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ORIGINAL PAPER

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THE USE OF FERMENTATION TO IMPROVE THE PRO-HEALTH PROPERTIES OF POTATO TUBERS

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ABSTRACT

Background. Lactic fermentation of potato tubers is a niche yet promising direction in research in functional foods, offering the possibility of enhancing their health-promoting value. Due to their high starch content and beneficial profile of bioactive compounds, potatoes are an important and a valuable raw material for food production. In response to consumer demand for novel products, an attempt was made to apply lactic fermentation to potatoes and to assess the impact of this process on their health-promoting properties.
Material and methods. Four potato cultivars were subjected to fermentation: Bila, Mia, Wega, and Werbena. For each cultivar, two variants of fermented products were prepared – one with dill and one with rosemary. The process was carried out at room temperature (approx. 21°C) for 25 days in 2% iodized sodium chloride solution. In the final products, dry matter content, health-promoting compounds (total polyphenols, flavonoids, chlorogenic acid), and antioxidant capacity (FRAP method) were determined. A sensory evaluation was also conducted among 50 respondents aged 19–65. Participants assessed basic sensory attributes (taste, aroma, color, texture) as well as palatability and overall desirability using a 5-point hedonic scale.
Results. The fermentation process increased the content of health-promoting compounds in all analyzed cultivars. The average increase in polyphenol content, regardless of cultivar and added herbs, was 13.0%, flavonoids 12.8%, and the chlorogenic acid content approximately doubled compared to the non-fermented samples. The increase in these compounds resulted in a marked improvement in antioxidant properties – on average by 32.8%. The highest accumulation of health-promoting compounds was found in the Bila cultivar, which after fermentation (regardless of the herb used), exhibited the highest antioxidant activity. In consumer evaluation, the highest ratings were given to products from the Mia and Werbena cultivars fermented with dill. Fermentation with dill, compared to rosemary, resulted in a greater increase in health-promoting compounds and better sensory ratings.
Conclusion. Lactic fermentation effectively enhances the nutritional and health-promoting value of potato tubers while also improves their organoleptic properties. The results indicate the potential for implementing fermented potatoes as innovative functional products that meet the needs of modern consumers.

Key words: potato, lactic fermentation, probiotics, lactic acid, health-promoting properties, functional food

INTRODUCTION

Lactic fermentation is one of the oldest and most widely used food bio-preservation processes, enabling improved shelf life, safety, and functional value of food (Zapaśnik et al., 2022; Aguirre-Garcia et al., 2024). The growing interest in fermented foods observed in recent years stems from both their sensory qualities and their documented health benefits, associated, among others, with increased levels of

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bioactive compounds and improved bioavailability of nutrients (Melini et al., 2019; Shah et al., 2023; Cruz-Aldaco et al., 2024). Vegetables such as cabbage, cucumber, carrot, and pepper are the raw materials most commonly used for fermentation. However, increasing attention is being paid to the possibility of applying this process to less commonly fermented plant materials (Tan et al., 2023; Ahmada et al., 2025; Press et al., 2025).

Potatoes (*Solanum tuberosum* L.), valued for their versatile culinary application and high nutritional value, are an essential component of diets worldwide. They are the third most consumed crop after wheat and rice, and more than one billion people include them in their daily meals. Global demand for potatoes is estimated at (3.75–3.83) × 10^8 $t \cdot yr^{-1}$ annually, with average daily consumption of about 0.43 pounds per person, corresponding to the size of a medium tuber (Eed et al., 2025). This raw material is cultivated on approximately 1.68 × 10^8 ha of agricultural land, and its importance as a food source remains high both globally and in the diet of the average Polish consumer (FAOSTAT 2023; Mishra et al., 2024). Potato tubers are a good source of energy, carbohydrates, protein, vitamins, and minerals (Raigond et al., 2024). In addition to basic nutrients, they contain numerous bioactive compounds such as polyphenols, flavonoids, chlorogenic acid, anthocyanins, and carotenoids (Rassheed et al., 2022; Barbaś et al., 2023), which exert beneficial effects on human health (Raigond et al., 2023). It should be noted, however, that the levels of these compounds can vary significantly depending on the potato variety and the color of the flesh and skin. Owing to their antioxidant capacity, potato bioactiv compounds may support protection against oxidative stress and aid in the prevention and management of various diseases (Hellmann et al., 2021; Raigond et al., 2023). Polyphenols act as strong antioxidants, neutralizing reactive oxygen species responsible for damage to lipids, proteins, enzymes, and DNA, which may lead to the development of numerous disorders (Rudrapal et al., 2022). Furthermore, their influence on the gut microbiome is associated with cytotoxic, anti-inflammatory, and potentially anticancer effects, as well as reduced risk of obesity and cardiovascular dysfunction (*Rana et al.*, 2022; Rasheed et al., 2022). Potato anthocyanins support the prevention of chronic diseases and may also improve cognitive function and reduce the risk of dementia (Lippert et al., 2017; do Rosario et al., 2024).

