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DETERMINATION OF OPTIMAL CINNAMON POWDER LEVEL IN BISCUITS USING MULTIVARIATE ANALYSIS AND EXPERIMENTAL VALIDATION

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ABSTRACT

The incorporation of plant - based functional ingredients into bakery products represents a promising approach to enhance their nutritional and technological properties. In this study, the optimal level of cinnamon powder in butter biscuits was determined using a combined experimental and data - driven approach. Biscuits containing 0 - 6 % cinnamon powder were produced and evaluated in terms of physicochemical composition, color characteristics, texture, electrochemical parameters (pH, EC, TDS, ORP), and sensory attributes. A multivariate analysis framework was applied, including Z - score normalization, correlation - based feature selection, regression modeling, and linear programming, to identify the most informative variables and determine the optimal formulation. The results showed that cinnamon addition significantly affected moisture, dietary fiber content, color parameters (L, a*, b*), and electrochemical properties, as well as sensory acceptance. The proposed model identified an optimal cinnamon powder level of 3.12 %, representing a balance between improved nutritional value and acceptable sensory and technological characteristics. At this level, biscuits exhibited enhanced functional properties, moderate color change (ΔE), and high overall acceptability. The study demonstrates the applicability of data - driven methods for formulation optimization in bakery products and provides a basis for the development of functional foods enriched with cinnamon.*

Keywords: cinnamon powder, biscuits, functional foods, multivariate analysis, optimization, sensory evaluation, color analysis.

INTRODUCTION

The development of functional bakery products with improved nutritional and sensory properties is a key direction in modern food science. One promising approach is the incorporation of plant - based ingredients with high biological value, such as cinnamon (*Cinnamomum* spp.), which is widely recognized for its antioxidant, antimicrobial, and aromatic properties [1].

Cinnamon is a rich source of dietary fiber (approximately 50 - 55 %), polyphenols, and bioactive compounds, which may significantly influence the physicochemical and technological properties of bakery products. Dietary fibers are known to affect water retention, fat binding, and structural stability, thereby playing an important role in product freshness and shelf - life [2, 3]. In baked products such as biscuits, the incorporation of fiber - rich ingredients can alter texture, density, and crispiness depending on the type and concentration of the additive [4].

Previous studies have investigated the incorporation of cinnamon in bakery products, demonstrating improvements in nutritional composition and functional properties. For instance, Ng et al. reported increased protein, fiber, and mineral content, along with reduced sucrose levels in biscuits supplemented with cinnamon powder [5]. Additionally, cinnamon has been associated with improved glycemic response, making it suitable for the development of products targeted at consumers with metabolic disorders. However, higher concentrations may negatively affect sensory characteristics, leading to darker color, coarser texture, and a slightly bitter taste due to phenolic compounds [6].

Color and sensory perception are critical quality attributes of biscuits. The addition of cinnamon typically results in reduced lightness (L*) and increased redness (a*), contributing to darker brown tones [7]. However, most studies rely on qualitative or limited instrumental color analysis, without comprehensive evaluation of color differences (ΔE) and their relationship with consumer acceptance.

In addition to conventional physicochemical and sensory parameters, electrochemical properties such as pH, electrical conductivity (EC), total dissolved solids (TDS), and oxidation - reduction potential (ORP) provide valuable information about the stability and antioxidant characteristics of food systems. Despite their relevance, these parameters are rarely applied in the evaluation of cinnamon - enriched bakery products.

From a methodological perspective, most studies focus on individual parameters without integrating them into a unified analytical framework. Advanced data analysis techniques, including feature selection and multivariate modeling, have been proposed to improve the interpretation of complex food systems. However, such approaches remain underexplored in the optimization of bakery formulations [8].

Furthermore, existing research lacks a systematic approach for determining the optimal level of cinnamon addition based on a combination of physicochemical, sensory, and instrumental parameters. Comparative analyses between literature - derived and experimentally obtained data are also limited, which restricts the development of generalized models for formulation optimization.

Therefore, the aim of the present study is to determine the optimal level of cinnamon powder in biscuits by applying a combined experimental and data - driven approach. Specifically, the study integrates literature data, experimental validation, multivariate feature selection, regression modeling, and linear programming to identify the most informative parameters and define an optimal formulation that balances nutritional value, technological properties, and sensory acceptability.

EXPERIMENTAL

Literature data collection and preprocessing

Data on cinnamon - enriched biscuits were compiled from available literature sources and are presented in Table 1 [5, 9, 10, 11]. The dataset includes multiple groups of characteristics, denoted as features F1 - F30.

These features encompass chemical composition (protein - F1, ash - F2, fat - F3, moisture - F4, carbohydrates - F5, sucrose - F6, dietary fiber - F7 - F9), physical properties (weight - F10, dimensions and shape - F20 - F22), textural parameters (firmness - F23, crispiness - F24), color characteristics (R, G, B - F11 - F13; L*, a*, b* - F14-F16; H, S, V - F17 - F19), and sensory attributes (aroma - F25, color - F26, appearance - F27, crispiness - F28, flavour - F29, overall acceptance - F30).

The incorporation of cinnamon powder into biscuits results in noticeable changes in their chemical composition, physicochemical properties, and sensory characteristics. With increasing cinnamon concentration, protein, fat, and dietary fiber contents increase, while moisture content decreases. Although dimensions and spread ratio remain relatively unchanged, an increase in firmness and stable crispiness is observed.

Color parameters are significantly affected by cinnamon addition. A decrease in lightness (L*) and the yellow - blue component (b*) is observed, accompanied by an increase in the red - green component (a*), resulting in darker brown tones. Sensory evaluation indicates that aroma, flavour, and overall acceptance vary depending on cinnamon concentration, with the highest scores reported for biscuits containing 4 % cinnamon. At higher concentrations, a decline in sensory scores is observed.

RGB color values were obtained using MATLAB (2017b) functions (*lab2rgb*), while HSV parameters were calculated using the *rgb2hsv* function.

