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DEVELOPMENT OF BUCKWHEAT BASED GLUTEN-FREE TORTILLAS ENRICHED WITH CHEESE POWDER: AN ELECTRE-BASED MULTICRITERIA EVALUATION

Peynir Tozu İle Zenginleştirilmiş Karabuğday Bazlı Glütensiz Tortillalarin Üretimi: Electre Tabanlı Çok Kriterli Değerlendirme

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Abstract

The development of nutritionally improved and sensorially acceptable gluten-free products remains an important challenge. This study aimed to produce buckwheat flour-based gluten-free tortillas enriched with cheese powder and evaluate their nutritional and sensory characteristics using the ELECTRE (ELimination and Choice Expressing REality) multicriteria decision-making approach. Four formulations containing 0% (Control), 2.5% (CP2.5), 5% (CP5), and 7.5% (CP7.5) cheese powder were prepared. Cheese powder significantly affected nutritional composition ($p < 0.05$), with energy, fat, and protein contents increasing to 357.50 kcal/100 g, 22.32%, and 8.59%, respectively, in CP7.5, compared with 315.64 kcal/100 g, 16.65%, and 6.27% in the Control. Sensory evaluation showed that CP5 generally had the most favorable profile. ELECTRE analysis identified flavor as the most important criterion (weight: 0.2308), followed by crispness (0.2051) and mouthfeel (0.1795). The final outranking order was CP5 > Control > CP2.5 > CP7.5, indicating that 5% cheese powder provided the best overall balance of sensory attributes. These findings suggest that moderate cheese powder incorporation can improve the nutritional profile of buckwheat-based gluten-free tortillas while maintaining desirable sensory characteristics, and that ELECTRE is useful for evaluating multiple sensory criteria and selecting the most preferred formulation.

Keywords: Buckwheat flour; Gluten-free tortillas; Cheese powder; Sensory evaluation; ELECTRE; Multicriteria decision-making

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1.Introduction

Celiac disease is a chronic immune-mediated disorder triggered by the ingestion of gluten in genetically susceptible individuals and is characterized by damage to the small intestinal mucosa. The current management of celiac disease requires strict and lifelong adherence to a gluten-free diet, which is essential for intestinal recovery and the prevention of long-term complications (Caio et al., 2019). However, the development of nutritionally adequate and sensorially acceptable gluten-free (GF) foods remains challenging because the absence of gluten may adversely affect dough structure, texture, sensory quality, and nutritional composition (Cappelli et al., 2020). In particular, the development of GF bakery products may be associated with limitations in structural integrity, texture, and consumer acceptability, highlighting the need for alternative ingredientts and appropriate formulation strategies (Khoury et al., 2018; Haixi et al., 2025; Arowolo et al., 2026). In this context, buckwheat (Fagopyrum esculentum) has attracted considerable attention as a naturally gluten-free pseudocereal with a favorable nutritional profile, being rich in protein, dietary fiber, minerals, and bioactive compounds (Sofi et al., 2022; Sonawane et al., 2024). The incorporation of buckwheat flour into gluten-free food formulations can improve nutritional quality while also influencing important technological and sensory properties, including color, texture, flavor, and overall acceptability (Sofi et al., 2022; Zamaratskaia et al., 2023).

Tortillas are versatile flatbread products commonly used to accompany a variety of dishes (Rodríguez-Noriega et al., 2021). In flour tortillas, softness, flexibility, and other textural characteristics are important quality attributes that influence their functionality during handling and consumption (Rodríguez-Noriega et al., 2021). However, the development of gluten-free (GF) tortillas may present additional formulation challenges, as the absence of gluten can affect dough structure and desirable textural properties, particularly flexibility and rollability. In addition to the selection of an appropriate GF flour, the incorporation of ingredients with strong sensory and nutritional contributions may provide an effective strategy for improving the quality of such products.

