature values for watermelon peel (Pp et al., 2022; Zia et al., 2023). WOPP had a significantly higher calcium content (76.85 mg/100g) than refined wheat flour (15 – 20 mg/100g) and was similar to whole wheat flour (30 – 40 mg/100g), thus making it a good source of this important mineral. (Amin et al., 2014). The iron content of 3.56±0.01 mg/100g is higher than some reported values (Amin et al., 2014) and makes it a potential source of this important micronutrient. Remarkably, the sodium content in WOPP was very low (1.55±0.04 mg/100g), a desirable characteristic for the production of healthier and low-sodium snack products (Pp et al., 2022). The potassium content was 28.61±0.05 mg/100g. The strong mineral profile of WOPP suggests its potential as a multi-mineral fortificant in food applications (Bhardwaj et al., 2022).

3.1.3. Antioxidant activity of WOPP

The antioxidant activity of WOPP was very high. The total phenolic content (TPC) was 12.22±0.01 mg GAE/g, which is significantly higher than the other watermelon waste fractions such as rind and pomace, reported by Zia et al., 2021 and Zia et al., 2023, respectively. This is consistent with the study by Ilahy et al. (2019) and Tarahi et al. (2023) which found that the outer peel/exocarp is the main source of phenolic compounds in watermelon fruit. In a similar way, the DPPH radical scavenging activity was 64.85±0.05%, which indicates excellent free radical neutralising potential (Gulcin & Alwasel, 2023; Zia et al., 2021). The high antioxidant activity may be due to the presence of high amounts of bioactive phytochemicals in the outer epidermal layer of the fruit (Ilahy et al., 2019; Meghwar et al., 2024).

3.2. Product characterization: WOPP-enriched wafers

3.2.1. Nutritional composition of enriched wafers

As can be seen in Table 1 and Figure 2, there were significant ($p<0.05$) and dose-dependent changes in the nutritional composition of the wafers when WOPP was added. As the WOPP substitution increased, the moisture, ash, fiber, protein and fat contents increased in a progressive manner, and the available carbohydrates (NFE) decreased in a corresponding manner. The hygroscopic behavior of the fibre-rich WOPP may explain the increase in moisture content, as the fibre matrix can absorb and hold more water in the product matrix due to the presence of hydrogen bonding and capillary forces in the dietary fibre structure. This finding is similar to the other reports on fruit peel powders in baked products, which revealed that dietary fiber has a water holding capacity, resulting in higher moisture retention (Burton-Freeman et al., 2021; Calderón-Oliver & López-Hernández, 2022). The high mineral density of WOPP is the reason for the substantial ash content (Capossio et al., 2022). Most importantly, the amount of crude fiber was significantly raised, making the WOPP-enriched wafer a good source of dietary fiber. The protein and fat content also significantly ($p<0.05$) increased with WOPP substitution, which is in accordance with the composition of WOPP (Aly et al., 2021). The opposing trends between the NFE and other components are clearly seen in Fig. 2, where the ash, fiber, protein and fat content increased with increasing doses of the treatments T0 to T3 while the NFE content decreased.

INSERT TABLE 1 HERE

INSERT FIGURE 2 HERE

3.2.2. Mineral fortification of enriched wafers

Table 2 and Figure 3 show that the mineral content of the wafers was significantly increased ($p<0.05$) with the increase in WOPP substitution, in a dose-dependent manner. All minerals (Ca, P, K, Na, Fe) showed significant increases as compared to the control wafer (T0: 0% WOPP) to the 15% WOPP wafer (T3: 15% WOPP substitution). For instance, the calcium content increased significantly and the levels of phosphorus and potassium also increased significantly. The iron content was very low in the control (T0: 0% WOPP) at 0.01±0.53 mg/100g, and was significantly increased by the addition of WOPP, with highest level in T3 (15% WOPP). The upward trend of all mineral lines from T0 (0% WOPP) to T3 (15% WOPP) (see Figure 3) is visually confirmed as a fortified mineral profile. The fortification approach can be used to correct the micronutrient deficiencies in refined flour-based snacks (Bhardwaj et al., 2022). Also, the positive Na/K ratio obtained with the fortification of WOPP is remarkable, as the sodium content is low and the potassium content is high in comparison with the conventional refined flour snacks.