A feature selection algorithm was developed to

Table 1. Summary of literature data on cinnamon - enriched biscuits.

Feature	Cinnamon, % / Characteristic	0	2	4	6
F1	Protein	6.32 ± 0.02	6.4 ± 0.02	6.53 ± 0.07	6.71 ± 0.12
F2	Ash	0.75 ± 0.04	0.92 ± 0.02	0.88 ± 0.03	0.93 ± 0.03
F3	Fat	22.28 ± 0.08	22.62 ± 0.04	22.73 ± 0.07	22.83 ± 0.07
F4	Moisture	1.97 ± 0.06	1.74 ± 0.08	1.4 ± 0.06	1.17 ± 0
F5	Carbohydrate	68.73 ± 0.09	68.5 ± 0.07	68.63 ± 0.09	68.48 ± 0.08
F6	Sucrose	17.43 ± 0.08	14.83 ± 0.07	12.83 ± 0.08	9.23 ± 0.04
F7	Total dietary fibre	1.21 ± 0.13	2.48 ± 0.22	3.39 ± 0.2	4.24 ± 0.36
F8	Insoluble dietary fibre	0.95 ± 0.11	1.98 ± 0.19	2.63 ± 0.17	3.38 ± 0.34
F9	Soluble dietary fibre	0.26 ± 0.02	0.52 ± 0.05	0.74 ± 0.04	0.92 ± 0.03
F10	Weight (g)	5.43 ± 0.08	5.43 ± 0.09	5.37 ± 0.06	5.37 ± 0.08
F11	R	217.77 ± 8.14	198.09 ± 14.77	159.79 ± 17.22	151.28 ± 16.83
F12	G	165.07 ± 10.59	143.13 ± 17.3	94.62 ± 15.59	86.8 ± 14.83
F13	B	66.64 ± 15.95	49.67 ± 17.53	26.09 ± 11.29	22.89 ± 10.92
F14	L	71.05 ± 2.89	63.3 ± 4.99	46.53 ± 4.57	43.43 ± 4.33
F15	a	9.72 ± 0.25	12.24 ± 0.88	21.41 ± 0.13	21.98 ± 0.07
F16	b	56.56 ± 2.66	55.24 ± 0.46	47.3 ± 2.18	45.4 ± 1.99
F17	H	0.14 ± 0.06	0.12 ± 0.06	0.14 ± 0.01	0.09 ± 0.02
F18	S	0.7 ± 0.05	0.76 ± 0.02	0.84 ± 0.04	0.86 ± 0.05
F19	V	0.9 ± 0.01	0.83 ± 0.04	0.68 ± 0.03	0.62 ± 0.03
F20	Diameter D, mm	36.04 ± 1.01	35.68 ± 0.6	35.33 ± 0.6	35.36 ± 0.6
F21	Thickness T, mm	5.02 ± 0.01	5.05 ± 0.01	5.04 ± 0.01	5.01 ± 0
F22	Spread ratio D/T	7.24 ± 0.21	7.18 ± 0.12	7.03 ± 0.02	7.02 ± 0.02
F23	Firmness F, kg	2.33 ± 0.09	2.37 ± 0.21	2.51 ± 0.15	2.57 ± 0.12
F24	Crispiness C, mm	0.42 ± 0.02	0.43 ± 0.03	0.41 ± 0.05	0.4 ± 0.03
F25	Aroma	4.92 ± 1.17	4.25 ± 1.2	4.73 ± 1.08	4.15 ± 1.37
F26	Colour	4.90 ± 1.31	4.11 ± 1.34	4.76 ± 0.95	4.22 ± 0.97
F27	Appearance	4.89 ± 1.14	4.02 ± 1.12	4.69 ± 1.03	4.13 ± 0.9
F28	Crispiness	4.83 ± 1.08	4.72 ± 0.91	4.49 ± 1.08	4.94 ± 1.1
F29	Flavour	4.96 ± 1.11	4.53 ± 1.1	4.25 ± 1.07	4.16 ± 1.37
F30	Overall acceptance	4.96 ± 1.01	4.33 ± 1	4.9 ± 0.99	4.38 ± 1.13

identify the most informative variables. The method is based on Z - score normalization, which standardizes the data for each feature to eliminate the influence of scale differences. The normalization is defined as follows Eq. (1):

$$x_{norm(i,j)} = \frac{x(i,j) - \mu_j}{\sigma_j} \quad (1)$$

where x(i, j) is the value of the j^{-th} feature for the i^{-th} sample; μ_j is the mean value of feature j; σ_j is the standard deviation of feature j; and $x_{norm}(i,j)$ is the normalized value.

Following normalization, the relationship between each feature and the cinnamon powder content was evaluated using the Pearson correlation coefficient, defined as follows Eq. (2):

$$r = \frac{cov(x_{norm}, y)}{\sigma_{x_{norm}} \sigma_y} \quad (2)$$

where y is the dependent variable (cinnamon powder percentage).

The absolute values of the correlation coefficients were used as weighting factors to select the most informative features among all analyzed variables.

The color difference (ΔE) was also determined. It ranges from 0 to 100, where values closer to 0 indicate that the color of biscuits with added cinnamon powder is similar to that of the control sample, while values closer to 100 indicate a more pronounced color difference, Eq. (3):

$$\Delta E = \sqrt{(L_c - L_a)^2 + (a_c - a_a)^2 + (b_c - b_a)^2} \quad (3)$$

where L_c, a_c, b_c represent the color components of the control sample; L_a, a_a, b_a - color components of the cinnamon-enriched sample.

A regression model, widely used in food product analysis, was applied [12]. It describes the relationship between the independent and dependent variables and can be expressed as follows Eq. (4):

$$z = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 \quad (4)$$

where the dependent variable is denoted as z, whereas x and y represent the independent variables, with model coefficients denoted by *b*. The model was evaluated based on the coefficient of determination (R^2), regression coefficients, standard error, p - values, and the Fisher test.

