# Sensory evaluation of cookies enriched with lyophilized black goji

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**The incorporation of bioactive-rich plant materials into bakery products represents a promising approach in the functional foods development targeting the enhancement of nutritional and health-promoting characteristics. The present study aimed to evaluate the sensory characteristics and acceptability of cookies enriched with lyophilized black goji berry powder (LBGBP) using standardized descriptive sensory analysis. Cookies were previously formulated by substituting wheat flour with increasing levels of LBGBP (2.5%, 5.0%, 7.5%, and 10.0%), while a formulation without supplementation served as the control sample. Sensory profiling was performed by a trained panel according to ISO 6658:2017 guidelines, evaluating appearance, odor, taste, and textural attributes. The results demonstrated that LBGBP incorporation significantly affected all evaluated sensory parameters ($p < 0.05$). Increasing LBGBP concentration intensified cookie color, consistent with previously observed instrumental color measurements, while surface appearance scores decreased at higher supplementation levels. Taste and odor scores progressively increased with LBGBP addition, and panelists described the flavor modifications as pleasant and desirable. Sensory hardness and fracturability significantly decreased with increasing substitution levels, indicating the formation of softer and less brittle cookie structures. Overall, the study demonstrated that LBGBP can be successfully incorporated into cookies, providing products with enhanced sensory complexity and distinctive characteristics. Formulations containing moderate levels of LBGBP achieved the most balanced sensory profile, suggesting their potential application in the development of functional bakery products with favorable consumer acceptability.**

***Keywords:*** black goji; cookies; sensory evaluation; color intensity; surface appearance; taste; odour; hardness; fracturability

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## 1. INTRODUCTION

Black goji (*Lycium ruthenicum* Murray) is a rich source of anthocyanins recognized as potent antioxidants (Gao et al., 2017; Lee and Choi, 2023; Liu et al., 2024). Traditionally, goji species are applied in the effort of treating different health conditions such as infertility, fatigue, headaches, and serves as anti-aging agent (Liu et al., 2024; Qian et al., 2017) while some clinical studies proved its benefits as hepatoprotective, neuroprotective, anti-inflammatory, antidiabetic, and antioxidant agents (Ai et al., 2021; Chen et al., 2013; Lee and Choi, 2023). Moreover, berries powder and extracts can be added into different food products (Jiang et al., 2021). The production of high-quality dried berries relies on the application of advanced drying techniques combined with appropriate pretreatment procedures, which contribute to the preservation of both sensory attributes and nutritional quality (Turan et al., 2023). However, the drying of goji berries represents a technological challenge due to their high moisture and sugar content, as well as the presence of a thin wax-coated epidermis and compact fleshy cellular structure (Cui et al., 2022; Liu et al., 2024). Among the drying technologies employed in the food industry, freeze-drying or lyophilization is considered as one of the most effective approaches, particularly for thermolabile materials (Cui et al., 2022). This process has been shown to provide enhanced retention of bioactive compounds, including phenolic constituents, polysaccharides, and anthocyanins, while simultaneously preserving favorable sensory characteristics and rehydration capacity of goji berries (Jiang et al., 2021; Turan et al., 2023).

Cookies are one of the most commonly consumed wheat-based products worldwide owing to their diverse flavor profiles, convenience, extended shelf life, and affordability. The incorporation of ingredients rich in bioactive compounds represents a promising strategy for enhancing their nutritional and functional value (Asadi et al., 2022; Filipović et al., 2022). Nevertheless, cookies constitute complex food matrices in which each component plays a specific technological and functional role. Consequently, modifications to conventional formulations may alter dough rheology and processing behavior, ultimately affecting the physicochemical and sensory quality of the final product (Blanco Canalis et al., 2017). Therefore, the development of fortified cookie formulations requires careful optimization of processing conditions and comprehensive quality evaluation to ensure desirable product characteristics (Filipović et al., 2022).

Sensory evaluation is recognized as an indispensable tool in modern food product development, particularly in the design of functional and fortified foods, where consumer perception often determines market success more strongly than nutritional composition alone. Recent studies have emphasized that sensory characteristics such as flavor, texture, appearance, and aroma are among the primary drivers of consumer acceptance, purchase intention, and repeated consumption behavior (Appiani et al., 2023; Drake et al., 2023).

