Journal of Food and Nutrition Research (ISSN 1336-8672) Vol. *63*, 2024, No. 2, pp. 111–121

Evaluation of qualitative parameters of commercial fermented coconut plant-based yoghurt alternatives on the market in Slovakia

BILJANA TRAJKOVSKA – BLANKA TOBOLKOVÁ – KRISTÍNA KUKUROVÁ – JANKA KUBINCOVÁ – BOŽENA SKLÁRŠOVÁ – JANKA KOREŇOVÁ

Summary

The study explored various quality parameters of plant-based yoghurt alternatives derived from coconuts, which are available on the Slovak market. Chemical characteristics elucidated the impact of post-acidification on shelf life, revealing pH fluctuations from 3.98 to 5.04. Colour analysis unveiled diverse profiles of individual samples, with Yog1 exhibiting distinct yellowish hues. Antioxidant properties varied regarding total polyphenols and flavonoids among samples, with higher $ABTS^{\bullet +}$ radical-scavenging activity attributed to aromatic amino acids. Microbiological analysis highlighted significant differences in viable counts of *Lactobacillus* spp., emphasizing the pivotal role of formulation and storage conditions in bacterial viability. Concentration of organic acids, specifically lactic and acetic acids, were found to vary and these variations were influenced by ingredients such as coconut water. Saturated fatty acids, predominantly octanoic, decanoic and dodecanoic acids, played a significant role in texture. Differences in acceptability scores were observed through sensory evaluation, with Yog2 notably standing out. These variations indicated correlation between sugar content and taste perception. The results suggested that there is a complex interaction of factors influencing the quality profile of these yoghurts. The study offers a basis for specific improvement in formulation, processing and overall consumer acceptability of this type of food product.

Keywords

plant-based food; dairy-free yoghurt; coconut; quality parameter

In the last decades, the consumer demands for health-promoting and more sustainable food has been growing, with new non–dairy milk alternatives (or milk analogues) being introduced to the market. These products are also known as plant-based yoghurt alternatives („vegurts“) and have become increasingly popular. Nowadays, a lot of people prefer various plant-based alternatives in their diet. The increased preference of these products is driven by various factors and consumer demands, including health-related challenges such as lactose intolerance or milk allergy, consumers' concerns about cows' milk hormones and cholesterol, ethical disputes regarding the use of animals, environmental issues, changes in lifestyle and also marketing that highlights health-promoting properties of these products [1]. Plant-based alternatives are consist of water extracts derived from plants. These can be processed by lactic acid fermentation, which involves production of organic acids and antimicrobials [2]. However, the choice of raw material has a great impact on the product quality as well as the process technology adopted [3]. The process fermentation improves the nutritional value of the product by increasing the content of free amino acids and vitamins [2]. Fermented dairy products are widely used and related with essential minerals, proteins and vitamins, together with beneficial lactic acid bacteria. On the other hand, the plant-based yoghurts have different tex-

Biljana Trajkovska, Department of Biotechnology, Faculty of Biotechnical Sciences, University st. Kliment Ohridski, Partizanska b.b., 7000 Bitola, North Macedonia.
Blanka Tobolková, Kristína Kukurová, Janka Kubincová, Božena Skláršová, Department of Chemistry and Food Analysis, Food Research Institute, National Agricultural and Food Centre, Priemyselná 4, 82475 Bratislava, Slovakia.
Janka Koreňová, Department of Microbiology, Molecular Biology and Biotechnology, Food Research Institute, National Agricultural and Food Centre, Priemyselná 4, 82475 Bratislava, Slovakia.

Correspondence author:
Biljana Trajkovska, tel.: +38978430751; e-mail: biljana.trajkovska@uklo.edu.mk

tual properties, which could be attributed to lower protein concentration and different gelation properties, compared with dairy yoghurts [4].

Recently, there has been a significant rise in the innovation and introduction of new plant-based foods and beverages, especially those based on coconut milk and utilizing various stabilizers like tapioca starch [5], inulin and locust bean gum [6]. This trend aims to improve the overall properties of the final products. Notably, advancements have been made in developing reduced-fat coconut yoghurt by CHETACHUKWU et al. [7]. Another example is the production of functional coconut yoghurt utilizing brewers' spent grain by NAIBAHO et al. [8] and the crafting of a fermented coconut beverage incorporating coconut milk with strawberry pulp by MAURO et al. [9]. On the other hand, there is limited information about the quality characteristics of commercial coconut plant-based yoghurt products in the literature. Therefore, this study aimed to evaluate the physico-chemical properties, rheological properties, contents of organic acids, antioxidant activity, fatty acid composition, microbiological properties and sensory characteristics of commercial coconut plant-based yoghurts. This evaluation aimed to discern variations in the technological properties and quality attributes among these products.