To determine the optimal amount of cinnamon powder in biscuits, a linear programming algorithm was applied using the function *linprog*, which solves an optimization problem aimed at determining a vector x, that minimizes a linear objective function $f^T x$ subject to specified linear constraints, Eq. (5):

$$\min_x f^T x \quad (5)$$

subject to one of the following Eq. (6):

$$Ax \leq b \qquad A_{eq} x = b_{eq} \qquad l \leq x \leq u \quad (6)$$

An algorithm of the following type was used "*Interior - point - legacy*". The algorithm converges to an optimal solution by iteratively exploring the interior region of the feasible solution space.

The experimental data were processed using Matlab (The MathWorks Inc., Natick, MA, USA).

All data were statistically analyzed at a significance level of $\alpha = 0.05$.

Raw materials and formulation of experimental biscuits with cinnamon powder

Raw materials

The following raw materials were used for biscuit preparation: wheat flour (type 500, Sofia Mel, GoodMills Bulgaria EOOD, Sofia, Bulgaria), powdered sugar (Agrana Trading EOOD, Sofia, Bulgaria), butter ("Sayana", Milky Group OOD, Haskovo, Bulgaria), hen eggs [13], liquid flavor (Dr. Oetker, Bielefeld, Germany), and cinnamon powder (ground cinnamon, origin: Indonesia; Mia Foods 21 EOOD, Sofia, Bulgaria).

Formulation

The composition of the biscuit formulations is presented in Table 2. Cinnamon powder partially replaced wheat flour, while the quantities of all other ingredients remained constant. The total mass of each formulation was 241 g.

Biscuit preparation process

The technological process for the preparation of

Table 2. Formulation of biscuits with cinnamon powder.

Ingredient (g)	0 % cinnamon powder	Variable cinnamon powder level, %
Wheat flour	100	100
Powdered sugar	50	50
Butter	83	83
Eggs	8	8
Liquid flavor	0.6	0.6
Cinnamon powder	0	According to formulation
Total, g	241	241

Table 3. Technological process for preparation of butter biscuits with cinnamon powder.

Step	Time	Temperature	Operation	Description
1	-	20 - 22°C	Raw material preparation	Flour sieving and egg sanitation
2	-	20 - 22°C	Dosing	Weighing of ingredients
3	5 - 10 min	18 - 20°C	Dough preparation	Mixing of ingredients; minimal processing to prevent butter softening
4	30 - 40 min	3 - 4°C	Cooling	Refrigeration of dough
5	-	18 - 20°C	Rolling	Rolling to 5 - 8 mm thickness
6	-	18 - 20°C	Shaping	Cutting using molds
7	-	18 - 20°C	Arrangement	Placing on baking trays
8	10 - 12 min	200°C	Baking	Convection baking
9	1 h	20 - 22°C	Cooling	Cooling at room temperature
10	-	20 - 22°C	Packaging	Packaging in polyethylene bags
11	-	20 - 22°C	Storage	Storage under dry and well - ventilated conditions

butter biscuits with cinnamon powder is presented in Table 3. The process consists of 11 stages. Certain operations were carried out at room temperature, while steps requiring prevention of butter softening were performed at lower temperatures. The total processing time was approximately 2.5 - 3 h.

Image acquisition and color analysis

Color digital images of the experimental biscuits were captured using a mobile device (E32S, Motorola, Inc., Schaumburg, IL, USA). The device was equipped with a 16 MP camera with a focal length of 26 mm, pixel size of 1 µm, and aperture of F2.2.

Illumination was provided by a dome light source with cool white LEDs (6400 K; model VT - 3528 - 60, V - TAC Europe Ltd., Plovdiv, Bulgaria), with a peak emission at 450 nm. Color calibration was performed using a standard color chart (Danes Picta BST11, Danes - Picta, Praha, Czech Republic) containing 24 color patches.

The acquired RGB images were converted to the CIELab color space (CIE 1976) using transformation functions under standard conditions (D65 illuminant, 2° observer).

Physical measurements

Spread factor

The spread factor (SF) was determined after baking by measuring the diameter (D, mm) and thickness (h, mm) of the biscuits. The diameter of each biscuit was measured at three different positions, and the average value was calculated. Similarly, thickness was measured at three points and averaged. Measurements were performed using a digital caliper (SEB-DC-023, Shanghai Shangerbo Import & Export Co., Ltd., Shanghai, PR China) with an accuracy of 0.05 mm and a maximum measuring range of 150 mm.

The spread factor (SF) was calculated using the following Eq. (7):

$$SF = \frac{D}{h} \tag{7}$$

where D represents the diameter of the biscuit after baking (mm), and h represents the thickness of the biscuit after baking (mm). The calculated parameter is dimensionless.

Baking loss determination

Baking losses were determined by measuring the mass of the biscuits after baking and subsequent cooling to room temperature using a technical balance (accuracy ± 0.1 g). Thermal losses were calculated according to the following Eq. (8):

$$TL = \frac{a-b}{a}.100, \% \tag{8}$$

where a represents the mass of the biscuit before baking (g), and b represents the mass after baking (g). Measurements were carried out using a technical balance (Pocket Scale MH - 200, ZheZhong Weighing Apparatus Factory, Yongkang City, Zhejiang Province, PR China), with a maximum capacity of 200 g and a resolution of 0.02 g.

Electrochemical analysis

Samples for the determination of pH, electrical conductivity (EC, $\mu S\ cm^{-1}$), total dissolved solids (TDS, ppm), and oxidation-reduction potential (ORP, mV) were prepared according to AACC Method 02 - 52.01 (electrometric method for hydrogen ion activity).

Distilled water was heated to 70°C, and the sample was added at a ratio of 1:10 (5 g in 50 mL). The mixture was homogenized and cooled to room temperature prior to analysis.