Cheese powder is a versatile dairy ingredient widely used in food formulations because of its characteristic flavor, storage stability, ease of handling, and potential to contribute to desirable sensory and functional properties (Deshwal et al., 2024). Its use in food formulations may therefore provide an opportunity to enhance the sensory characteristics and nutritional value of GF products. Nevertheless, increasing the level of cheese powder may not affect all quality attributes in the same direction; for example, improvements in flavor may occur simultaneously with changes in color, aroma, mouthfeel, or crispness. Therefore, determining the most desirable GF tortilla formulation represents a multicriteria decision problem, in which several sensory attributes with different levels of importance must be considered simultaneously.

Multi-criteria decision-making (MCDM) methods provide systematic approaches for evaluating alternatives when several criteria must be considered concurrently (Mardani et al., 2015). Among these methods, the ELECTRE (ELimination Et Choix Traduisant la REalité) approach is based on an outranking concept and evaluates alternatives through pairwise comparisons using concordance and discordance relationships (Figueira et al., 2013). This approach enables the relative importance of different criteria to be incorporated into the

decision process and may therefore provide a useful framework for identifying the most preferable formulation when no single quality parameter is sufficient to represent overall product performance. Accordingly, the present study aimed to develop cheese powder-enriched gluten-free tortillas based on buckwheat flour and to investigate their technological, nutritional, textural, and sensory characteristics. The formulations were evaluated according to seven sensory criteria, namely appearance, crust color, inner color, aroma, flavor, mouthfeel, and crispness. The relative importance of these criteria was converted into normalized weights, and the resulting weighted sensory data were subsequently integrated using an ELECTRE-based multicriteria decision-making approach to establish pairwise outranking relationships and identify the most preferred tortilla formulation. From a gastronomy perspective, the development of acceptable gluten-free tortilla alternatives may contribute to diversifying specialized dietary options and expanding the range of products suitable for contemporary culinary applications.

2. Materials and Methods

2.1. Gluten-Free Tortilla Production

Gluten-free tortillas were formulated using buckwheat flour as the sole flour source. The control formulation (C) consisted exclusively of buckwheat flour, whereas cheese powder was incorporated into the experimental formulations at levels of 2.5%, 5.0%, and 7.5%, designated as CP2.5, CP5, and CP7.5, respectively. The selected cheese powder levels were determined based on preliminary sensory evaluations conducted prior to the main experiment. During these preliminary evaluations, cheese powder incorporation levels above 10% were found to produce undesirable sensory characteristics, particularly in terms of flavor, and were therefore excluded from further experimentation. Accordingly, cheese powder incorporation levels of 2.5–7.5% were selected to provide acceptable sensory characteristics while enabling the evaluation of increasing cheese powder concentrations in the gluten-free tortilla formulations.

All ingredients were thoroughly mixed to obtain homogeneous dough formulations, followed by tortilla formation and baking under standardized conditions. The resulting tortillas were cooled to room temperature and subjected to subsequent physicochemical, textural, and sensory analyses. Representative images of the gluten-free tortilla samples are presented in Figure 1.

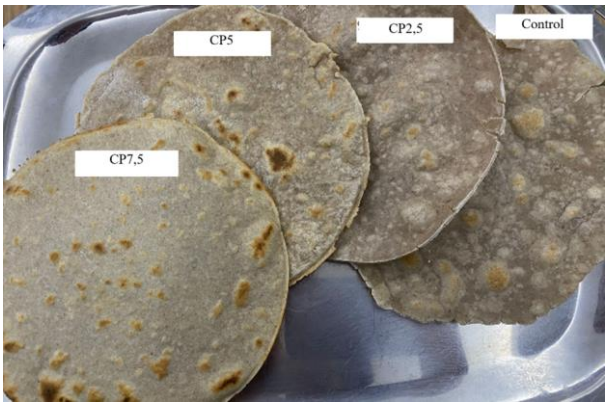


Figure 1. Appearance of the gluten-free tortilla formulations: control (C) and cheese powder-enriched formulations (CP2.5, CP5, and CP7.5)

2.2. **Proximate Composition and Energy Value**

The proximate composition of the gluten-free tortilla samples was evaluated in accordance with AOAC standard methods (AOAC, 2019). Sample moisture was quantified by gravimetric determination after oven drying to constant mass (AOAC 934.01), while the inorganic residue was obtained by ashing at 550 °C in a muffle furnace (AOAC 942.05). Nitrogen concentration was measured by the Kjeldahl procedure (AOAC 960.52) and converted to crude protein content using the corresponding nitrogen conversion factor.