MATERIALS AND METHODS

Plant–based yoghurts

Six commercial coconut plant-based yoghurts were analysed in this study (Tab. 1). All of them were made from coconut and were declared as natural products. Products were purchased in August 2022 from local supermarkets Lidl, Tesco, Yeme SK or Drogerie Markt in Bratislava, Slovakia. The weight of the individual samples ranged from 120 g to 160 g. The nutritional composition and lists of ingredients are presented in Tab. 1 and Tab. 2.

pH

The pH of the samples was measured with a pH meter with a glass electrode HI 2211 (Hanna Instruments, Vöhringen, Germany) at 20 °C, which was previously standardized with buffers of pH 4.0 and pH 7.0.

Titratable acidity

The titratable acidity (*TA*) was measured according to the method described by GRASSO et al. [10]. Briefly, 10 g of commercial coconut plant-based yoghurt alternatives was weighed and titrated with 0.1 mol·l^{-1} NaOH with phenolphthalein as indicator. All samples were analysed in triplicates. *TA* was expressed as millilitres of NaOH per kilogram of sample.

Water holding capacity

Samples of 20 g were placed in 50 ml tubes and centrifuged at 640 ×*g* for 20 min at 4 °C (centrifuge Sigma 2-16KC; Sigma-Aldrich, St. Louis, Missouri, USA). After centrifugation, the supernatant was collected and weighed. Water holding capacity (*WHC*) was calculated according to the method described by GRASSO et al. [10] and expressed in percent (Eq. 1):

Tab. 1. Composition of coconut plant-based yoghurts.

Product	Country of origin	Component		Other components
		Characteristics	Proportion [%]	
Yog1	Germany	Preparation (drinking water, partially defatted coconut pulp, yoghurt cultures)	7.0	Starch, coconut fat, coconut oil, stabilizer (pectin), sea salt
Yog2	Poland	Plant-based milk (water, coconut extract)	90.5	Sugar, starch, fava bean protein, vegan yoghurt cultures
Yog3	Slovakia	Plant-based milk (coconut cream, water) and coconut water (1 : 1)	66.0	Drinking water, modified starch, yoghurt cultures (*Str. thermophilus*, *Lb. delbrueckii* subsp. *bulgaricus*)
Yog4	Germany	Plant-based milk (coconut, water)	99.0	Tapioca starch, vegan yoghurt cultures
Yog5	Germany	Pulp extract (drinking water, coconut pulp extract)	94.6	Modified starch, fava bean protein, yoghurt cultures (*Str. thermophilus*, *Lb. delbrueckii* subsp. *bulgaricus*); contain naturally present sugars
Yog6	Poland	Plant-based milk (water, coconut extract)	95.8	Starch, fava bean protein, vegan yoghurt cultures, no added sugar; contains naturally present sugars

Tab. 2. Nutritional parameters of coconut plant-based yoghurts.

Parameters	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
Energy [kJ·kg-1]	610	3 990	3 480	5 300	3 130	3 920
Total lipids [g·kg-1]	58	53	61	119	51	71
Saturated lipids [g·kg-1]	52	50	57	105	49	67
Total saccharides [g·kg-1]	67	110	60	45	66	67
Sugar [g·kg-1]	10	57	6	6	7	9
Fibre [g·kg-1]	2	< 5	0.0	–	–	<5
Proteins [g·kg-1]	18	9	6	8	7	9
Salt [g·kg-1]	1.1	0.2	0.7	0.1	0.2	0.2
Lactose [g·kg-1]	–	–	0.0	–	–	–

Content is expressed per kilogram of product.

$$WHC = \left(1 - \frac{W_{sup}}{W_s}\right) \times 100 \quad (1)$$

where, W_{sup} is weight of supernatant expressed in grams, W_s is weight of sample expressed in grams.

Water activity

Water activity (a_w) was measured using LabMaster a_w-meter (Novasina, Lachen, Switzerland).

Dry matter

Two grams (2 g) of yoghurt was weighed in aluminium dish and dried at 130 ± 1 °C in an oven (Denver Instrument, Göttingen, Germany) to constant weight [11].