Despite the major role of potatoes in consumer diets, few studies focus on the use of lactic fermentation to enhance the nutritional and health value of tubers. Available research confirms that potatoes and their by-products, such as pulp, peels, and starch-processing waste, can be effectively subjected to lactic (Smerilli et al., 2015; Aregbe et al., 2019; Hu et al., 2025). However, the literature remains limited, particularly regarding the influence of cultivar type and herbal additives on the course and outcomes of fermentation. The growing consumer interest in functional foods and innovative fermented products encourages further research into the potential of fermentation as a method for enhancing the chemical composition and sensory quality of potato tubers.

The aim of this study was to evaluate the effect of lactic fermentation on the content of selected bioactive compounds and antioxidant capacity of four potato cultivars, and to determine how the addition of dill and rosemary affects the sensory characteristics of the obtained products.

MATERIAL AND METHODS

Material

The research material consisted of tubers of four potato cultivars originating from a field experiment established in 2021 at the Agricultural Advisory Center located in Minikowo (53°10′02″N, 17°44′22″E, Kuyavian-Pomeranian Voivodeship). The potato cultivars used for fermentation were Bila, Mia, Werbena, and Wega. Characteristics of the cultivars are presented in Table 1.

Methods

Preparation of fermented products

For each cultivar, two variants of fermented products were prepared: one with the addition of dill, and the other with the addition of rosemary. In 1-liter jars, approximately 800 g of unpeeled, boiled potato tubers were placed along with 10 g of garlic (2 cloves), 4 g of horseradish (2 pieces, 2 cm × 1 cm × 1 cm), 1 g of white mustard seeds (½ teaspoon), 2 bay leaves, 2 allspice berries, and either 5 g of dill flower heads with leaves and stems or 1.4 g of rosemary. A 2% (w/v) solution of sodium chloride (NaCl, table salt, iodized) was prepared and added at a 1:1 weight-to-volume ratio relative to the potatoes. The fermentation process was carried out for 25 days at 21 °C. All spices were purchased from retail stores.

Table 1. Tuber characteristics of the potato cultivars evaluated in this research (own elaboration based on https://zamarte.com and http://www.norika.pl)

Variety	Type	Starch (%)	Shape	Skin	Flesh	Key traits	Storage	Use
Bila	B (general-purpose)	12.6	oval-round	yellow	yellow	–	very good	boiling, steaming, mashed, baking
Mia	AB (slightly waxy)	~12	oval	yellow	yellow	low darkening during cooking	very good	boiling, baking
Wega	B (slightly waxy)	~13	oval	lightly netted	dark yellow	low discoloration	very good	direct consumption, semi-finished products
Werbena	B (general-purpose)	~11.5	oval-round	yellow, smooth	light yellow	–	very good	general culinary use

Laboratory tests

Freeze-drying of potato tubers

For the freeze-drying process, unpeeled boiled potato tubers (control group) and fermented potato tubers were cut into cubes (0.5 × 0.5 cm) and placed in zip-lock bags. The samples (200 g each) were pre-frozen in a freezer at −22 °C. Freeze-drying of potatoes in open zip-lock bags placed on trays was carried out using a CHRIST ALPHA 1–4 LSC freeze-dryer (Germany) under the following conditions: condenser temperature −55 °C, vacuum 4 kPa, and shelf temperature set to 20 °C during secondary drying. The potato samples were dried until a constant mass was achieved. The final moisture content in the material was below 2%. The drying process continued for 24 hours.