Incorporation of bioactive-rich ingredients frequently leads to modifications in sensory quality, including changes in colour, bitterness, astringency, texture, and overall palatability. Consequently, comprehensive sensory and hedonic analyses are essential to identify formulations that successfully combine improved functional properties with high consumer acceptability (Baker et al., 2022; Huey et al., 2024).

Furthermore, contemporary research highlights that consumer acceptance of novel and functional foods is strongly influenced by sensory perception, with intrinsic product attributes often representing the decisive factor for product adoption and long-term market sustainability (Appiani et al., 2023; Laureati et al., 2024). Therefore, sensory analysis, together with consumer preference testing, has become an integral component of evidence-based food innovation, enabling the optimization of product quality, functionality, and commercial viability.

The goal of this study was to investigate the sensory characteristics and consumer-oriented quality of cookies enriched with freeze-dried black goji berry powder previously developed and chemically characterized. Particular emphasis was placed on determining the influence of black goji berry incorporation on the appearance, odour, taste, and textural attributes of the cookies by applying standardized descriptive sensory analysis performed by a trained sensory panel. Furthermore, the study aimed to identify the formulation with the most favourable sensory profile and overall acceptability, thereby assessing the feasibility of incorporating freeze-dried black goji berries into bakery products without compromising sensory quality and consumer acceptance.

## 2. MATERIALS AND METHODS

### 2.1. Material

#### 2.1.1. Black goji powder

Powder of the lyophilized black goji berry - LBGBP was produced from the fresh goji berries as raw material, which were collected in September of 2024, at the local plantation near Pančevo, Serbia. Collected berries were submitted to a freeze-drying process, using lyophilizator: Model LF 100, at company: Elbi d.o.o., Valjevo. Freeze-drying process consisted of following stages:

- rapid freezing (at −60 °C, during few hours), in effort of stabilizing internal cellular structures and preventing large ice crystals formation;
- primary drying (during approximately 24–36 h), where about 90–95% of the original moisture was removed;
- secondary drying - desorption phase (during approximately 72 h), reducing final moisture content to below 5%.

Dried whole fruits were further ground to the fine powder using MILL130 (Bakery Pastry and Pizza Equipment, RAM S.r.l., Vicenza, Italy) and sieving via 0.30 mm and 0.15 mm mesh sizes (Yugoslavian Pharmacopeia IV) set of sieves in effort of obtaining fractions of the dimensions between 150 and 300 $\mu$m. The obtained fractions were further packaged into pouches made of triplex barrier, filled with inert nitrogen gas (Besser Vacuum S.r.l., Dignano, Italy) (Šavikin et al., 2026).

#### 2.1.2. Materials for cookies preparation

All the material used for cookie samples production was obtained from local sources. Following materials were used: white wheat flour, type T-400 - "Danubius", Novi Sad, Serbia, the moisture content: 14%; margarine - "AD Dijamant", Zrenjanin, Serbia; sugar - "Šajkaška" Žabalj, Serbia, NaCl - "Produkt", Stara Pazova, Serbia; $NaHCO_3$ - "Aleva", Novi Kneževac, Serbia; glucose - "BIO-UNA", Novi Sad, Serbia (Šavikin et al., 2026).

### 2.2. Cookie samples production

Cookie samples without and with flour substitution by lyophilized black goji powder (LBGBP) were previously produced at the Institute of Food Technology in Novi Sad, Serbia, using a pilot plant for bakery production, following AACC method 10–50 D (Šavikin et al., 2026). The cookie samples are marked with C0 (without LBGBP); C2.5 (2.5% of LBGBP); C5 (5% of LBGBP); C7.5(7.5% of LBGBP); C10(10% of LBGBP). The incorporation of LBGBP into the formulations resulted in a progressive increase in both total phenolic content (TPC) and total anthocyanins content (TAC). TPC increased from 16.84 $\pm$ 2.14 mg GAE/100 g in sample C2.5 to 58.09 $\pm$ 5.71 mg GAE/100 g in sample C10. TAC values increased from 1.19 $\pm$ 0.05 mg GAE/100 g in C2.5 to 10.13 $\pm$ 4.53 mg GAE/100 g in C10 (Šavikin et al., 2026).