For lipid analysis, the samples were subjected to solvent extraction using a VELP SER148 extraction system operated according to the manufacturer's instructions (VELP, 2020). Dietary fiber was quantified by an enzymatic-gravimetric procedure in accordance with AOAC 991.43. Rather than being measured directly, carbohydrate content was derived from the proximate composition data by difference after accounting for moisture, ash, protein, fat, and dietary fiber. The energy contribution of the tortillas was then calculated from their macronutrient composition using the modified Atwater factors (Merril and Watt, 1973).

2.3. Sensory Evaluation

The sensory evaluation was conducted to determine the panelists' preferences for the formulated gluten-free tortilla bread samples. Ethical approval for the study was obtained from the Social Sciences Scientific Research Proposal Ethical Evaluation Board of Sivas Cumhuriyet University on September 24, 2025 (Decision No. 17). A total of 30 panelists, consisting of students enrolled in the Cookery Program of Cumhuriyet Vocational School, participated in the sensory evaluation. The samples were evaluated in two stages, before and after tasting. Before tasting, the samples were evaluated in terms of appearance, crust color, inner color, and aroma, whereas flavor, mouthfeel, and crispness were evaluated after tasting. A nine-point hedonic scale was used, with scores ranging from 1 (lowest degree of liking) to 9 (highest degree of liking).

2.4. Statistical Analysis

Statistical analysis of the data was performed using one-way Analysis of Variance (ANOVA). Differences among group means were evaluated using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p<0.05$. All experimental data are expressed as Mean ± Standard Deviation. Means within the same row sharing different superscript letters (a–d) indicate statistically significant differences ($p<0.05$).

2.5. ELECTRE-Based Multi-Criteria Decision Analysis

The ELECTRE-I (ELimination Et Choix Traduisant la REalité - ELimination and Choice Expressing the REality) method was employed to determine the most preferable tortilla formulation by simultaneously considering multiple sensory criteria. ELECTRE is an outranking-based multi-criteria decision-making approach that evaluates alternatives through pairwise comparisons using concordance and discordance principles (Figueira et al., 2013)

The sensory criteria incorporated into the decision model were derived from the sensory evaluation conducted by the panelists. Seven criteria representing the sensory characteristics of the tortilla samples were considered: appearance, crust color, inner color, aroma, flavor, mouthfeel and crispness. The relative importance of these criteria was determined by the 30 panelists using a nine-point importance scale, where 1 represented the lowest importance and 9 represented the highest importance. The final importance score for each criterion was calculated as the arithmetic mean of the scores assigned by the 30 panelists.

First, the sensory performance values of the tortilla alternatives were arranged in a decision matrix. The decision matrix was then transformed into a normalized matrix using the vector normalization procedure given in Eq. (1). This procedure eliminates the differences in the scales of the criteria and provides dimensionless values that can be compared across alternatives.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \qquad \textbf{Eq.1}$$

Following normalization, each normalized criterion value was multiplied by its corresponding criterion weight to obtain the weighted normalized decision matrix. The resulting matrix represents the relative contribution of each criterion to the overall evaluation of the alternatives.

$$Y_{ij} = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \dots & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & \dots & w_n x_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_1 x_{m1} & w_2 x_{m2} & \dots & w_n x_{mn} \end{bmatrix} \qquad \textbf{Eq.2}$$

In the second stage, concordance and discordance sets were determined for each pair of tortilla alternatives. For a pair of alternatives Aa and Ab, the concordance set consists of the criteria for which alternative Aa performs at least as well as alternative Ab. In contrast, the discordance set consists of the criteria for which Aa performs worse than Ab. The corresponding concordance and discordance sets were determined using Eqs. (3) and (4).