INSERT TABLE 2 HERE

INSERT FIGURE 3 HERE

3.2.3. Antioxidant enhancement of enriched wafers

The antioxidant properties of the wafers (Table 3, Figure 4) were the most significant functional improvement. The total phenolic content (TPC) and DPPH radical scavenging activity significantly increased with the increase in WOPP substitution. The TPC also increased significantly when compared to the control and 15% WOPP wafer, and DPPH radical scavenging activity also exhibited a significant dose-dependent improvement. This dramatic improvement is evident from the curves of TPC and DPPH activity in Figure 4, which exhibit steep upward trends. This shift is a paradigm change from a snack with a low antioxidant content to one with high bioactive content that could help to reduce oxidative stress when consumed in a regular diet (Gulcin & Alwasel, 2023; Marinelli et al., 2021). The high phenolic content and other bioactive compounds in the watermelon exocarp are well transferred to the wafer matrix, which explains the significant correlation between the addition of the WOPP and the antioxidant activity.

INSERT TABLE 3 HERE

INSERT FIGURE 4 HERE

3.2.4. Sensory evaluation of enriched wafers

The most important factor in the successful introduction of any new food product is consumer acceptance. The sensory scores for all attributes are detailed in Table 4 and summarized in Figure 5. Importantly, enrichment with WOPP did not compromise sensory appeal, and at optimal levels it improved sensory appeal. One of the interesting results was that the scores for the critical textural attributes were highest in the wafer with 5% WOPP (T1) (8.05±0.89 for crispiness and 8.55±0.69 for taste) than the control (Arepally et al., 2020; Zia et al., 2022b). The improved taste perception at 5% WOPP substitution could be explained by the Maillard reaction products that are created during baking, since the amino acids and reducing sugars found in WOPP may be involved in the Maillard reaction and produce desirable flavor compounds. Furthermore, the natural flavor compounds found in the watermelon peel, including aldehydes and ketones, such as (E, Z)-2,6-nonadienal and (E)-2-nonenal, might play a role in the enhancement of the taste profile at low inclusion rates. This indicates that the inclusion level should be kept at a minimum to enhance mouthfeel and flavor profile without adding undesirable sensory notes (Ho & CheDahri, 2016; Zia et al., 2023). The color of the WOPP-enriched wafers, which is due to various compounds such as chlorophyll, was also accepted, especially in the T1 treatment (Tarahi et al., 2023).

The most important result of this study was that 10% WOPP (T2) had the highest score for overall acceptability (8.3±0.86), which was significantly higher than the 5% variant (T1) and the control (T0) (Gbaa et al., 2019). The overall acceptability of T2 is superior, possibly due to an optimal balance of multiple attributes, as T2 showed acceptable crispiness (7.1±1.25) and taste (7.85±1.18), while providing superior nutritional benefits with significantly higher fiber, minerals and antioxidants content than T3, and a more appealing color profile than T3. The gradual color change from the light cream of the control to the light green of T2 was found to be visually appealing by the panelists while the darker green color of T3 (15% WOPP) was given with lower color scores. Moreover, the crispness of T2 was still acceptable (7.2±1.79), while the crispness of T3 was significantly lower (6.65±1.73) because of the impact of the fiber content on the wafer structure. As seen in Figure 5, T1 performed best in terms of taste and crispiness, whereas T2 had high scores in all the attributes and the best overall score. This suggests that a 10% substitution rate is optimal, providing significant nutritional and antioxidant benefits (Tables 1-3, Figures 2-4) and the highest consumer liking.

INSERT TABLE 4 HERE

INSERT FIGURE 5 HERE

4. Conclusion

In this study, the valorization of an agricultural by-product, watermelon outer peel (WOP), as a functional ingredient with high nutrient content for wafer snacks is successfully demonstrated. The addition of 10% WOPP in the wafers resulted in a remarkable improvement in the nutritional and bioactive properties of the wafers, such as dietary fiber, protein, mineral content, and antioxidant activity, along with an improvement in sensory acceptability. The results should be regarded, however, with some limitations: sensory evaluation was subjective, using a relatively small panel of 20; there was no in-vitro or in-vivo study of the bioavailability of the enhanced nutrients and antioxidants; and there was no data on the dough techno-functional properties (e.g., pasting properties, dough rheology) that could explain the textural changes observed in the batter containing the WOPP. In spite of these constraints, it is a viable model for the valorization of agricultural waste in the production of functional foods, thus reinforcing the circular economy concept in food production. Further studies are warranted to scale up the production and to carry out extensive shelf-life stability tests as well as in-vivo bioavailability studies of nutrients and bioactive compounds to fully prove the health benefits of WOPP-enriched snack products.

Conflict of interest

No conflict of interest has been declared by the author.