### 2.3. Methods of cookie descriptive sensory analysis

Panel of ten evaluators with the experience in food product sensory analysis performed cookie samples sensory profile evaluation, in accordance with the standard: ISO 6658:2017.

Leading evaluator initially selected sensory profiling descriptors for the cookie samples by applying the descriptive sensory method, which were subsequently finely altered by other evaluators in an effort to define cookies' sensory profiles in the best manner.

Total of six descriptors were defined:

- cookie appearance descriptors for color intensity and surface appearance,
- one taste descriptor,
- one odor descriptor
- and two textural properties descriptors for sensory hardness and fracturability.

All descriptors were included in the final Cookies samples descriptive sensory analysis form, Appendix 1, supplementary material 1.

Seven-point scale was used for descriptor intensity definition, where the mark 1 was applied for the lowest intensity while mark 7 was used for the highest intensity (ISO 4121:2003), with the exception for the surface appearance descriptors, where the best mark was 7, while the worst was 1.

Descriptive sensory analysis was done 24 h post baking of the cookies, in the laboratory for sensory analysis of the Institute of Food Technology, Novi Sad, Serbia, which is designed following the ISO 8589:2007 standard. Panelists firstly read and filled out the Informed consent form, integral part of the Cookies samples descriptive sensory analysis form, Appendix 1, supplementary material 1, which follows the Declaration of Helsinki guidelines in its content. The cookie samples were presented to the panelists on white plastic plates, each identified by a randomly assigned three-digit code generated using a table of random numbers. The panelists were provided with sufficient water to cleanse their palates between the evaluation of individual samples.

The study, prior descriptive sensory analysis execution, was sent for approval by the Ethics Committee of the University of Novi Sad, Faculty of Technology Novi Sad, were following approval was obtained: protocol code: 020-25/2, date of approval: 26.01.2026.

### 2.4. Statistical analysis

Z-score analysis transforms the quality responses obtained for the cookie samples into a dimensionless scale using min–max normalization, thereby enabling direct comparison among the evaluated quality attributes and facilitating subsequent statistical analysis (Szarek et al., 2024). The highest total Z-score, calculated as a predefined combination of the individual segment Z-scores, indicates the cookie sample with the most favorable overall quality profile (Nićetin et al., 2024).

Segment Z-score for descriptive sensory analysis was calculated as following:

$$S_{8i} = \frac{\sum_{j=1}^{3}\left(1 - \frac{x_{ji} - x_{j\min}}{x_{j\max} - x_{j\min}}\right) + \sum_{k=1}^{3}\frac{x_{ki} - x_{k\min}}{x_{k\max} - x_{k\min}}}{6} \quad (1)$$

where $x_j$ are: colour intensity, taste and odour; and $x_k$ are: surface appearance, hardness and fracturability.

Total quality cookie samples' Z-score was calculated using previously published authors of the study results for nutritive quality score ($S_1$–$S_3$), technological quality score ($S_4$ – S6) and storage stability score ($S_7$) (Šavikin et al., 2026), and supplementing them with descriptive sensory analysis score ($S_{8i}$) quality, as following:

$$S_i = \left(0.1 \cdot S_{1i} + 0.1 \cdot S_{2i} + 0.1 \cdot S_{3i} + 0.15 \cdot S_{4i} + 0.10 \cdot S_{5i} + 0.05 \cdot S_{6i} + 0.1 \cdot S_{7i} + 0.3 \cdot S_{8i}\right) \cdot 100\% \quad (2)$$

where cookie samples' nutritive ($S_{1i}$ to $S_{3i}$), technological ($S_{4i}$ to $S_{6i}$) and descriptive sensory ($S_{8i}$) quality characteristics Z-scores values, contributed with 30% of significance for every quality group, while storage stability quality characteristics Z-scores values ($S_{7i}$) contributed with 10% of significance to the total Z-score.

$$\max\,[Si] \rightarrow \text{optimum} \quad (3)$$

Microsoft Excel ver. 2016. was used for Z-score values calculation (Microsoft Corporation, Redmond, WA, USA).

Analysis of variance (ANOVA) was performed using StatSoft Statistica, ver. 12 (StatSoft Europe, Hamburg, Germany). The results are expressed as mean value ± standard deviation. Statistical significance was assessed using one-way analysis of variance (ANOVA) at a 95% confidence level, followed by Tukey's post-hoc test. Differences were considered statistically significant at $p < 0.05$.