$$\mathrm{C_{ab}} = \{ j, x_{aj} \geq x_{bj} \} \qquad \textbf{Eq.3}$$

$$\mathrm{D_{ab}} = \{ j, x_{aj} < x_{bj} \}_{\text{=J-Cab}} \qquad \textbf{Eq.4}$$

In the third stage, the concordance index was calculated for each pair of alternatives based on the criteria included in the corresponding concordance set. The concordance index represents the total weight of the criteria supporting the preference of one alternative over another. The concordance indices obtained from all pairwise comparisons were subsequently arranged into a concordance matrix.

$$C_{ab}=\sum_{jeCab} \boldsymbol{wj} \quad \textbf{Eq.5}$$

In the fourth stage, the discordance index was calculated for each pairwise comparison using the criteria included in the corresponding discordance set. The discordance index reflects the magnitude of the largest relative disadvantage of one alternative compared with another and is standardized according to the maximum difference observed among the alternatives. The calculated discordance indices were subsequently arranged into a discordance matrix.

$$\boldsymbol{d_{ab}} = \frac{\max\limits_{j\in D_{ab}} |v_{aj}-v_{bj}|}{\max\limits_{j\in J, m,n\in I} |v_{mj}-v_{nj}|} \quad \textbf{Eq.6}$$

In the fifth stage, the overall concordance threshold was calculated from the concordance indices obtained for all pairwise comparisons. This threshold represents the average level of concordance among the alternatives and was used to identify sufficiently strong concordance relationships.

$$\bar{\boldsymbol{c}} = \sum_{a=1}^{m} \sum_{b}^{m} \boldsymbol{c(a,b)/m(m-1)} \quad \textbf{Eq.7}$$

In the sixth stage, the overall discordance threshold was calculated from the discordance indices obtained from the pairwise comparisons. The resulting value represents the average level of discordance among the alternatives and was used to identify whether the disadvantage of one alternative over another was sufficiently large to prevent an outranking relationship.

$$\bar{\boldsymbol{d}} = \frac{\sum_{a=1}^{m} \sum_{b}^{m} \boldsymbol{d(a,b)}}{\boldsymbol{m(m-1)}} \quad \textbf{Eq.8}$$

Finally, the concordance and discordance threshold values were jointly considered to determine the outranking relationships between the tortilla alternatives. An alternative was considered to outrank another alternative when the corresponding concordance condition was satisfied and the discordance condition did not indicate a sufficiently large disadvantage. The resulting outranking relationships were represented in the total dominance matrix. The preference order of the tortilla formulations was then determined according to the resulting dominance relationships.

3. RESULT AND DISCUSSION

3.1. Proximate Composition and Energy Value

The energy values and proximate chemical composition of the gluten-free tortilla formulations supplemented with varying levels of cheese powder (CP) are presented in Table 1. The incorporation of cheese powder into the buckwheat flour-based gluten-free tortilla formulations significantly affected the energy value and nutritional composition of the samples ($p < 0.05$). The energy content of the tortillas increased significantly with increasing levels of cheese powder, from 315.64 kcal/100 g in the control group to 357.50 kcal/100 g in the CP7.5 formulations. The increase in energy content may be associated with the relatively high protein and fat contents of the incorporated cheese powder (Shakoor et al., 2025).

Table 1. Energy values and nutritional composition of tortilla samples

	Control	CP2.5	CP5	CP7.5
Energy (Kcal)	315.64±3.24^{c}	336.02±3.18^{b}	339.33±2.47^{b}	357.50±2.17^{a}
Fat Content (%)	16.65±0.85^{d}	19.82±1.17^{c}	20.85±0.98^{b}	22.32±1.21^{a}
Protein Content (%)	6.27±0.47^{d}	7.04±0.51^{c}	8.04±0.43^{b}	8.59±0.37^{a}
Dry Matter (%)	75.13±1.98^{b}	75.86±2.37^{ab}	75.16±2.29^{b}	78.48±2.24^{a}
Carbohydrate Content (%)	38.03±1.10^{a}	35.40±1.02^{b}	33.01±1.14^{c}	34.03±1.24^{bc}
Dietary Fiber Content (%)	2.86±0.12^{d}	3.04±0.14^{c}	3.13±0.20^{b}	3.46±0.19^{a}
Ash Content (%)	14.18±0.22^{a}	13.59±0.31^{b}	13.26±0.24^{b}	13.54±0.29^{b}

Values are presented as Mean ± Standard Deviation. Means within the same row carrying different superscript letters (a–d) are statistically significantly different ($p < 0.05$).