Determination of dry matter, bioactive compounds and antioxidant capacity

The dry matter content of potato tubers was determined according to the AOAC method 950.01 (AOAC, 1990), as described by Pobereżny et al. (2017), using a WAMED SUP–100 dryer. He obtained dry matter (d.m.) values were also used to express the content of the analyzed compounds and antioxidant capacity on a dry-matter basis. The determinations were performed in methanolic extracts prepared from lyophilized potato tubers according to the procedure described by Gościnna et al. (2021). Total polyphenol content was determined using the spectrophotometric Folin–Ciocalteu method according to Fang et al. (2006), with a calibration curve prepared for gallic acid equivalents (Sigma-Aldrich, St. Louis, MO, USA). Absorbance was measured at 735.8 nm, and the results were expressed as mg gallic acid$\cdot kg^{-1}$ fresh matter (f.m.). Flavonoid content was determined using the method described by Papoutsis et al. (2016), with a calibration curve prepared for quercetin (Sigma-Aldrich, St. Louis, MO, USA) and absorbance measured at 510 nm; the results were expressed as mg quercetin$\cdot kg^{-1}$ f.m. Chlorogenic acid content was determined using the colorimetric method with sodium nitrate according to Griffiths et al. (1992), measuring absorbance at 510 nm and expressing the results as mg chlorogenic acid equivalents·kg^{-1} f.m. Antioxidant capacity was measured using the FRAP (Ferric Reducing Antioxidant Power) method according to Benzie and Strain (1996), with a calibration curve prepared for Fe^{2+} ions and absorbance measured at 593 nm. All measurements were performed using a SHIMADZU UV-1800 UV-Vis spectrophotometer (Japan). Analyses were carried out in three laboratory replicates.

Sensory evaluation

The sensory evaluation was conducted among 50 respondents aged 19–65 years. The panel included non-professional participants who were, familiar with the typical sensory characteristics of potato products. The assessment took place in a room providing standard sensoryconditions: neutral lighting, constant temperature, and absence of foreign odors. Respondents evaluated the properties of the fermented potatoes, such as taste, aroma, color, and texture. The samples were coded with random three-digit numbers and presented in random order to eliminate order effects and bias.

The assessments were carried out using a five-point hedonic scale, where:
5 – very good, very desirable,
4 – good, desirable,
3 – average, acceptable,
2 – poor, undesirable,
1 – unacceptable.

Statistical analysis

The effect of the examined factors on the physicochemical properties was assessed using analysis of variance (ANOVA) with Statistica 13.1 software. Tukey's test at a significance level of $\alpha = 0.05$ was applied to determine significant differences between the means. Relationships between the analyzed quality parameters were determined based on the linear correlation coefficient ($p < 0.05$). The obtained results were presented as mean values ± standard deviation (SD), calculated from three replicates of each sample.

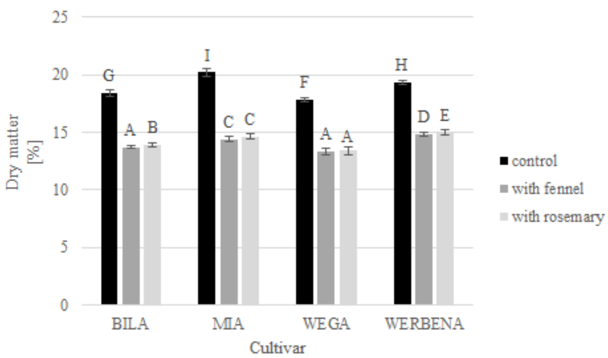
RESULTS AND DISCUSSION

Figure 1 presents the results for dry matter content (a), total polyphenols (b), flavonoids (c), chlorogenic acid (d), and antioxidant capacity (FRAP) (e) for the control sample (cooked tubers without fermentation) and the fermented samples (tubers after lactic fermentation).