Texture characteristics

To determine instrumental textural properties of coconut plant-based yoghurts, the back extrusion test was performed using a TA.XT plus texture analyser (Stable Micro Systems, Godalming, United Kingdom) by Forward Extrusion Rig (HDP/FE). All samples were stored overnight at 4 °C, as previously described by Grasso et al. [10]. A standardized amount of 100 g of the sample was consistently filled into the Perspex polycarbonate cylinder sample container (Stable Micro Systems and compressed using 30 kg load cell at a test speed of 1.0 mm·s^{-1} at laboratory temperature (22 ± 2 °C) by auto trigger through extrusion disk (diameter 3 mm). Product catchment drawer (A/CAT) was placed under the heavy-duty platform (HDP) for collection of the extruded sample during the test. The textural parameters were analysed using Exponent software (Stable Micro Systems). Firmness of yoghurt sample was defined as the maximum positive force required for sample extrusion (expressed in grams) and yoghurt consistency was calculated as the area of the positive region (expressed in kilograms per second). Stickiness of sample was defined as the force needed to unstick the probe (expressed in kilograms) and yoghurt adhesiveness was calculated as the total work required to unstick the probe (expressed in kilograms per second).

Fatty acid methyl esters

For analysis of the fatty acid methyl esters composition, 100 μl of each homogenized sample was taken. In the next stage, samples were subjected to lipid extraction with the use of methanol (1 ml) and hexane (2 ml). After each solvent addition, samples were homogenized on vortex mixer. Homogenates were subjected to 5 min ultrasonication in an ultrasonic bath (Kraintek, Podhájska, Slovakia). Then, samples were mixed at 225 ×*g* for 25 min on Promax 2020 shaker (Heidolph Instruments, Schwabach, Germany) and centrifuged at 10 000 ×*g* for 10 min at room temperature (22 ± 2 °C). A volume of 1 ml from the upper fraction was taken and added 100 μl of 0.5 mol·l^{-1} sodium methoxide. Samples were mixed for 15 min at 1 000 ×*g* on Multi Speed Vortex MSV-3500 (BioSan, Riga, Latvia). In the final step, 60 μl of 0.03 g·l^{-1} oxalic acid was added and samples were kept at –18 °C until the analysis for a maximum of one month.

Methyl esters were analysed by gas chromatography-mass spectrometry (GC-MS) with the use of Agilent equipment 5975C (Agilent Technologies, Santa Clara, California, USA). The analytical separation was performed on a DB-23 column (60 m × 250 μm × 0.25 μm; J&W Scientific, Folsom, California, USA). Helium was used as a carrier gas at a flow rate of 1.85 ml·min^{-1} (linear velocity 35 cm·s^{-1} measured at 50 °C). The injector temperature was set at 230 °C. The oven temperature program was as follows: an initial increase from 50 °C with a holding time of 1 min to 100 °C at a rate of 25 °C·min^{-1}, followed by an increase to 175 °C at a rate of 4 °C·min^{-1} with a holding time of 0 min, and finally, a subsequent increase to 230 °C with a holding time of 5.25 min. Identification of fatty methyl esters was done by comparing retention times to standards.

Organic acids

Organic acids were extracted with a mixture water and methanol in a ratio of 95 : 5 (v/v). A homogenous sample weighing 1 ± 0.01 g was combined with 10 ml of the extraction mixture, 100 μl of Carrez solution I (prepared by dissolving 15 g of potassium hexacyanoferrate (II) trihydrate in 100 ml of water), was added and mixed carefully. Subsequently, 100 μl of Carrez solution II (prepared by dissolving 30 g of zinc sulphate heptahydrate in 100 ml of water) was added and mixed again. The samples were shaken for 10 min, sonicated for 5 min and centrifuged at 3 500 ×*g* for 5 min at room temperature (22 ± 2 °C). The supernatant was filtered through a nylon membrane syringe filter (0.45 μm pore size; Frisenette, Knebel, Denmark).

The Agilent 1290 HPLC system (Agilent Technologies) equipped with a binary gradient pump at a flow rate of 0.8 ml·min^{-1}, an autosampler and a photo-diode array detector (DAD) set at 210 nm were used for analysis. The separation was performed on Synergi HYDRO-RP column (250 mm × 4.6 mm, particle size 4 μm; Phenomenex, Torrance, California, USA). The mobile phase consisted of A (water and H_3PO_4 99 : 1, v/v) and B (acetonitrile) with the following gradient: 100 % A and 0 % B between 0 min and 15 min; 40 % A and 60 % B between 15 min and 20 min; 40 % A and 60 % B between 20 min and 26 min. Samples of 10 μl were injected. External calibration was used to calculate the content of individual organic acids.