A significant and progressive increase was observed in both fat and protein contents following cheese powder incorporation ($p < 0.05$). The fat content increased from 16.65% in the control tortillas to 22.32% in CP7.5, while the protein content increased from 6.27% to 8.59%, respectively. The increase in protein content observed with increasing cheese powder incorporation is consistent with previous studies reporting improvements in the protein content of cereal-based and gluten-free bakery products following the addition of dairy-derived ingredients (Alexa et al., 2026; Krupa-Kozak et al., 2013). The concomitant increase in fat content may be attributed to the contribution of fat naturally present in the cheese powder. Such nutritional enhancement is particularly relevant for gluten-free formulations, for which improving nutritional quality, particularly protein content, remains an important consideration (Yağdı & Gülsünoğlu Konuşkan, 2021; Menaka et al., 2024).

Dry matter content ranged from 75.13% to 78.48%, with the highest value observed in CP7.5 ($p < 0.05$). However, the statistical grouping indicated that the differences among Control, CP2.5, and CP5 were not significant, whereas CP7.5 exhibited a significantly higher dry matter content than Control and CP5. In contrast, carbohydrate content showed an overall decreasing tendency with cheese powder incorporation, declining from 38.03% in the control group to 33.01% in CP5 and 34.03% in CP7.5. This reduction can be attributed to the replacement of a portion of buckwheat flour with cheese powder, which altered the relative contribution of carbohydrate-rich components to the formulation. Dietary fiber content increased significantly with increasing cheese powder incorporation ($p < 0.05$), reaching 3.46% in CP7.5 compared with 2.86% in the control. Because cheese powder is not typically considered a major source of dietary fiber, this increase may be related to changes in the relative composition of the formulations rather than a direct contribution of the cheese powder

itself. In contrast, ash content decreased from 14.18% in the control to 13.54% in CP7.5 ($p < 0.05$). Although the control differed significantly from all cheese powder-containing formulations, no significant differences were observed among CP2.5, CP5, and CP7.5. Overall, cheese powder incorporation modified the nutritional profile of the buckwheat-based gluten-free tortillas, particularly by increasing their protein and fat contents and, to a lesser extent, dietary fiber content.

3.2. Sensory Evaluation Results

Sensory evaluation plays a pivotal role in the design and consumer acceptance of novel food matrices, particularly in gluten-free product development. Protein enrichment can improve the nutritional value of gluten-free bakery products, while the incorporation of novel ingredients may also modify their aroma and sensory characteristics (Nissen et al., 2020). Reformulation of gluten-free bakery products can substantially affect their sensory characteristics, including flavor, texture, appearance, and overall consumer acceptability (Chae et al., 2025). Therefore, evaluating panelist perception across core sensory descriptors, including appearance, crust color, inner color, aroma, flavour, mouthfeel, and crispness, is essential to verify whether functional fortification aligns with sensory quality and consumer acceptability. The sensory profiles of the gluten-free tortilla formulations fortified with cheese powder (CP) are illustrated in Figure 2. Cheese powder incorporation significantly affected the sensory characteristics of the formulations, although the magnitude of the response varied among the evaluated attributes ($p < 0.05$).