For each parameter, three consecutive measurements were performed, and the results were expressed as mean values and standard deviations.

Sample weight was determined using a technical balance (Pocket Scale MH - 200, ZheZhong Weighing Apparatus Factory, Yongkang City, Zhejiang Province, PR China) with a resolution of 0.02 g.

Measurements of pH, EC, TDS, and temperature were carried out using a combined meter (PH - TDS - EC - TEMP Meter, Nanjing Tsung Water Technology Company Ltd., Nanjing, PR China). ORP was measured using a dedicated instrument (Model ORP - 2069, Shanghai Longway Optical Instruments Co., Ltd., Shanghai, PR China), while temperature was additionally monitored using a digital thermometer (V&A VA6502, Shanghai Vihua V&A Instrument Co., Ltd., Shanghai, PR China).

Sensory evaluation

Sensory evaluation of the biscuits was performed in accordance with the standard BDS EN ISO 13299:2016 (Sensory analysis - Methodology - General guidance for establishing a sensory profile). The assessment was carried out by a panel of nine trained participants from the Department of Food Technologies, Faculty of Technics and Technologies, Yambol, Trakia University, in compliance with the institutional ethical code [14]. A 5 - point Likert scale was used to evaluate the sensory attributes. The results were expressed as mean values for each parameter.

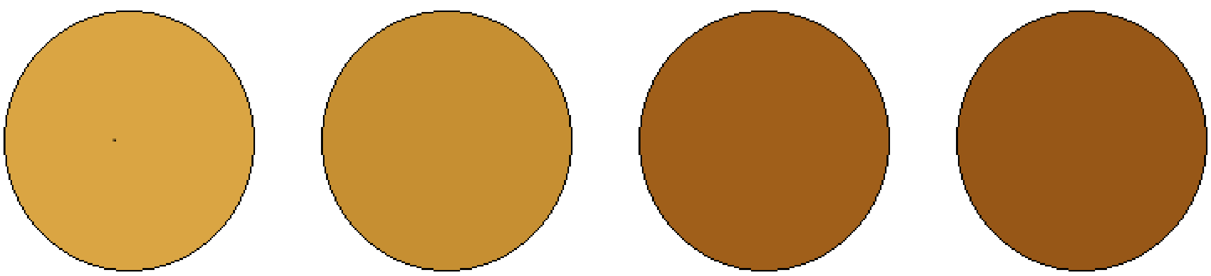
RESULTS AND DISCUSSION

Analysis of literature data

The average color profiles of cinnamon - enriched biscuits based on literature data are presented in Fig. 1. With increasing cinnamon powder concentration, a progressive darkening of the biscuit color is observed, shifting from light brown to dark brown tones. This trend is consistent with the known influence of phenolic compounds and Maillard reactions in bakery products.

The color difference (ΔE) between the control sample and cinnamon - enriched samples is shown in Fig. 2. A significant increase in ΔE is observed at higher cinnamon concentrations (4 % and 6 %), with values exceeding 20, indicating clearly perceptible differences to the human eye ($p < 0.05$). This confirms that cinnamon addition strongly affects the visual quality of biscuits.

Feature selection was performed using an algorithm developed by the authors, presented in Fig. 3. The



a) 0 % b) 2 % c) 4 % d) 6 %

Fig. 1. Average color profiles of cinnamon - enriched biscuits based on literature data.

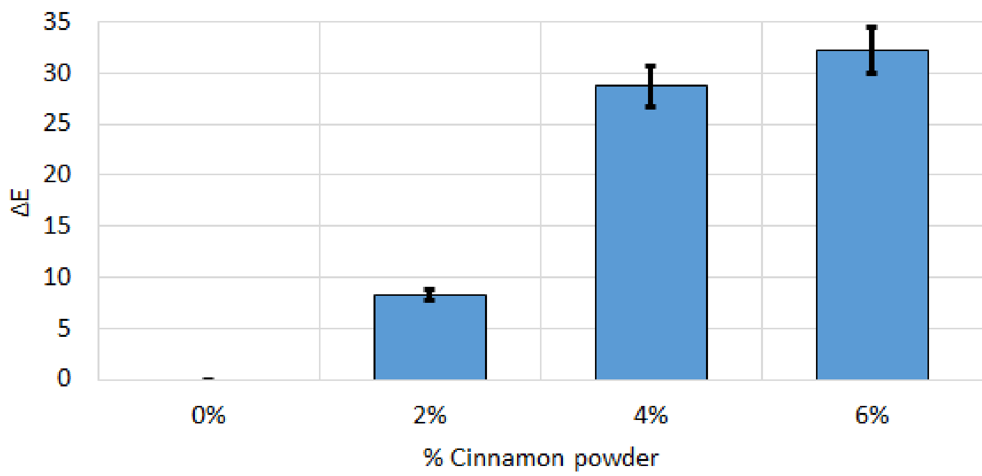


Fig. 2. Color difference (ΔE) between control and cinnamon - enriched biscuit samples. All differences are statistically significant ($p < 0.05$).

```
clc, clear all, close all
% Define feature names
features = { Names of all features };
% Input data 4 samples, 30 features each
X = [ 4x30 ];
% Target variable Cinnamon powder percentage
cinnamon_pct = [0; 2; 4; 6];
% Normalize feature matrix using Z - score normalization
Xraw = X(:,1:end);                % Extract raw feature matrix
mu = mean(Xraw, 1);               % Compute mean of each feature
sigma = std(Xraw, 0, 1);          % Compute standard deviation of each feature
% Apply normalization
Xnorm = (Xraw - repmat(mu, size(Xraw,1), 1)) ./ repmat(sigma, size(Xraw,1), 1);
% Calculate correlation between each feature and cinnamon percentage
corrVals = corr(Xnorm, cinnamon_pct);
% Sort features by absolute correlation value (descending)
[sortedCorr, idx] = sort(abs(corrVals), 'descend');
topFeatures = features(idx);
% Display all features ranked by correlation with cinnamon percentage
fprintf('Top features correlated with cinnamon powder percentage:\n');
for i = 1:length(features)
   fprintf('%2d. % - 25s Correlation = %+6.3f\n', i, topFeatures{i}, corrVals(idx(i)));
end
```

Fig. 3. Algorithm for selection of informative features based on correlation analysis.

algorithm evaluates the relationship between 30 biscuit characteristics, compiled from available literature data, and the cinnamon powder concentration. Initially, the dataset was standardized using Z - score normalization to eliminate the influence of differences in measurement scales among variables. Subsequently, the correlation between each feature and the cinnamon powder content was calculated.