Colour measurement

The colour of each sample was evaluated from reflectance spectra measured by UV-3600 double-beam spectrometer (Shimadzu, Kyoto, Japan) in 1 cm cuvette 100-QS-Suprasil (Hellma, Müllheim, Germany) as previously described by Tobolková et al. [12]. The following setup was used: spectral range from 380 nm to 780 nm, sampling interval of 2 nm; slit width of 0.1 nm. Colour values in CIE *L*a*b** colour system were calculated using the ColorLite Panorama Shimadzu software v3.1.16 (LabCognition, Shimadzu) using Illuminate D65 and 10° standard observer angle. Whiteness index (WI) was calculated according to the method described by Hirschler [13].

UV–Vis and EPR spectroscopy

All UV–Vis experiments were performed using ultraviolet-visible near-infrared (UV-Vis-NIR) spectrophotometer Shimadzu 3600 (Shimadzu) with accessory as previously described by Tobolková et al. [14]. Electron paramagnetic resonance (EPR) spectroscopy experiments were performed by a portable X-band EPR spectrometer e-scan (Bruker Biospin, Ettlingen, Germany). Approximately 20 g of sample was placed in a 50 ml tube and centrifuged at 10 000 ×*g* for 10 min at 4 °C. Supernatant was used for evaluation of total polyphenols concentration (*TPC*), total flavonoids concentration (*TFC*) and antioxidant activity.

Total polyphenols concentration

A volume of 100 μl of supernatant was transferred into a tube and mixed with 7.9 ml of deionized water and 500 μl of Folin-Ciocalteu reagent (Sigma-Aldrich). After 10 min, 1.5 ml of 200 g·l^{-1} sodium carbonate was added, the mixture homogenized and allowed to stand for 60 min at room temperature (22 ± 2 °C). Absorbance was measured at 765 nm. Results were expressed as milligrams of gallic acid equivalent (GAE), per litre of yoghurt.

Total flavonoids concentration

A volume of 1 ml of supernatant in a test tube was mixed with 2 ml of deionized water and 150 μl of 50 g·l^{-1} sodium nitrite. After 6 min, 150 μl of 100 g·l^{-1} aluminium chloride hexa-hydrate was added. After 6 min, 2 ml of 40 g·l^{-1} sodium hydroxide was added and after 15 min absorbance was measured at 510 nm. Results were expressed as milligrams of rutin equivalent (RE), per litre of yoghurt.

Antioxidant activity

Exactly 300 μl of sample was mixed either with 700 μl of 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) ($ABTS^{\bullet +}$) in deionized water (initial concentration 0.1 mmol·l^{-1}) or of 2,2-diphenyl-1-picrylhydrazyl ($^{\bullet}$DPPH) in ethanol (initial concentration 0.1 mmol·l^{-1}). The mixture was purged with 2 ml of air and immediately transferred into EPR flat cell. EPR measurements started exactly 3 min after the $^{\bullet}$DPPH or $ABTS^{\bullet +}$ addition and a set of 10 PR spectra was recorded in time domain during 15 min. Every EPR spectrum represented an average of 30 individual scans. The experiments were performed in duplicates. Results of both assays were expressed as Trolox equivalent according to POLOVKA et al. [15].

Microbiological analysis

An amount of 10 g of each sample was homogenized in 90 ml of a diluent solution (8.5 $g \cdot l^{-1}$ NaCl and 1 $g \cdot l^{-1}$ tryptone) and serial 10-fold dilutions were prepared. Presumptive lactobacilli were enumerated on de Man-Rogosa-Sharpe agar (Sigma-Aldrich) acidified to pH 5.2 and incubated under anaerobic conditions at 37 °C for 72 h. Thermophilic streptococci were enumerated on yeast glucose lactose peptone (YGLP) agar incubated under aerobic conditions at 45 °C for 24 h [16].

Sensory evaluation

Commercial yoghurt samples were evaluated by the trained sensory panel from National Agricultural and Food Centre in Bratislava, Slovakia (16 members consisting of 15 women and 1 man, aged between from 34 and 60 years) using a hedonic test. Approximately 10 g of homogenized sample were placed in a glass cup coded in a randomized order by three-digit numbers and served cooled at 4 °C. Appearance, colour, consistency, odour; mouthfeel texture, taste, after-taste and overall acceptability were rated using 100 mm of unstructured line scale with the description of the extreme points, where 0 mm corresponded to “extremely dislike” and 100 mm to “extremely like”, together with verbal comments and expression of personal willingness to buy the product.