## 3. RESULTS AND DISCUSSION

### 3.1. Descriptive sensory analysis

Descriptive sensory analysis of food products enables the identification of key sensory attributes that can be further optimized during the development of new products. It also provides valuable insights into the feasible levels of incorporation or substitution of conventional raw materials with innovative ingredients while maintaining desirable sensory characteristics. (Kumar et al., 2021; Zlatanović et al., 2019).

Table 1 presents the results of the descriptive sensory analysis of the cookie samples, demonstrating the effects of progressive flour substitution with LBGBP on the sensory profile of the developed products.

The sensory response related to color intensity statistically significantly increased, with the LBGBP input increase, following the same trend observed in the instrumental color analysis (results published in previous work of the same authors (Šavikin et al., 2026), particularly the L* parameter. This effect can be attributed to the high anthocyanin content of black goji berries (Islam et al., 2017), which contributed to the development of darker and more intensely colored products.

In contrast, the surface appearance of the cookies deteriorated with increasing LBGBP incorporation, with a statistically significant decline observed at the 7.50% substitution level. Such changes may be associated with modifications in dough structure and baking behavior caused by the incorporation of fiber- and polyphenol-rich plant material (Wang et al., 2020).

Taste and odor scores exhibited a concentration-dependent increase, with each level of LBGBP substitution producing statistically significant differences compared to the control sample (C0). Importantly, the panelists described the flavor and aroma modifications as pleasant and desirable, indicating that the characteristic sensory attributes of black goji berries positively contributed to the overall sensory perception of the cookies. These findings suggest that LBGBP may improve the sensory distinctiveness and flavor complexity of bakery products when incorporated at appropriate levels.

The sensory texture descriptors, namely hardness and fracturability, showed statistically significant decreases with increasing LBGBP supplementation. The most pronounced reduction in both parameters was observed at the 7.50% substitution level, indicating the development of softer and less brittle cookie structures. These findings are in strong agreement with previous instrumental texture analysis results (Šavikin et al., 2026), suggesting a high correlation between instrumental measurements and human sensory perception. The mechanisms previously proposed to explain the instrumental texture modifications, including disruption of the gluten network and the water-binding capacity of berry-derived fibers (Nićetin et al., 2024; Wang et al., 2020), may also account for the observed sensory texture changes.

Overall, the results confirm that the sensory acceptability of cookies enriched with fruit-derived powders is strongly dependent on the level of supplementation. Excessive incorporation may negatively affect certain quality attributes, emphasizing the importance of formulation optimization to achieve a balance between improved functional value and desirable sensory characteristics (Shabnam et al., 2020).

### 3.2. Evaluation of the overall quality

The Z-score analysis was utilized to provide an integrated assessment of the cookies' quality and to optimize overall cookies' quality characteristics, by combining nutritive, technological, storage stability and sensory parameters into a single, integral dimensionless score. As previously reported by Šavikin et al. (2026), the nutritive (S1–S3) and storage stability

**Table 1.** Descriptive sensory analysis of cookies without and with lyophilized black goji berry powder flour substitution.

| Sample no. | Color intensity | Surface appearance | Taste | Odour | Hardness | Fracturability |
|---|---|---|---|---|---|---|
| **C0** | 1.50±0.50$^{a}$ | 6.83±0.29$^{b}$ | 1.17±0.29$^{a}$ | 1.17±0.29$^{a}$ | 7.00±0.00$^{c}$ | 6.33±0.58$^{b}$ |
| **C2.5** | 2.83±0.29$^{ab}$ | 5.33±0.29$^{ab}$ | 3.00±0.00$^{b}$ | 2.67±0.58$^{b}$ | 6.17±0.29$^{c}$ | 5.50±0.87$^{b}$ |
| **C5** | 4.17±0.29$^{ab}$ | 5.00±0.00$^{ab}$ | 4.0±0.00$^{c}$ | 4.00±0.00$^{c}$ | 4.83±0.29$^{b}$ | 4.80±0.76$^{b}$ |
| **C7.5** | 4.67±1.53$^{b}$ | 3.67±1.76$^{a}$ | 5.17±0.29$^{d}$ | 5.00±0.00$^{d}$ | 2.67±0.58$^{a}$ | 2.50±0.80$^{a}$ |
| **C10** | 5.17±1.75$^{b}$ | 3.17±1.04$^{a}$ | 6.17±0.29$^{e}$ | 6.00±0.00$^{e}$ | 2.17±0.76$^{a}$ | 2.15±0.79$^{a}$ |

Results are shown as average values and standard deviations of three repetitions (n=3).
$^{a\text{-}e}$ Different superscript letters within the same column indicate statistically significant differences among the corresponding values ($p < 0.05$).