In the control group, the dry matter content showed significant variation between cultivars. The highest value was recorded for cultivar Mia (20.2%), and the lowest for Wega (17.8%) (Fig. 1a). According to the literature, the dry matter content in potato tubers ranges from 18.3% to 25.6% (Nowacki 2021) and is determined by both genetic factors and environmental conditions, such as cultivation practices, fertilization, and soil quality (Pobereżny et al. 2021; Gościnna et al. 2024; Wszelaczyńska et al. 2024). Lactic fermentation resulted in a statistically significant decrease in dry matter content in all tested samples (Fig. 1a). The largest decrease was observed for cultivar Mia, and the smallest for Werbena. Differences in dry matter content depending on the addition of dill or rosemary were not statistically significant within each cultivar (Fig. 1a). Dry matter losses during fermentation are a natural consequence of the transformation of soluble carbohydrates, proteins, and other organic compounds into fermentation products (Wróbel et al. 2023).

The contents of polyphenolic compounds, flavonoids, and chlorogenic acid in the control potato tubers differed significantly between cultivars (Fig. 1b–d). The highest levels of total polyphenols, flavonoids, and chlorogenic acid were recorded for cultivar Wega (917.0; 185.6; and 268.6 mg·kg^{-1} f.m. and 5151.7; 1042.8; 1508.8 mg·kg^{-1} d.m. respectively), while the lowest were found in Mia (828.8; 170.8; 175.3 mg·kg^{-1} f.m., 4103.1; 845.6; 867.8 mg·kg^{-1} d.m. respectively) (Fig. 1b–d).

a



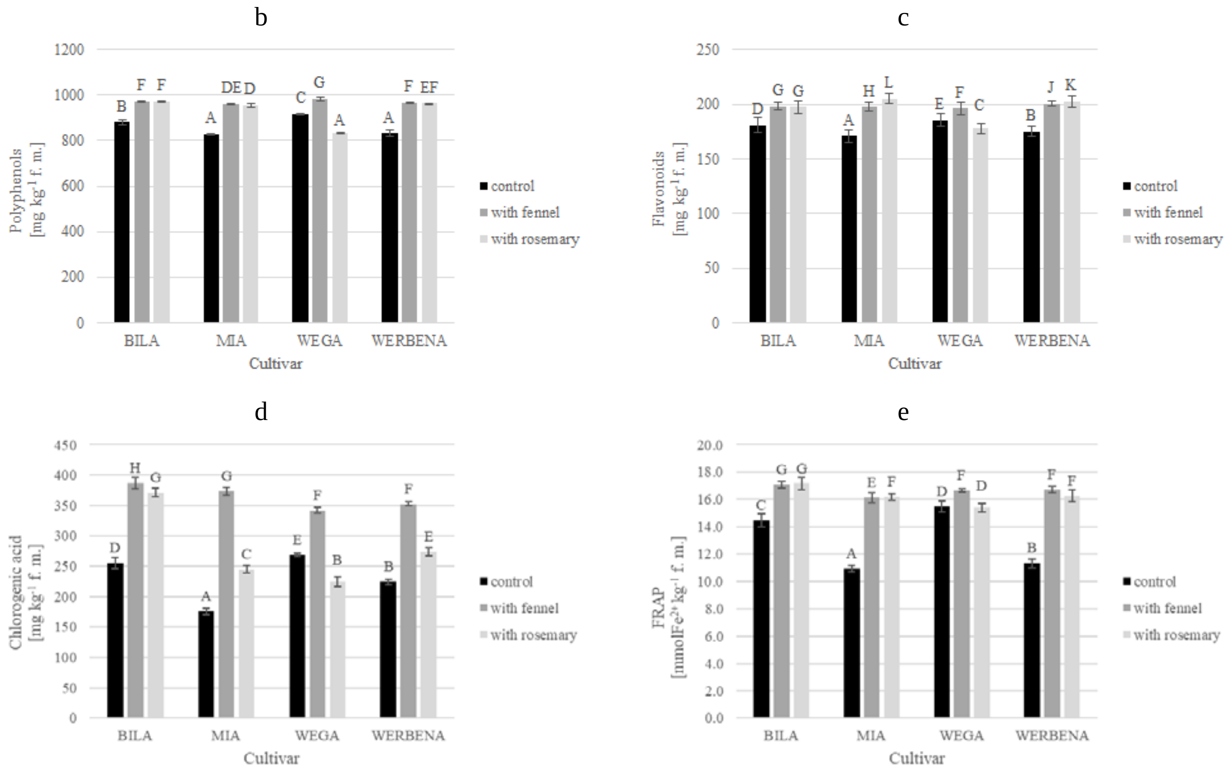


Fig. 1. Content of dry matter – a, total polyphenols – b, flavonoids – c, chlorogenic acid – d and antioxidant capacity (FRAP) – e in pickled potato tubers and in the control sample. A, B… – means marked with the same letter do not differ significantly ($p \leq 0.05$)