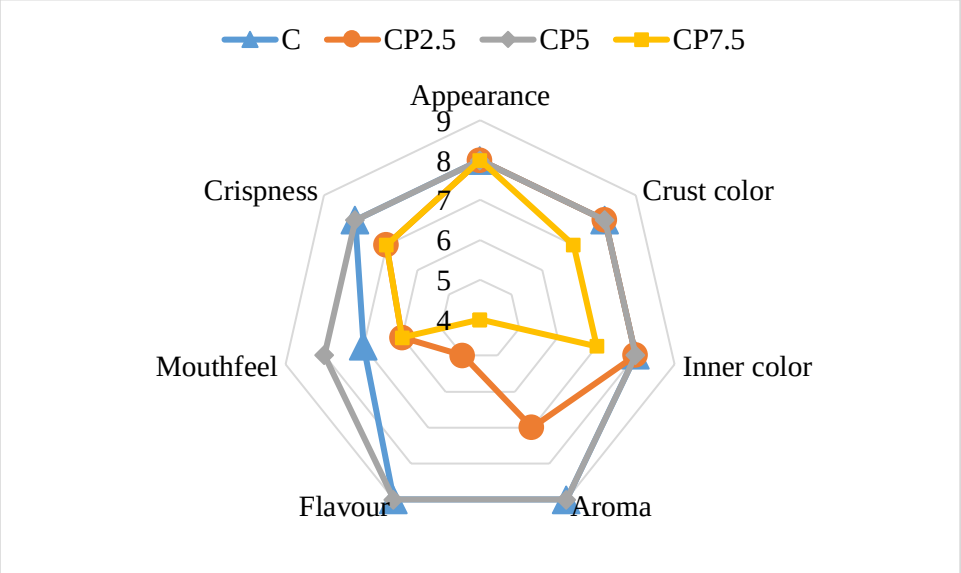


Figure 2. Sensory properties of gluten-free tortillas formulated with different levels of cheese powder

The visual attributes were generally well accepted across the formulations. Appearance scores remained relatively high and comparable among the samples, indicating that cheese powder incorporation did not markedly impair the overall visual appearance of the tortillas. In contrast, crust color and inner color showed a more pronounced response at the highest

cheese powder level. The Control (C), CP2.5, and CP5 formulations received scores of approximately 8.0 for both color-related attributes, whereas CP7.5 exhibited lower scores of approximately 7.0. This reduction may be associated with the contribution of cheese-derived proteins and reducing sugars to non-enzymatic browning during baking, which can result in darker coloration (Rocchetti et al., 2023). Thus, although moderate cheese powder incorporation maintained favorable visual characteristics, the highest incorporation level appeared to negatively affect color acceptability.

Aroma and flavour profiles revealed a more pronounced differentiation among the formulations, highlighting the sensory contribution of cheese powder. The Control sample (C) and CP5 formulation achieved the highest aroma and flavour scores, both reaching 9.0. The favorable sensory response observed for CP5 may be attributed, at least in part, to the contribution of desirable dairy-derived and savory flavor notes from the cheese powder. Previous research has shown that hard cheese powders can provide characteristic flavor attributes such as umami, harmony, and kokumi, supporting their use as flavoring agents or flavor enhancers in food applications (Varming et al., 2013). In contrast, increasing the cheese powder level to 7.5% (CP7.5) resulted in a marked decrease in both aroma and flavour acceptability, with scores of approximately 4.0. This substantial decline suggests that excessive cheese powder incorporation may have produced an overly intense dairy-derived sensory profile that was less acceptable to the panelists. The lower scores observed for CP7.5 therefore indicate that the sensory benefits of cheese powder were not proportional to its incorporation level and that an optimum level existed around 5%.

Textural and oral sensations, evaluated through mouthfeel and crispness, further supported the superior sensory performance of CP5. The mouthfeel score reached 8.0 for CP5, whereas the Control, CP2.5, and CP7.5 formulations received scores of approximately 7.0, 6.0, and 4.0, respectively. The higher mouthfeel score observed for CP5 may be related to the contribution of dairy-derived fat and proteins to the sensory perception of texture and smoothness. Dairy fat is known to contribute to smoothness and creaminess, while dairy proteins can influence mouthfeel, viscosity, and structural properties of food systems (Corvera-Paredes et al., 2022). However, this interpretation should be considered as a possible mechanism rather than a direct causal explanation unless supported by instrumental texture or compositional data. In terms of crispness, the Control and CP5 formulations exhibited the highest scores (approximately 8.0), indicating a desirable crisp texture. The lower crispness scores observed for CP2.5 and CP7.5 suggest that both insufficient and excessive cheese powder incorporation may have altered the structural characteristics responsible for the preferred crispness of the tortillas.