The features were then ranked according to the strength of their correlation, regardless of direction (positive or negative), and the most strongly correlated variables were identified. The absolute values of the correlation coefficients were used as weighting factors to select the most informative features among all analyzed variables.

The results of the feature selection process are presented in Fig. 4. Seven chemical characteristics were identified as informative. Among the color parameters, all components of the RGB and HSV models, as well as L* and b* from the CIELab color space, showed high relevance. Only one physical parameter and two sensory attributes were found to be informative.

Based on these results, a feature vector comprising 18 variables was constructed:

FV1 = [F1 F3 F4 F6 F7 F8 F9 F11 F12 F13 F14 F16 F17 F18 F19 F23 F27 F28]

The selected features were further reduced to two latent variables (LV_1 and LV_2), which were used to develop a regression model for determining the optimal cinnamon powder level in biscuits.

After removing non - significant coefficients ($p > \alpha$), the final regression model was obtained:

$$\%C = 2.8 + 3.5LV_1 + 1.3LV_2 + 0.6LV_1^2 \quad (10)$$

The model demonstrated high predictive performance,

```
clc, clear all, close all
% Define feature names
features = { Names of all features };
% Input data 4 samples, 30 features each
X = [ 4x30 ];
% Target variable Cinnamon powder percentage
cinnamon_pct = [0; 2; 4; 6];
% Normalize feature matrix using Z - score normalization
Xraw = X(:,1:end);                 % Extract raw feature matrix
mu = mean(Xraw, 1);                % Compute mean of each feature
sigma = std(Xraw, 0, 1);           % Compute standard deviation of each feature
% Apply normalization
Xnorm = (Xraw - repmat(mu, size(Xraw,1), 1)) ./ repmat(sigma, size(Xraw,1), 1);
% Calculate correlation between each feature and cinnamon percentage
corrVals = corr(Xnorm, cinnamon_pct);
% Sort features by absolute correlation value (descending)
[sortedCorr, idx] = sort(abs(corrVals), 'descend');
topFeatures = features(idx);
% Display all features ranked by correlation with cinnamon percentage
fprintf('Top features correlated with cinnamon powder percentage:\n');
for i = 1:length(features)
   fprintf('%2d. % - 25s Correlation = %+6.3f\n', i, topFeatures{i}, corrVals(idx(i)));
end
```

Fig. 3. Algorithm for selection of informative features based on correlation analysis.

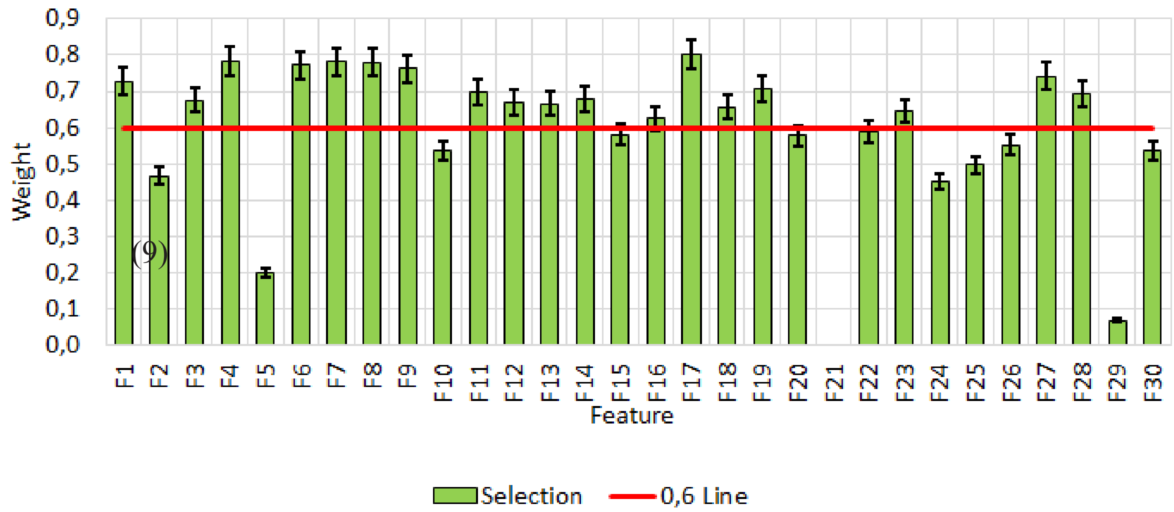


Fig. 4. Results of correlation - based feature selection indicating the most informative variables across chemical, color, physical, and sensory parameters.

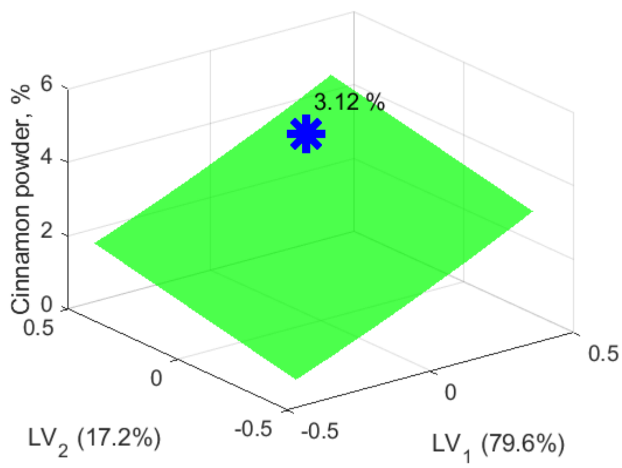


Fig. 5. Determination of the optimal cinnamon powder level in biscuits based on regression modeling in latent variable space.