Acknowledgments

The authors would like to thank the Department of Nutrition & Health Promotion, University of Home Economics, Lahore, Pakistan for providing laboratory facilities and technical support in conducting this research. The authors also would like to thank the sensory panelists for their participation and feedback.

References:

Adegunwa, M. O., Oloyede, I. O., Adebanjo, L. A., & Alamu, E. O. (2019). Quality attribute of plantain (Musa paradisiaca) sponge-cake supplemented with watermelon (Citrullus lanatus) rind flour. *Cogent Food & Agriculture*, *5*(1), 1631582. https://doi.org/10.1080/23311932.2019.1631582

Ahamad, S., Azmin, S. N. H. M., Nor, M. S. M., Zamzuri, N. D. D., & Babar, M. (2022). Recent trends in preprocessing and extraction of watermelon rind extract: A comprehensive review. *Journal of Food Processing and Preservation*, *46*(7). https://doi.org/10.1111/jfpp.16711

Ajiboye, B. O., Shonibare, M. T., & Oyinloye, B. E. (2020). Antidiabetic activity of watermelon (Citrullus lanatus) juice in alloxan-induced diabetic rats. *Journal of Diabetes & Metabolic Disorders*, *19*(1), 343–352. https://doi.org/10.1007/s40200-020-00515-2

Aly, A. A., El-Deeb, F. E., Abdelazeem, A. A., Hameed, A. M., Alfi, A. A., Alessa, H., & Alrefaei, A. F. (2021). Addition of whole barley flour as a partial substitute of wheat flour to enhance the nutritional value of biscuits. *Arabian Journal of Chemistry*, *14*(5), 103112. https://doi.org/10.1016/j.arabjc.2021.103112

Amin M, Ullah S, Rehman S, Ullah Z and Amir M (2014) Comparison of different types of water melon for their important nutrients. *Journal of Biology, Agriculture and Healthcare* 4(14): 59-66.

Arepally, D., Reddy, R. S., Goswami, T. K., & Datta, A. K. (2020). Biscuit baking: A review. *LWT*, *131*, 109726. https://doi.org/10.1016/j.lwt.2020.109726

Awasthi, M. K., Kumar, V., Yadav, V., Sarsaiya, S., Awasthi, S. K., Sindhu, R., Binod, P., Kumar, V., Pandey, A., & Zhang, Z. (2021). Current state of the art biotechnological strategies for conversion of watermelon wastes residues to biopolymers production: A review. *Chemosphere*, *290*, 133310. https://doi.org/10.1016/j.chemosphere.2021.133310

Benmeziane, F., & Derradji. (2023). Composition, bioactive potential and food applications of watermelon (citrullus lanatus) seeds – a review. *Journal of Food Measurement & Characterization*, *17*(5), 5045–5061. https://doi.org/10.1007/s11694-023-02012-5

Bhardwaj, K., Najda, A., Sharma, R., Nurzyńska-Wierdak, R., Dhanjal, D. S., Sharma, R., Manickam, S., Kabra, A., Kuča, K., & Bhardwaj, P. (2022). Fruit and Vegetable Peel-Enriched Functional Foods: Potential Avenues and health Perspectives. *Evidence-based Complementary and Alternative Medicine*, *2022*, 1–14. https://doi.org/10.1155/2022/8543881

Burton-Freeman, B., Freeman, M., Zhang, X., Sandhu, A., & Edirisinghe, I. (2021). Watermelon and l-Citrulline in Cardio-Metabolic Health: Review of the Evidence 2000–2020. *Current Atherosclerosis Reports*, *23*(12), 81. https://doi.org/10.1007/s11883-021-00978-5

Calín-Sánchez, Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel, A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs. *Foods*, *9*(9), 1261. https://doi.org/10.3390/foods9091261

Calderón-Oliver, M., & López-Hernández, L. H. (2020). Food vegetable and fruit waste used in meat products. *Food Reviews International*, *38*(4), 628–654. https://doi.org/10.1080/87559129.2020.1740732

Capossio, J. P., Fabani, M. P., Román, M. C., Zhang, X., Baeyens, J., Rodriguez, R., & Mazza, G. (2022). Zero-Waste Watermelon Production through Nontraditional Rind Flour: Multiobjective Optimization of the Fabrication Process. *Processes*, *10*(10), 1984. https://doi.org/10.3390/pr10101984

Carrillo-López, A., & Yahia, E. M. (2018). Morphology and anatomy. In *Elsevier eBooks* (pp. 113–130). https://doi.org/10.1016/b978-0-12-813278-4.00006-3