Overall, the sensory results indicate that CP5 provided the most favorable balance among appearance, aroma, flavour, mouthfeel, and crispness. In particular, the 5% cheese powder formulation achieved high aroma and flavour scores while maintaining favorable visual and textural characteristics. By contrast, the 7.5% formulation showed clear reductions in color, aroma, flavour, and mouthfeel acceptability, suggesting that excessive cheese powder incorporation can adversely affect sensory quality. Therefore, CP5 appears to represent the most promising formulation from a sensory perspective, providing a balanced improvement in the overall acceptability of the gluten-free tortilla.

3.3. ELECTRE-Based Evaluation of Gluten-Free Tortillas

The sensory criteria were assigned different importance levels according to their perceived relevance in the evaluation of the tortilla formulations. Among the seven criteria, flavor received the highest importance score (9), corresponding to a normalized weight of 0.2308, followed by crispness (0.2051) and mouthfeel (0.1795) (Table 2). Appearance, aroma, crust color, and inner color had weights of 0.1538, 0.1282, 0.0769, and 0.0256, respectively. Thus, flavor represented the most influential sensory criterion in the ELECTRE analysis.

The sensory scores were subsequently normalized to eliminate the effect of the original scoring scale and to make the criteria comparable. The normalized values were then multiplied by the corresponding criterion weights to obtain the weighted normalized decision matrix (Table 3, Table 4). CP5 exhibited the highest weighted normalized values for mouthfeel (0.1056), while C and CP5 showed identical weighted values for flavor (0.1458) and aroma (0.0766). The relatively high weighted values of flavor and crispness reflected their greater contribution to the overall decision due to their higher criterion weights.

Table 2. Mean importance scores and normalized weights of the sensory criteria used in the ELECTRE analysis

Criterion	Importance score	Weight
Appearance	6	0.1538
Crust color	3	0.0769
Inner color	1	0.0256
Aroma	5	0.1282
Flavor	9	0.2308
Mouthfeel	7	0.1795
Crispness	8	0.2051

Table 3. Normalized decision matrices of the tortilla formulations

Alternative	Appearance	Crust Color	Inner Color	Aroma	Flavor	Mouthfeel	Crispness
C	0.5000	0.5153	0.5153	0.5974	0.6317	0.5147	0.5322
C2.5	0.5000	0.5153	0.5153	0.4646	0.3509	0.4411	0.4656
C5	0.5000	0.5153	0.5153	0.5974	0.6317	0.5882	0.5322
C7.5	0.5000	0.4509	0.4509	0.2655	0.2807	0.4411	0.4656

Table 4. Weighted normalized decision matrices of the tortilla formulations

Alternative	Appearance	Crust color	Inner color	Aroma	Flavor	Mouthfeel	Crispness
C	0.0769	0.0396	0.0132	0.0766	0.1458	0.0924	0.1092
C2.5	0.0769	0.0396	0.0132	0.0596	0.0810	0.0792	0.0955
C5	0.0769	0.0396	0.0132	0.0766	0.1458	0.1056	0.1092
C7.5	0.0769	0.0347	0.0116	0.0340	0.0648	0.0792	0.0955

The concordance analysis was performed to determine the degree to which each tortilla formulation was supported as being at least as good as another formulation across the weighted sensory criteria. The concordance values ranged from 0.1538 to 1.0000 (Table 5). CP5 demonstrated complete concordance with C, CP2.5, and CP7.5, with concordance indices of 1.0000 in all three pairwise comparisons. Similarly, C showed complete concordance with CP2.5 and CP7.5, whereas its concordance index against CP5 was 0.8205. In contrast, CP7.5 showed relatively low concordance values against C and CP5 (0.1538), indicating weaker support for its superiority in the pairwise comparisons.