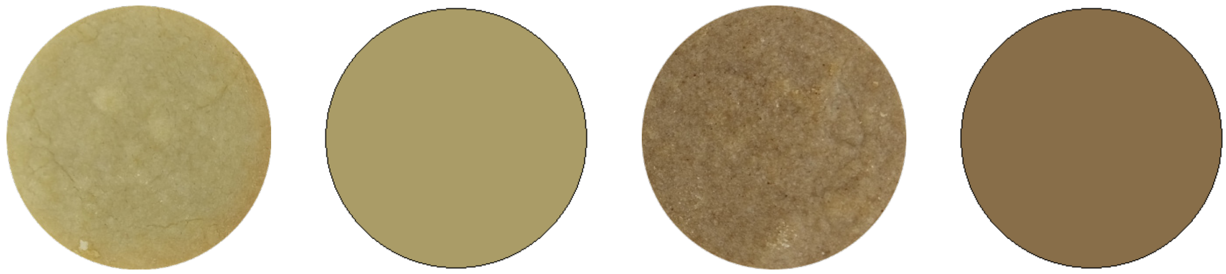
with a coefficient of determination of $R^2 = 0.97$. According to the Fisher test, $F(2, 9) = 194.28$, which exceeds the critical value ($Fcr = 4.26$), indicating strong statistical significance ($p << 0.05$). The standard error of the model was $SE = 0.39$.

The developed regression model was used to determine the optimal level of cinnamon powder in biscuits. The graphical representation of the optimization results is presented in Fig. 5. The optimal cinnamon powder content (3.12 %) is in the latent variable space at $LV_1 \approx 0.048$ and $LV_2 \approx 0.002$. This position indicates that the formulation lies near the transition zone between lower and higher levels of the latent variables, which are associated with key quality attributes such as flavour, aroma, and texture.

The identified value of 3.12 % represents a balanced formulation point, where the beneficial effects of cinnamon incorporation are maximized without adversely affecting the overall quality characteristics of the biscuits.

Comparative analysis of experimental biscuits with and without 3.12 % cinnamon powder

The visual appearance and average color profiles of



a) 0 % b) 3.12 %

Fig. 6. Visual appearance and average color profiles of biscuits.

Table 4. Color component values of biscuits with and without cinnamon powder.

Sample / Color component	0 % Control	3.12 % Cinnamon powder
R	170.39 ± 3.42	135.76 ± 5.46
G	156.16 ± 4.46	110.22 ± 6.08
B	103.29 ± 4.94	72.6 ± 6.3
L	97.14 ± 0	51.11 ± 10.49
a	- 21.55 ± 0	76.89 ± 15.77
b	94.48 ± 0	64.52 ± 13.24
H	0.17 ± 0	0 ± 0
S	1 ± 0	0.96 ± 0.2
V	1 ± 0	0.96 ± 0.2

the control sample and the sample containing 3.12 % cinnamon powder are presented in Fig. 6. A noticeable darkening of the biscuit color is observed because of cinnamon addition.

The values of color components obtained from RGB, CIELab, and HSV color models are presented in Table 4. A significant decrease in R, G, B, and L* values was observed, indicating darkening of the biscuits and a reduction in brightness.

The increase in parameter a* suggests an enhancement of red tones, while the decrease in b* indicates a reduction in yellow hues. The HSV indices (H, S, and V) also show a decreasing trend, further confirming the shift in the overall color profile due to the incorporation of cinnamon powder.

These results are consistent with the visual observations and confirm the strong impact of cinnamon addition on biscuit color characteristics.

The color difference between the control sample and the sample containing 3.12 % cinnamon powder was $\Delta E = 18.92$, indicating a clearly perceptible difference to the human eye.

Baking losses of biscuits with cinnamon powder are presented in Fig. 7. The results show that baking losses in the control sample were 2 %, while the addition of cinnamon powder increased the losses to 6 %. This indicates that cinnamon incorporation enhances mass loss during thermal processing, with a pronounced effect compared to the control sample. This behavior can be attributed to the higher dietary fiber content and altered dough structure, which facilitate moisture evaporation during baking.

The spread factor of biscuits with cinnamon powder is presented in Fig. 8. The results indicate that the incorporation of cinnamon leads to an increase in the spread factor of the biscuits. This effect can be attributed to the presence of dietary fibers and bioactive compounds in cinnamon, which influence dough structure and promote expansion during baking.

Changes in the physicochemical characteristics of

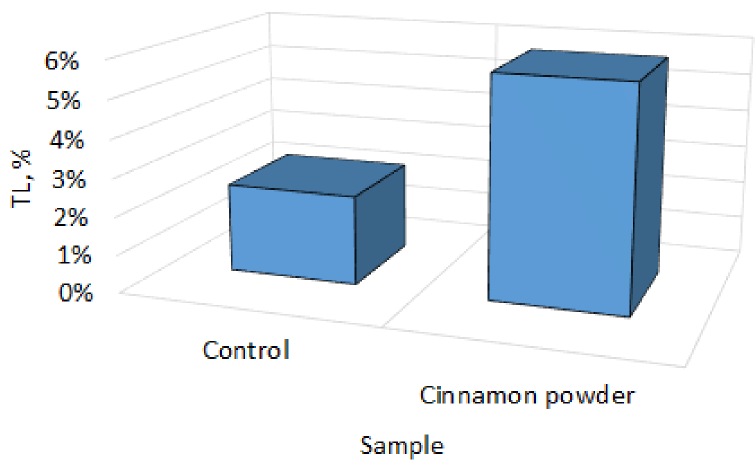


Fig. 7. Baking losses of biscuits with and without cinnamon powder.