Scientific reports indicate substantial variability in polyphenol content depending on genotype, tuber color, and tissue type (Ru et al., 2019). In whole tubers, these values range from 225.3 to 858.5 mg gallic acid·kg^{-1} f.m., while in the flesh alone they range from 202.6 to 630.5 mg gallic acid·kg^{-1} f.m. (Ru et al., 2019). Coloured cultivars contain markedly higher amounts of these compounds: purple potatoes contain 1621.9–5102.0 mg gallic acid·kg^{-1} dry matter, red 1524.0–2614.9 mg gallic acid·kg^{-1} d.m., whereas yellow cultivars contain lower levels ranging from 1133.7 to 1146.3 mg gallic acid·kg^{-1} d.m. (Rasheed et al., 2022). Similarly, flavonoid concentrations are approximately twice as high in red and purple-fleshed cultivars compared to white-fleshed ones (Hamouz et al., 2007). Chlorogenic acid, in turn, occurs in a broad range from 6.0 to 2740.0 mg·kg^{-1} d.m. (Wichrowska, 2022), accounting for up to 90% of total polyphenols in potato tubers (Friedman et al., 2009).

Lactic fermentation increased the levels of total polyphenols, flavonoids, and chlorogenic acid in most tested variants (by 7–16%; 9–20%; and 16–113%, respectively). The only exception was Wega fermented with rosemary, which showed reductions of 9.3%, 4.0%, and 17.0% for these compounds (Fig. 1b–d). The greatest relative increase was observed for chlorogenic acid in fermented Mia samples (113%). These biochemical shifts were reflected in antioxidant capacity. Among the control samples, Wega exhibited the highest FRAP value (15.5 mmol Fe^{2+}·kg^{-1} f.m.), whereas Mia had the lowest (10.9 mmol Fe^{2+}·kg^{-1} f.m.) (Fig. 1e). Fermentation increased antioxidant capacity in all variants except Wega with rosemary. These findings are consistent with previous reports demonstrating that fermentation enhances antioxidant potential through enzymatic biotransformation, release of bound phenolics, and microbial synthesis of bioactive metabolites (Zhao et al,. 2021; Sarıtaş et al., 2024). Hydrolysis of phenolic glycosides leads to aglycones with higher antioxidant capacity (Hur SunJin et al., 2014), and certain microbial strains are capable of producing antioxidant metabolites de novo (Dhiman et al., 2025).

A strong positive correlation was observed between bioactive compound content and the antioxidant capacity (FRAP) (Fig. 2). Total polyphenols showed the strongest correlation ($r = 0.919$, $p \leq 0.05$), followed by chlorogenic acid ($r = 0.824$; $p \leq 0.05$) and flavonoids ($r = 0.712$; $p \leq 0.05$).

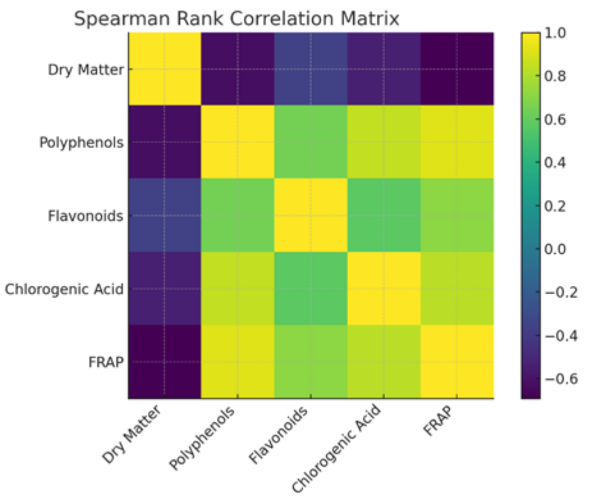


Fig. 3. Spearman's rank correlation matrix between dry matter content, bioactive compound content (polyphenols, flavonoids, chlorogenic acid), and antioxidant capacity (FRAP).