Table 5. Concordance matrix for pairwise comparison of the tortilla formulations

	C	C2.5	C5	C7.5
C	–	**1.0000**	**0.8205**	**1.0000**
C2.5	0.2564	–	0.2564	**1.0000**
C5	**1.0000**	**1.0000**	–	**1.0000**
C7.5	0.1538	0.5385	0.1538	–

The discordance analysis complemented the concordance assessment by identifying substantial disadvantages of one formulation relative to another (Table 6). Discordance values ranged from 0.0000 to 1.0000. P5 exhibited a discordance value of 0.0000 against all other formulations, indicating the absence of a substantial criterion-level disadvantage in these pairwise comparisons. In contrast, C showed a discordance value of 1.0000 against CP5, while CP2.5 showed a discordance value of 1.0000 against both C and CP5. CP7.5 also exhibited a discordance value of 1.0000 against C, CP2.5, and CP5.

Table 6. Discordance matrix for pairwise comparison of the tortilla formulations

	C	C2.5	C5	C7.5
C	–	0.0000	**1.0000**	0.0000
C2.5	**1.0000**	–	**1.0000**	0.0000
C5	0.0000	0.0000	–	0.0000
C7.5	**1.0000**	**1.0000**	**1.0000**	–

The mean values of the off-diagonal concordance and discordance indices were used as the respective threshold values. The concordance threshold was calculated as 0.6816, whereas the discordance threshold was 0.5000. Accordingly, an alternative was considered to outrank another alternative when its concordance index was equal to or greater than 0.6816 and its discordance index was equal to or lower than 0.5000.

Table 7. Total dominance matrix and order of preference of the tortilla formulations

	C	C2.5	C5	C7.5	Order of preference
C	–	1	0	1	**2**
C2.5	0	–	0	1	**3**
C5	1	1	–	1	**1**
C7.5	0	0	0	–	**4**

The total dominance matrix was subsequently used to establish the final order of preference among the tortilla formulations (Table 7). CP5 occupied the first position, outranking all three competing formulations. C was ranked second, followed by CP2.5 and CP7.5. Accordingly, the final ELECTRE preference order was CP5 > C > CP2.5 > CP7.5. The superior position of CP5 can be attributed to its consistently high sensory performance, particularly in flavor, aroma, mouthfeel and crispness, while maintaining the highest or joint-highest scores for the visual criteria.

4. CONCLUSION

This study demonstrated that cheese powder incorporation can substantially modify the nutritional and sensory characteristics of buckwheat flour-based gluten-free tortillas. Increasing the cheese powder level significantly increased energy, fat, and protein contents, with the CP7.5 formulation showing the highest values. However, the highest cheese powder level did not result in the most favorable sensory response. In particular, CP7.5 showed marked reductions in crust color, inner color, aroma, flavor, and mouthfeel scores, indicating that excessive cheese powder incorporation may negatively affect sensory acceptability. The sensory evaluation indicated that CP5 provided the most balanced profile, particularly with respect to aroma, flavor, mouthfeel, and crispness. This finding was further supported by the ELECTRE analysis, in which flavor received the highest criterion weight, followed by crispness and mouthfeel. The resulting outranking analysis placed CP5 first, followed by the Control, CP2.5, and CP7.5 formulations, yielding the final preference order of CP5 > Control > CP2.5 > CP7.5. Overall, the findings suggest that 5% cheese powder represents a promising incorporation level for developing nutritionally improved and sensorially acceptable buckwheat-based gluten-free tortillas. Rather than maximizing cheese powder incorporation, the results highlight the importance of identifying an appropriate level that balances nutritional enhancement with sensory quality. The ELECTRE-based multicriteria decision-making approach successfully integrated the relative importance of multiple sensory attributes and provided a systematic basis for formulation selection. From a gastronomy perspective, the CP5 formulation may offer a practical gluten-free tortilla alternative with potential for incorporation into contemporary culinary applications and specialized dietary product development.

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