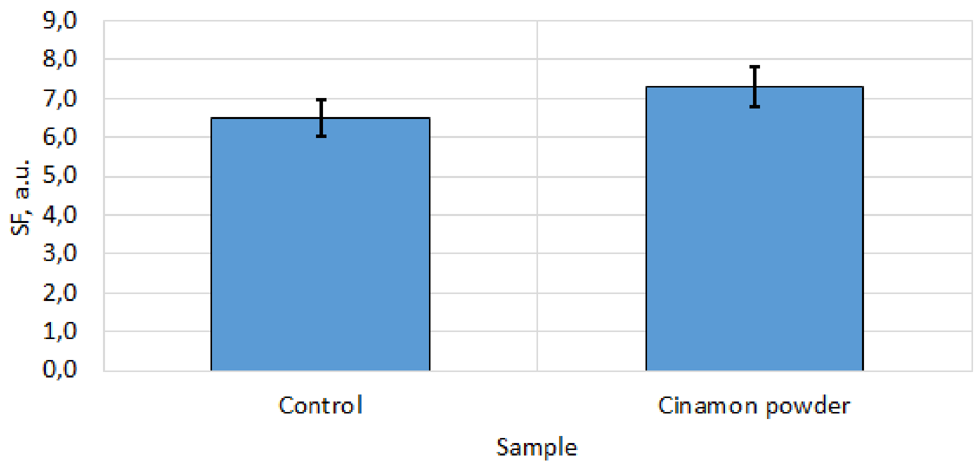


Fig. 8. Spread factor of biscuits with and without cinnamon powder.

Table 5. Physicochemical properties of biscuits with and without cinnamon powder.

Characteristic / Sample	pH	TDS, ppm	EC, µS cm^{-1}	ORP, mV
0 % Control	9.5 ± 0.02	575 ± 24	1150.5 ± 48.5	206 ± 42
3.12 % Cinnamon powder	9.5 ± 0.03	541 ± 38	1091.0 ± 84.0	161 ± 13

biscuits with cinnamon powder are presented in Table 5. The addition of 3.12 % cinnamon powder did not significantly affect pH, which remained alkaline (≈ 9.5). However, a decrease in total dissolved solids (TDS) and electrical conductivity (EC) was observed.

The oxidation - reduction potential (ORP) also decreased from 206 mV in the control sample to 161 mV in the cinnamon - enriched biscuits, indicating a shift toward a more reducing environment.

This behavior can be attributed to the presence of phenolic compounds with antioxidant properties, which influence the electrochemical characteristics of the system.

The results of the sensory evaluation of biscuits with cinnamon powder are presented in Table 6. The addition of 3.12 % cinnamon powder resulted in a slight decrease

Table 6. Sensory evaluation results of biscuits with and without cinnamon powder.

Characteristic / Sample	0 % Control	3.12 % Cinnamon powder
Appearance	4.93 ± 0.06	4.66 ± 1.13
Texture	4.93 ± 0.06	4.69 ± 1.14
Aroma	4.93 ± 0.06	4.61 ± 1.07
Flavour	4.93 ± 0.06	4.52 ± 0.99
Chewiness	4.93 ± 0.06	4.29 ± 1.08
Overall acceptability	4.93 ± 0.06	4.55 ± 1.00

in all sensory attributes compared to the control sample.

The most affected parameters were chewiness and flavour, which may be associated with changes in texture and the increased intensity of aromatic compounds. Despite this decrease, the overall acceptability remained high (4.55 ± 1.00), indicating good consumer acceptance and confirming the potential of cinnamon as a functional ingredient without significantly compromising sensory quality. These results suggest that moderate levels of cinnamon incorporation can enhance functional properties while maintaining acceptable sensory characteristics.

The increase in spread factor (SF) observed in cinnamon - enriched biscuits can be attributed to the specific properties of cinnamon. It contains dietary fibers capable of absorbing water and forming hydrophilic structures, which promote dough expansion during baking. In addition, the essential oils present in cinnamon exhibit mild plasticizing effects, improving dough elasticity and contributing to increased spread. Similar observations have been reported by Lansakara et al. [15].

The increase in thermal losses is associated with the higher fiber content and the absence of gluten - forming components, which weaken the dough structure and facilitate moisture evaporation during baking. Furthermore, phenolic compounds in cinnamon may influence thermal conductivity, accelerating water loss. As a result, a greater reduction in mass is observed compared to the control sample, in agreement with findings reported by Andres - Bello et al. and Hosry et al. [16, 17].

The observed changes in pH, TDS, EC, and ORP are related to the antioxidant properties of cinnamon and its phenolic compounds, which contribute to the formation of a more reducing environment in the product. These results indicate that cinnamon affects the ionic composition and electrochemical characteristics of biscuits without significantly altering their alkaline balance. This is consistent with the findings of Ranasinghe et al. [1], who reported that cinnamon bioactive compounds can influence the electrochemical properties of food systems.

Sensory evaluation results indicate that moderate levels of cinnamon addition (approximately 3 - 4 %) maintain high consumer acceptability. This supports previous findings by Uddin et al. [18], demonstrating that functional ingredients can enhance flavour and aroma, while excessive concentrations may negatively affect overall sensory perception.

The obtained results also extend the findings of Titova et al., who demonstrated that regression models combined with intelligent feature selection can effectively link instrumental measurements (e.g., EC and ORP) with sensory attributes in complex food systems, improving classification and prediction accuracy [8].

Overall, the results demonstrate that cinnamon powder can be successfully incorporated into biscuit formulations as a functional ingredient with minimal compromise in quality.

CONCLUSIONS

- The optimal cinnamon powder level in biscuits was determined to be approximately 3.12 %, ensuring a balance between functional enhancement and acceptable sensory quality.
- Cinnamon incorporation leads to improved nutritional composition (increased protein, fat, and dietary fiber) and reduced moisture content, alongside significant changes in color parameters toward darker tones.