Esparza, I., Jiménez-Moreno, N., Bimbela, F., Ancín-Azpilicueta, C., & Gandía, L. M. (2020). Fruit and vegetable waste management: Conventional and emerging approaches. *Journal of Environmental Management*, *265*, 110510. https://doi.org/10.1016/j.jenvman.2020.110510

FAOSTAT (2023) FAOSTAT Statistical database. Food and Agricultural Organization of the United Nations, FAO. https://www.fao.org/faostat/en/#data/QV

Fernandes AC, Morais C, Franchini B, Pereira B, Pinho O and Cunha LM (2024) Clean-label products: Factors affecting liking and acceptability by Portuguese older adults. *Appetite* 197: 107307. https://doi.org/10.1016/j.appet.2024.107307

Gbaa, S. T., Ahemen, S. A., Eke, M. O., & Ochelle, P. O. (2019). Effect of Watermelon Rind (Citrullus lanatus) Addition on the Chemical and Sensory Quality of Sorghum Based Mumu. *Asian Food Science Journal*, 1–15. https://doi.org/10.9734/afsj/2019/v11i430066

Goryńska-Goldmann, E., Gazdecki, M., Rejman, K., Łaba, S., Kobus-Cisowska, J., & Szczepański, K. (2021). Magnitude, Causes and scope for reducing food losses in the Baking and Confectionery Industry—A Multi-Method Approach. *Agriculture*, *11*(10), 936. https://doi.org/10.3390/agriculture11100936

Grahovac, J., & Rončević, Z. (2021). Environmental impacts of the confectionary industry. In *Elsevier eBooks* (pp. 189–216). https://doi.org/10.1016/b978-0-12-821363-6.00012-6

Gulcin, İ., & Alwasel, S. H. (2023). DPPH radical scavenging assay. *Processes*, *11*(8), 2248. https://doi.org/10.3390/pr11082248

Ho, L., & Dahri, N. C. (2016). Effect of watermelon rind powder on physicochemical, textural, and sensory properties of wet yellow noodles. *CyTA - Journal of Food*, 1–8. https://doi.org/10.1080/19476337.2015.1134672

Ilahy, R., Tlili, I., Siddiqui, M. W., Hdider, C., & Lenucci, M. S. (2019). Inside and Beyond color: Comparative overview of functional quality of tomato and watermelon fruits. *Frontiers in Plant Science*, *10*, 769. https://doi.org/10.3389/fpls.2019.00769

Imoisi, C., Iyasele, J., Michael, U., & Imhontu, E. (2020). The effects of watermelon rind flour on the functional and proximate properties of wheat bread. *Journal of Chemical Society of Nigeria*, *45*(5). https://doi.org/10.46602/jcsn.v45i5.537

Manivannan, A., Lee, E., Han, K., Lee, H., & Kim, D. (2020). Versatile Nutraceutical Potentials of Watermelon—A Modest Fruit Loaded with Pharmaceutically Valuable Phytochemicals. *Molecules*, *25*(22), 5258. https://doi.org/10.3390/molecules25225258

Marinelli, V., Lucera, A., Incoronato, A. L., Morcavallo, L., Del Nobile, M. A., & Conte, A. (2020). Strategies for fortified sustainable food: the case of watermelon-based candy. *Journal of Food Science and Technology*, *58*(3), 894–901. https://doi.org/10.1007/s13197-020-04603-2

Maoto, M. M., Beswa, D., & Jideani, A. I. O. (2019). Watermelon as a potential fruit snack. *International Journal of Food Properties*, *22*(1), 355–370. https://doi.org/10.1080/10942912.2019.1584212

Meghwar, P., Saeed, S. M. G., Ullah, A., Nikolakakis, E., Panagopoulou, E., Tsoupras, A., Smaoui, S., & Khaneghah, A. M. (2024). Nutritional benefits of bioactive compounds from watermelon: A comprehensive review. *Food Bioscience*, *61*, 104609. https://doi.org/10.1016/j.fbio.2024.104609

Merrylin, J., Preethi, Saratale, G. D., & Banu, J. R. (2020). Production of biopolymers and feed protein from food wastes. In *Elsevier eBooks* (pp. 143–162). https://doi.org/10.1016/b978-0-12-818353-3.00007-9

Mititelu, M., Oancea, C., Neacșu, S. M., Musuc, A. M., Gheonea, T. C., Stanciu, T. I., Rogoveanu, I., Hashemi, F., Stanciu, G., Ioniță-Mîndrican, C., Belu, I., Măru, N., Olteanu, G., Cîrțu, A., Stoicescu, I., & Lupu, C. E. (2023). Evaluation of Junk Food Consumption and the Risk Related to Consumer Health among the Romanian Population. *Nutrients*, *15*(16), 3591. https://doi.org/10.3390/nu15163591