Sensory evaluation

The results of the sensory evaluation of the studied fermented potato tubers are presented in Table 2. Four sensory attributes were analyzed: taste, aroma, flesh color, and texture.

In terms of taste, the highest scores were given to products prepared with the addition of fennel from the Mia (5.0 points) and Werbena (5.0 points) varieties, followed by the Bila variety (4.0 points). The addition of rosemary proved unfavorable in this category – in all variants it caused a noticeable deterioration of taste perception, lowering the score to 2.5–3.5 points.

Both fennel and rosemary also influenced the variability of aroma scores (Table 2). The highest scores were obtained for fermented tubers from the Mia and Werbena varieties (5.0 points with fennel and 4.0 points with rosemary). For the Bila variety, the aroma score was 4.5 points with fennel and 3.5 points with rosemary. The lowest values were recorded for the Wega variety, which received 3.0 points (with fennel) and 2.5 points (with rosemary).

In most cases, the fermentation process did not negatively affect the flesh color. Variants including the Bila, Mia, and Werbena varieties received high scores ranging from 4.0 to 5.0 points, indicating good stability of this attribute. Only the Wega variety showed a significant deterioration in color, considered undesirable.

The fermentation process also clearly changed the texture of the fermented potato tubers (Table 2). The highest score (4.5 points) was awarded to products from the Werbena variety with rosemary. Slightly lower values were assigned to both herbal variants from the Mia variety and the Werbena variant with fennel. The lowest scores were given to the Wega variety and the Bila variant with rosemary (3.0 points). The type of herbal additive significantly influenced the overall sensory evaluation of the studied samples. Fennel promoted higher taste and aroma scores, whereas rosemary in many cases reduced sensory acceptability, particularly with respect to taste. Fennel, a herb commonly used in vegetable fermentation, can enhance the aromatic profile of products and mitigate undesirable flavor notes that may develop during fermentation (Sahoo and Prakash, 2017; Tan et al., 2023; Zafar et al., 2023). Conversely, due to its intensity and the dominant nature of its essential oils, rosemary in combination with the natural aroma of fermented tubers may hinder the achievement of a balanced sensory profile (Qiu et al., 2024).

These findings indicate that the potato variety also plays an important role in shaping the sensory quality of the product. The Mia and Werbena varieties stood out with the highest scores across all analyzed categories, indicating their greater suitability for lactic fermentation of potato tubers. Differences in flesh structure, chemical composition, water content, starch, simple sugars, and polyphenols may influence both the course of fermentation and the final flavor-aroma profile (Saud et al., 2024; Zheng et al., 2024; Ali et al., 2025). The results of this study suggest that a harmonious combination of raw material of high sensory quality (Mia, Werbena) and a properly selected herbal additive (preferably fennel) allows for the production of a final product with high acceptability.

Table 2. Sensory evaluation of potato tubers subjected to the pickling proces on a scale from 1 to 5 points

Quality attribute	Bila		Mia		Wega		Werbena	
	F*	R**	F	R	F	R	F	R
Taste	4.0	3.5	5.0	3.0	2.5	2.5	5.0	3.5
Aroma	4.5	3.5	5.0	4.0	3.0	2.5	5.0	4.0
Flesh color	4.5	4.0	5.0	5.0	1.0	1.0	5.0	5.0
Consistency	3.5	3.0	4.0	4.0	3.0	3.0	4.0	4.5

* with fennel
** with rosemary

CONCLUSIONS

The conducted study demonstrated that lactic fermentation significantly enhances the health-promoting value of potato tubers. The fermentation process resulted in an average increase of 13.0% in polyphenol content and 12.8% in flavonoid content, while the level of chlorogenic acid increased up to twofold compared with the control samples. This rise in bioactive compounds contributed to a notable improvement in the antioxidant capacity of the fermented potatoes, with antioxidant capacity increasing on average by 32.8%. At the same time, lactic fermentation led to a reduction in dry matter content, which decreased by approximately 25.3%.