- The addition of cinnamon increases baking losses and spread factor, likely due to the water - binding capacity of dietary fibers and the plasticizing effect of essential oils.
- Electrochemical properties showed no significant change in pH, but decreased TDS, EC, and ORP, indicating modifications in ionic composition and antioxidant - related characteristics.
- Despite slight reductions in individual sensory attributes, overall acceptability remained high (4.55 ± 1.00), confirming cinnamon powder as a suitable functional ingredient.
- The combined approach of multivariate analysis and experimental validation proved effective for formulation optimization and provides a practical basis for the development of functional bakery products.

Authors' contributions

Z.Z.: conceptualization; Zh.G.: methodology; M.M.: validation; V.Y: formal analysis; M.G., S.B.: investigation; Z.Z.:data curation; Z.Z., Zh.G.: writing - original draft preparation, review and editing.

REFERENCES

1. P. Ranasinghe, S. Pigera, G.A. Premakumara, P. Galappaththy, G.R. Constantine, P. Katulanda, Medicinal properties of 'true' cinnamon (*Cinnamomum zeylanicum*): A systematic review, BMC Complement. Altern. Med., 13, 275, 2013. DOI: 10.1186/1472-6882-13-275
2. N. Mehta, S. Ahlawat, D. Sharma, R. Dabur, Novel trends in development of dietary fiber rich meat products - A critical review, J. Food Sci. Technol., 52, 2, 2015, 633-647. DOI: 10.1007/s13197-013-1010-2
3. N. Błaszczyk, A. Rosiak, J. Kałużna-Czaplińska, The Potential Role of Cinnamon in Human Health, Forests, 12, 5, 2021, 648. DOI: 10.3390/f12050648
4. M.S. Blanco Canalis, M.E. Steffolani, A.E. León, P.D. Ribotta, Effect of different fibers on dough properties and biscuit quality, J. Sci. Food Agric., 97, 6, 2017, 1607-1615. DOI: 10.1002/jsfa.7909
5. S.H. Ng, W.I. Wan Rosli, Effect of cinnamon powder addition on nutritional composition, physical properties and sensory acceptability of butter biscuits, Malays. J. Nutr, 20, 2, 2014, 245-253.
6. P.I. Modi, J.K. Parikh, M.A. Desai, Sonohydrodistillation: Innovative approach for isolation of essential oil from the bark of cinnamon. Ind. Crops Prod., 142, 2019, 111838. DOI: 10.1016/j.indcrop.2019.111838
7. K.B. Killday, M.A. Markus, C. Fischer, K.L. Colson, Analysis of coumarin and other compounds in commercially available cinnamon and cinnamon supplements utilizing quantitative nuclear magnetic resonance spectroscopy, Planta Med., 81, 11, 2015, PA13. DOI: 10.1055/s-0035-1556196
8. T. Titova, V. Nachev, C. Damyanov, Intelligent methods applied in multisensor food analysis, J. Inform. Innov. Technol., 2-3, 1, 2019, 67-70.
9. E.K. Djidjor, H. Opoku, B. Mohammed, G.N. Karikari, Nutritional composition and acceptability of biscuits produced from a blend of wheat, cinnamon and desiccated coconut flour, East Afr. Sch. J. Agric. Life Sci., 3, 2, 2020, 64-69. DOI: 10.36349/EASJALS.2020.v03i02.008
10. R. Yenrina, N. Pratiwi, Rini, T. Anggraini, The addition effect of cinnamon powder (*Cinnamomum burmanii*) on the characteristics of gluten-free cookies made from tempeh and mocaf flour. IOP Conf. Ser.: Earth Environ. Sci., 1059, 1, 2022, 012061. DOI: 10.1088/1755-1315/1059/1/012061
11. E.G. Khudair, S.A. AL Sahib, B.M. AL-Timimi, Evaluate the effect of Cinnamomum zeylanicum oil extract in inhibition of bacteria in laboratory biscuit, Iraqi J. Agric. Sci., 55, 3, 2024, 1048-1063. DOI: 10.36103/h2cgqb53
12. Ts. Georgieva, A. Mihaylova, P. Daskalov, Research of the possibilities for determination of some basic soil properties using image processing, Proc. 7th Int. Conf. Energy Effic. Agric. Eng., 2020, p. 1-4.
13. Regulation No. 1 of January 9, 2008, Bulgaria, (in Bulgarian)
14. https://trakia-uni.bg/wp-content/uploads/2024/04/EtichenKodeks.pdf, accessed on 16 September 2025
15. L.H.M.P.R. Lansakara, S.P. Kodithuwakku, S.M.C. Himali, J.K. Vidanarachchi, Effects of supplementation of insoluble dietary fiber obtained from cinnamon spent bark waste on the performance of nile tilapia (*Oreochromis niloticus*) fingerlings, Trop. Agric. Res., 35, 2, 2024, 131-142. DOI:

10.4038/tar.v35i2.8744

16. L. El Hosry, V. Elias, V. Chamoun, M. Halawi, P. Cayot, A. Nehme, Bou- E. Maroun, Maillard reaction: mechanism, influencing parameters, advantages, disadvantages, and food industrial applications: A Review. Foods, 14, 11, 2025, 1881. DOI: 10.3390/foods14111881
17. A. Andrés-Bello, V. Barreto-Palacios, P. García-Segovia, J. Martínez-Monzó, Effect of pH on color and texture of food products, Food Eng. Rev., 5, 3, 2013, 158-170. DOI: 10.1007/s12393-013-9067-2
18. M. Uddin, N. Mashahid, J.A. Anta, M.R. Acharjee, Development and evaluation of functional biscuits infused with functional spices and white pea flour: A comprehensive study on optimizing glycemic control and incorporating anti-diabetic additives. Appl. Food Res., 5, 1, 2025, 100710. DOI: 10.1016/j.afres.2025.100710