McClements, D. J., & Grossmann, L. (2021). A brief review of the science behind the design of healthy and sustainable plant-based foods. *Npj Science of Food*, *5*(1), 17. https://doi.org/10.1038/s41538-021-00099-y

Md Noh MF., Gunasegavan, R. D., Khalid, N. M., Balasubramaniam, V., Mustar, S., & Rashed, A. A. (2020). Recent techniques in Nutrient Analysis for Food Composition database. *Molecules*, *25*(19), 4567. https://doi.org/10.3390/molecules25194567

Olaitan NI, Eke MO and Agudu SS (2017) Effect of watermelon (Citrullus lanatus) rind flour supplementation on the quality of wheat-based cookies. *International Journal of Engineering and Science,* 6, 38-44. https://www.scirp.org/reference/referencespapers?referenceid=3391193

PP, S. B., Sagar, V. R., Kar, A., Varghese, E., Singh, S., & Choudhary, H. (2021). Identification and Quantification of Physicochemical and Bioactive Components from Sugar Baby Variety of Watermelon (Citrullus lanatus). *Agricultural Research*, *11*(3), 410–420. https://doi.org/10.1007/s40003-021-00583-7

Pires, C. A., De Oliveira Cavalcante, L. S. P., De Carvalho, A. a. M., De Siqueira, P. A., Santos, G. V. D., De Paiva Anciens Ramos, G. L., Souto, R. N. M., De Barros Pinto Moreira, R. V., Teodoro, A. J., Conte, C. A., Junior, Cadena, R., & Domingues, J. R. (2023). Watermelon (Citrullus lanatus) rind flour: Development and characterization of a novel watermelon byproduct. *Journal of Food Science*, *88*(11), 4495–4508. https://doi.org/10.1111/1750-3841.16779

Rațu, R. N., Veleșcu, I. D., Stoica, F., Usturoi, A., Arsenoaia, V. N., Crivei, I. C., Postolache, A. N., Lipșa, F. D., Filipov, F., Florea, A. M., Chițea, M. A., & Brumă, I. S. (2023). Application of Agri-Food By-Products in the food industry. *Agriculture*, *13*(8), 1559. https://doi.org/10.3390/agriculture13081559

Thiviya, P., Gamage, A., Kapilan, R., Merah, O., & Madhujith, T. (2022). Production of Single-Cell Protein from Fruit Peel Wastes Using Palmyrah Toddy Yeast. *Fermentation*, *8*(8), 355. https://doi.org/10.3390/fermentation8080355

Tarahi, M., Fakhr-Davood, M. M., Ghaedrahmati, S., Roshanak, S., & Shahidi, F. (2023). Physicochemical and Sensory Properties of Vegan Gummy Candies Enriched with High-Fiber Jaban Watermelon Exocarp Powder. *Foods*, *12*(7), 1478. https://doi.org/10.3390/foods12071478

Usatiuk, S., & Bozhko, A. (2023). PROSPECTS OF THE USE OF NON-TRADITIONAL VEGETABLE RAW MATERIALS IN THE PRODUCTION OF CONFECTIONERY PRODUCTS. *Food Science and Technology*, *17*(2). https://doi.org/10.15673/fst.v17i2.2600

Zia, S., Khan, M. R., & Aadil, R. M. (2022) a. Kinetic modeling of different drying techniques and their influence on color, bioactive compounds, antioxidant indices and phenolic profile of watermelon rind. *Journal of Food Measurement & Characterization*, *17*(1), 1068–1081. https://doi.org/10.1007/s11694-022-01674-x

Zia, S., Khan, M. R., Aadil, R. M., & Shahid, M. (2022) b. Development and storage stability of value-added watermelon fruit butter by incorporating watermelon rind byproduct. *Journal of Food Processing and Preservation*, *46*(11). https://doi.org/10.1111/jfpp.17031

Zia, S., Khan, M. R., Khaneghah, A. M., & Aadil, R. M. (2023). Characterization, bioactive compounds, and antioxidant profiling of edible and waste parts of different watermelon (Citrullus lanatus) cultivars. *Biomass Conversion and Biorefinery*, *15*(2), 2171–2183. https://doi.org/10.1007/s13399-023-04820-7

Zia, S., Khan, M. R., Shabbir, M. A., & Aadil, R. M. (2021). An update on functional, nutraceutical and industrial applications of watermelon by-products: A comprehensive review. *Trends in Food Science & Technology*, *114*, 275–291. https://doi.org/10.1016/j.tifs.2021.05.039

Fig. 1. Visual appearance of wafers enriched with 0% (T0), 5% (T1), 10% (T2), and 15% (T3) watermelon outer peel powder (WOPP).