**Table 2.** Results of the Z-score analysis of cookies without and with LBGBP flour substitution.

| | | C0 | C2.5 | C5 | C7.5 | C10 |
|---|---|---|---|---|---|---|
| Nutritive quality score | $S_1$* | 0.09 | 0.33 | 0.63 | 0.71 | 0.83 |
| | $S_2$* | 0.00 | 0.20 | 0.42 | 0.70 | 1.00 |
| | $S_3$* | 0.00 | 0.16 | 0.46 | 0.75 | 1.00 |
| Technological quality score | $S_4$* | 0.60 | 0.42 | 0.47 | 0.35 | 0.40 |
| | $S_5$* | 0.50 | 0.87 | 0.68 | 0.65 | 0.50 |
| | $S_6$* | 1.00 | 0.54 | 0.42 | 0.05 | 0.00 |
| Storage stability score | $S_7$* | 0.00 | 0.17 | 0.47 | 0.56 | 1.00 |
| Descriptive sensory score | $S_8$ | 1.00 | 0.70 | 0.47 | 0.14 | 0.00 |
| Total Score | | 49.94% | 47.39% | 49.75% | 43.40% | 49.31% |

*Results of nutritive quality score, technological quality score and storage stability score were previously published in our manuscript Šavikin et al., 2026.

(S7) scores increased progressively with increasing levels of LBGBP substitution, with the highest Z-score values recorded at the 10% substitution level.

Technological quality ($S_4$–$S_6$), however, declined at higher LBGBP flour substitution levels, indicating on cookie samples compromised structure and mechanical properties (Šavikin et al., 2026).

Trend of the effect of LBGBP flour substitution on descriptive sensory score also followed the trend of the effect on technological quality score, indicating on reduced subjective acceptance of sensory characteristics.

The highest total Z-score values (excluding control sample C0) were obtained for sample C5 (49.75%) indicating on the level of LBGBP flour substitution which provide optimal balance between functional enrichment and acceptable sensory and technological quality characteristics.

In comparison to the previous quality optimization focused only on nutritive and technological characteristics, where calculated optimal level of LBGBP substitution was 10% (Šavikin et al., 2026) it can be seen that integrating descriptive sensory analysis in the total quality optimization, led to the shift of the optimum to 5% of LBGBP substitution, primarily due to negative effect of sensory texture characteristics.

## 4. CONCLUSION

The incorporation of lyophilized black goji berry powder (LBGBP) into cookie formulations significantly influenced the sensory properties and overall quality characteristics of the developed products. Increasing levels of LBGBP substitution resulted in darker cookies with intensified color attributes, while simultaneously affecting surface appearance and textural properties. The addition of LBGBP positively modified odor and taste profiles, with panelists perceiving these changes as pleasant and desirable, indicating the potential of black goji berry powder to enhance sensory complexity and product attractiveness. Furthermore, increasing LBGBP concentrations led to reduced sensory hardness and fracturability, producing softer and less brittle cookie structures. These findings were in agreement with the previously conducted and published instrumental texture and colour analysis, confirming a strong correlation between instrumental measurements and sensory perception. Although higher substitution levels adversely affected certain appearance and texture attributes, moderate incorporation levels provided the most balanced sensory profile and acceptable product quality. Overall, the study demonstrated that freeze-dried black goji berry powder can be successfully utilized as potent ingredient in bakery products without compromising consumer-oriented sensory quality. The obtained results support the feasibility of developing innovative functional cookies enriched with black goji berry powder, while emphasizing the importance of optimizing supplementation levels to achieve the best balance between enhanced functional value and sensory acceptability.

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## CONFLICT OF INTEREST

The authors declare that they have no financial and commercial conflicts of interest.

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