Among the analyzed cultivars, Mia and Werbena proved to be the most suitable for fermentation, as the resulting products exhibited a desirable soft texture, attractive light-yellow color, appropriate aroma, and high palatability scores. Furthermore, the use of dill during fermentation promoted a greater increase in bioactive compound content and antioxidant capacity compared with rosemary. Sensory evaluation results confirmed that potatoes fermented with dill were rated more favorably than those fermented with rosemary. The use of fermentation in potato processing thus creates opportunities for developing foods with unique functional and health-promoting properties.

In summary, both the choice of cultivar and the type of herbal additive play a key role in shaping the sensory quality of fermented potato tubers. Optimal results are obtained when using cultivars with stable sensory characteristics and dill as an additive, as it positively influences the flavor and aroma of the product. In contrast, the use of rosemary requires caution, as its intense aroma may reduce the sensory acceptability of fermented tubers.

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WYKORZYSTANIE PROCESU FERMENTACJI DO POPRAWY WŁAŚCIWOŚCI PROZDROWOTNYCH BULW ZIEMNIAKA

Streszczenie

Fermentacja mlekowa bulw ziemniaka stanowi niszowy, lecz obiecujący kierunek badań nad żywnością funkcjonalną, dający możliwość zwiększenia jej wartości prozdrowotnej. Ze względu na wysoką zawartość skrobi oraz korzystny profil związków bioaktywnych ziemniak jest istotnym składnikiem diety i cennym surowcem do produkcji żywności. W odpowiedzi na rosnące zainteresowanie konsumentów nowymi produktami podjęto próbę zastosowania fermentacji bulw ziemniaka oraz oceny wpływu tego procesu na jego właściwości prozdrowotne. Fermentacji poddano cztery odmiany ziemniaka: Bila, Mia, Wega i Werbena. Dla każdej z nich przygotowano dwa warianty produktów fermentowanych – z dodatkiem kopru lub rozmarynu. Proces prowadzono w temperaturze pokojowej (ok. 21°C) przez 25 dni, stosując 2% roztwór jodowanego chlorku sodu. W gotowych produktach oznaczono zawartość suchej masy, wybranych związków prozdrowotnych (polifenoli ogółem, flawonoidów, kwasu chlorogenowego) oraz pojemność antyoksydacyjną metodą FRAP. Przeprowadzono również ocenę sensoryczną wśród 50 respondentów w wieku 19–65 lat. Uczestnicy oceniali, w skali 5-stopniowej, podstawowe cechy sensoryczne (smak, aromat, barwę, teksturę) oraz smakowitość i ogólną pożądalność produktów końcowych. Fermentacja przyczyniła się do zwiększenia zawartości związków prozdrowotnych we wszystkich analizowanych odmianach. Średni wzrost zawartości polifenoli – niezależnie od odmiany i zastosowanych ziół – wyniósł 10,2%, flawonoidów 10,7%, a zawartość kwasu chlorogenowego była ponad dwukrotnie wyższa niż w próbkach niefermentowanych. Wzrost poziomu tych związków wpłynął na wyraźną poprawę właściwości antyoksydacyjnych, średnio o 28,7%. Największą akumulację związków prozdrowotnych odnotowano w odmianie Bila, która po fermentacji (zarówno z koprem, jak i rozmarynem) wykazała najwyższą aktywność antyoksydacyjną. W ocenie konsumentów najwyżej oceniono produkty z odmian Mia i Werbena fermentowane z koprem. Dodatkowo fermentacja z dodatkiem kopru, w porównaniu z dodatkiem rozmarynu, skutkowała wyższą zawartością związków bioaktywnych i korzystniejszym profilem sensorycznym. Fermentacja mlekowa skutecznie zwiększa wartość odżywczą i prozdrowotną bulw ziemniaka, jednocześnie poprawiając ich właściwości organoleptyczne. Uzyskane wyniki wskazują na duży potencjał wykorzystania fermentowanych ziemniaków jako innowacyjnych produktów funkcjonalnych, odpowiadających potrzebom współczesnych konsumentów.

Słowa kluczowe: ziemniak, fermentacja mlekowa, probiotyki, kwas mlekowy, właściwości prozdrowotne, żywność funkcjonalna