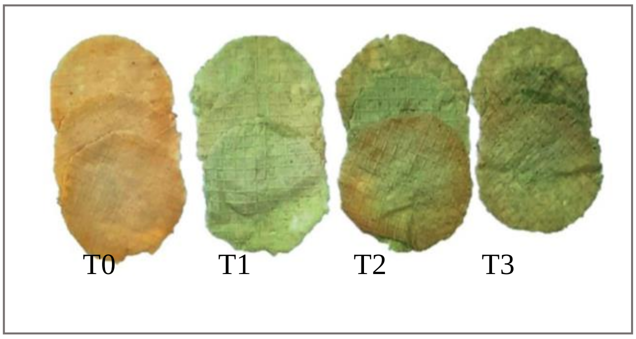


Fig. 2. Line chart for Proximate Composition

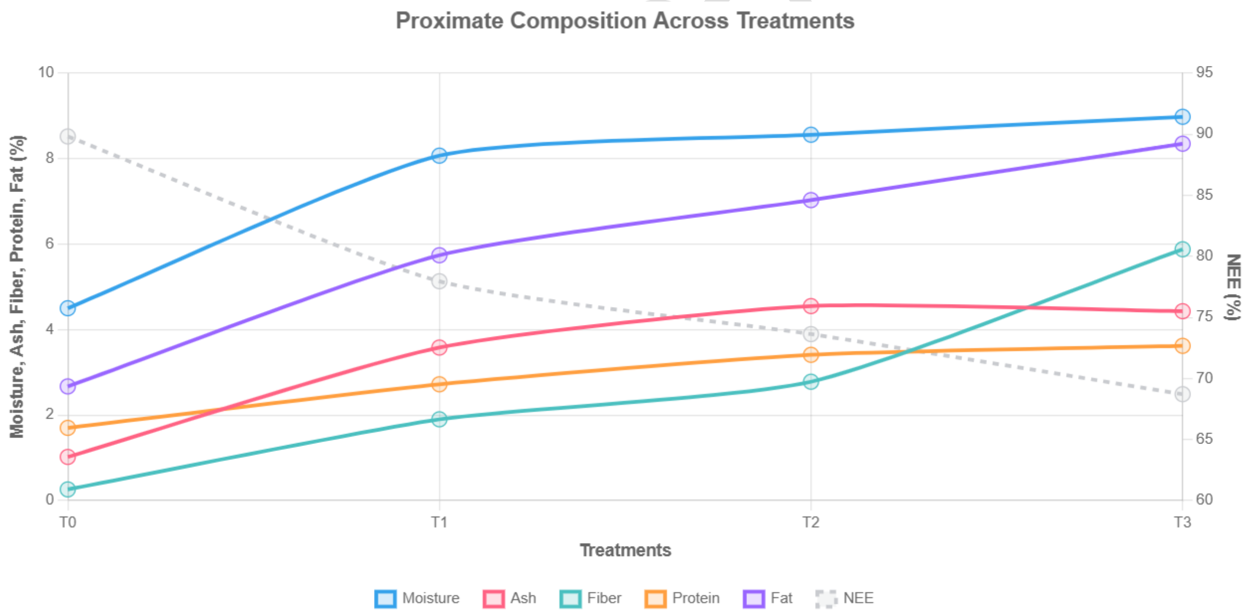


Fig. 3. Line chart for Mineral Composition

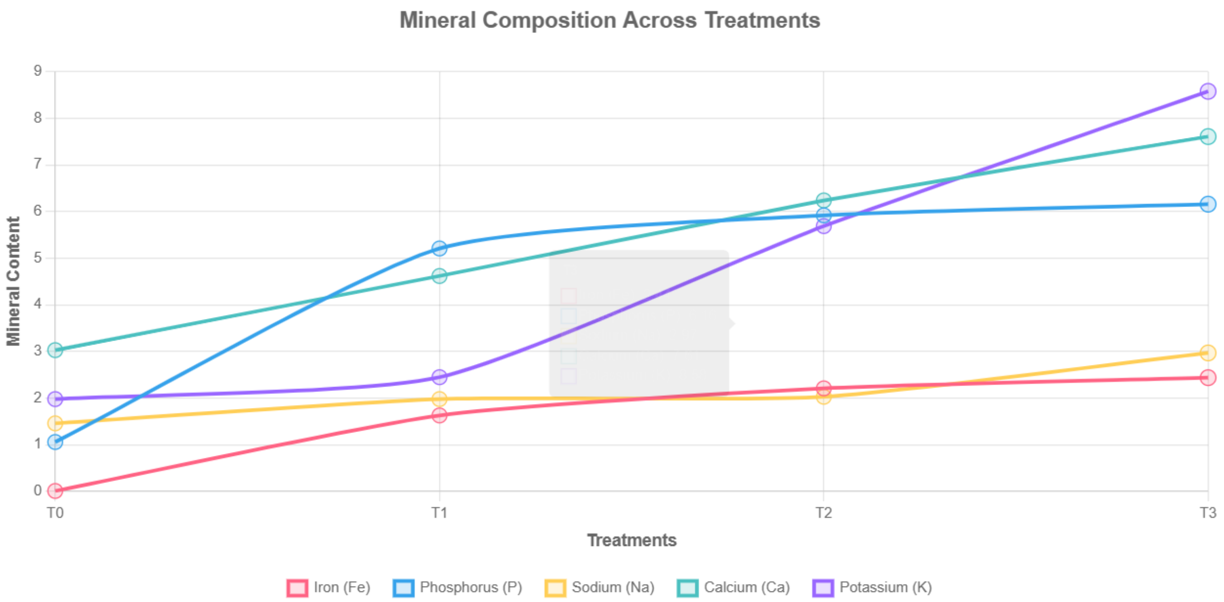


Fig. 4. Line chart of Antioxidant Composition

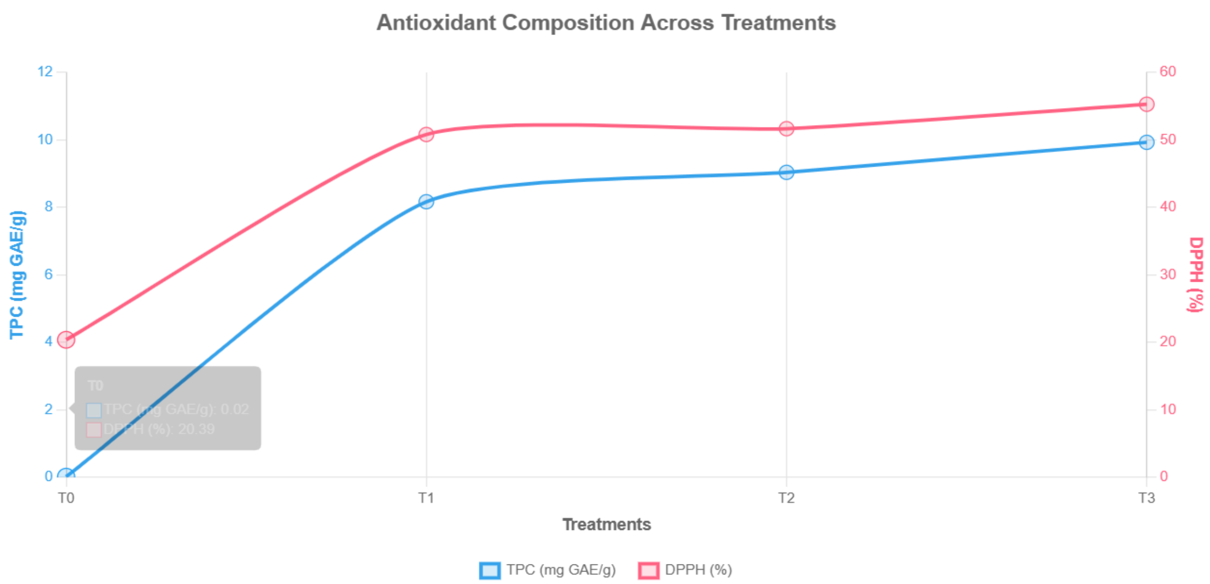


Fig. 5. Line chart for sensory analysis

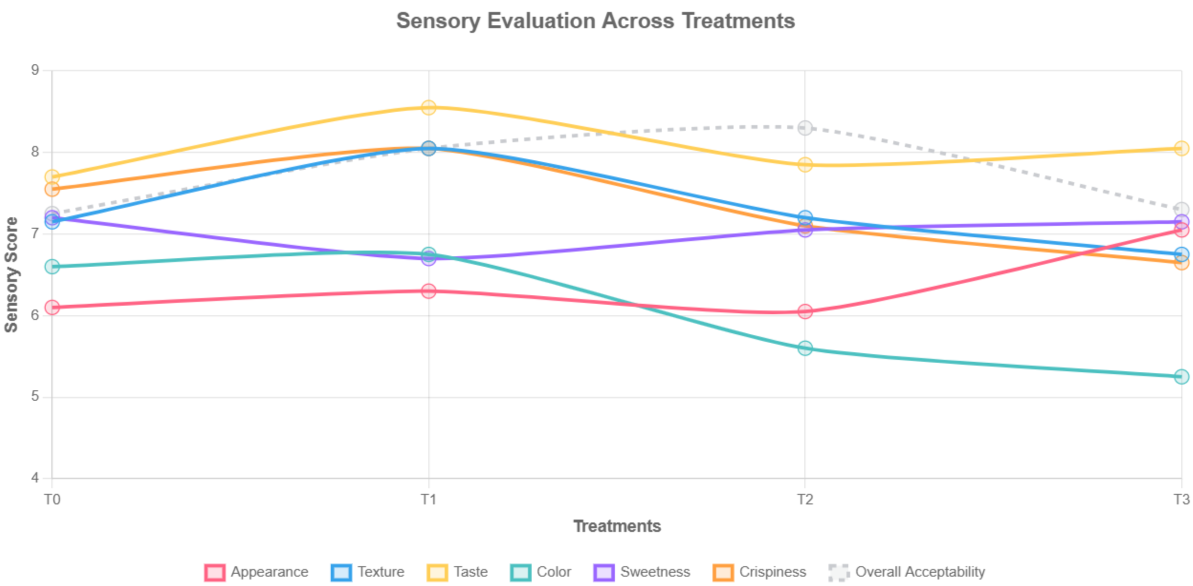


Table. 1. Mean Values for Proximate Composition

Proximate	T0	T1	T2	T3
Moisture	4.50 ± 0.25d	8.07 ± 0.02b	8.56 ± 0.03a	8.98 ± 0.01a
Ash	1.02 ± 0.14d	3.58 ± 0.33b	4.55 ± 0.03a	4.43 ± 0.06a
Fiber	0.26 ± 0.12h	1.90 ± 0.17g	2.78 ± 0.04f	5.88 ± 0.02
Protein	1.70 ± 0.23h	2.72 ± 0.04fg	3.41 ± 0.05c	3.62 ± 0.01
Fat	2.67 ± 0.35h	5.74 ± 0.34f	7.03 ± 0.02c	8.35 ± 0.01a
NFE	89.82 ± 0.10a	77.96 ± 0.36d	73.63 ± 0.08e	68.71 ± 0.18g

Table. 2. Mean Values for Mineral Composition

Minerals	T0	T1	T2	T3
Fe	0.01 ± 0.53i	1.63 ± 0.45h	2.21 ± 0.62e	2.44 ± 0.01d
P	1.06 ± 0.00d	5.21 ± 0.00c	5.92 ± 0.01b	6.16 ± 0.00b
Na	1.46 ± 0.00h	1.98 ± 0.00g	2.03 ± 0.01g	2.97 ± 0.01f
Ca	3.03 ± 0.00g	4.62 ± 0.04f	6.24 ± 0.00e	7.61 ± 0.01c
K	1.98 ± 0.00f	2.45 ± 0.04f	5.69 ± 0.01c	8.58 ± 0.03a

Table. 3. Mean Values of Antioxidant Composition

Treatments	TPC (mg GAE/g)	DPPH (%)
T0	0.02 ± 0.00	20.39 ± 0.24
T1	8.17 ± 0.11	50.81 ± 0.10
T2	9.04 ± 0.22	51.67 ± 0.01
T3	9.93 ± 0.05	55.29 ± 0.26

Table. 4. Mean values for sensory analysis

Treatments	T0	T1	T2	T3
Appearance	6.1 ± 1.11	6.3 ± 1.17	6.05 ± 1.53	7.05 ± 0.99
Texture	7.15 ± 1.18	8.05 ± 0.83	7.2 ± 1.79	6.75 ± 1.37
Taste	7.7 ± 0.73	8.55 ± 0.69	7.85 ± 1.18	8.05 ± 0.76
Color	6.6 ± 1.23	6.75 ± 1.42	5.6 ± 1.82	5.25 ± 1.41
Sweetness	7.2 ± 1.51	6.7 ± 1.13	7.05 ± 1.76	7.15 ± 1.09
Crispiness	7.55 ± 0.89	8.05 ± 0.89	7.1 ± 1.25	6.65 ± 1.73
Overall Acceptability	7.25 ± 0.85	8.05 ± 1.00	8.3 ± 0.86	7.3 ± 1.53