Statistical analysis

Statistical analysis was performed using 2-way analysis of variance (ANOVA) followed by Tukey’s honestly significant difference (HSD) test. The statistical analysis was performed using XLSTAT software version 2019.2.2 (Addinsoft, New York City, New York, USA). The level of significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Chemical characteristics

Yoghurt post-acidification is an unwanted process which leads to shorter shelf life of the product, increasing the acidity and syneresis [17].

The pH values of the coconut plant-based yoghurts ranged from 3.98 ± 0.00 to 5.04 ± 0.00 (Tab. 3). The differences in these values could result from the use of different ingredients in the formulation, during preparation which could lead to different extent of pH reduction, from different storage temperatures and duration, as well as from different microbial activity [18]. Also, addition of additives could reduce the pH level during storage [5].

TA of the samples ranged from 470 ± 0 $ml \cdot kg^{-1}$ to 830 ± 0 $ml \cdot kg^{-1}$ with significant differences ($p < 0.05$). Yog1 and Yog3 exhibited a lower *TA*, highlighting the importance of carefully selecting and determining the appropriate lactic acid bacteria (LAB) strain for specific plant-based yoghurt alternatives, which is crucial to achieving optimal fermentation [17]. Generally, the decrease in pH leads to an increase in *TA* as a result of the ability of LAB to utilize carbohydrates to produce lactic acid [19].

On the other hand, the dry matter content ranged from 12.3 ± 0.1 % to 17.9 ± 0.1 % ($p < 0.05$; Tab. 3), which could be related to the dry matter of the raw material [3].

The primary purpose of incorporating hydrocolloids into yoghurt is to improve its consistency and increase viscosity. This helps to reduce whey separation and bind excess water, ultimately prolonging the product’s shelf life. Additionally, incorporating stabilizers aids in maintaining consistency among batches [20]. *WHC* of samples ranged from 91.1 ± 0.4 % to 100.0 ± 0.0 % (Tab. 3). These high values (> 90 %) may be due to the presence of hydrocolloids in the mixture. Additionally, the high content of total solids also led to increased *WHC* and decreased syneresis [21].

Tab. 3. Physico-chemical characteristics of coconut plant-based yoghurts.

	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
pH	4.28 ± 0.00 ^{de}	3.98 ± 0.00 ^{f}	4.19 ± 0.00 ^{e}	5.04 ± 0.00 ^{a}	4.38 ± 0.00 ^{cd}	4.47 ± 0.00 ^{c}
TA [$ml \cdot kg^{-1}$]	470 ± 0 ^{a}	800 ± 0 ^{b}	520 ± 0 ^{c}	620 ± 0 ^{d}	740 ± 0 ^{e}	830 ± 0 ^{f}
Dry matter [%]	12.3 ± 0.1 ^{ef}	17.6 ± 0.1 ^{b}	13.6 ± 0.1 ^{d}	17.9 ± 0.1 ^{a}	12.4 ± 0.0 ^{e}	14.3 ± 0.2 ^{c}
Water activity	0.97 ± 0.00 ^{a}	0.96 ± 0.00 ^{a}	0.97 ± 0.00 ^{a}	0.97 ± 0.00 ^{a}	0.97 ± 0.00 ^{a}	0.97 ± 0.00 ^{a}
WHC [%]	92.1 ± 0.0 ^{c}	99.8 ± 0.0 ^{a}	98.4 ± 0.5 ^{b}	91.1 ± 0.4 ^{c}	100.0 ± 0.0 ^{a}	99.6 ± 0.1 ^{ab}

Different small letters in superscript in the same row indicate statistically significant differences ($p < 0.05$).
TA – titratable acidity (expressed as millilitres of NaOH), *WHC* – water holding capacity.

Tab. 4. Textural characteristics of coconut plant-based yoghurts.

	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
Firmness [g]	341.20 ± 22.10 c	595.40 ± 75.20 b	914.00 ± 280.50 a	460.00 ± 41.30 bc	542.60 ± 36.30 b	513.80 ± 54.30 b
Consistency [kg·s-1]	6.60 ± 0.30 c	10.70 ± 1.00 b	16.60 ± 4.30 a	8.90 ± 0.80 bc	10.10 ± 0.70 b	9.50 ± 1.00 b
Stickiness [kg]	–0.11 ± 0.01 a	–0.13 ± 0.01 b	–0.15 ± 0.03 b	–0.12 ± 0.01 ab	–0.13 ± 0.01 ab	–0.13 ± 0.02 b
Adhesiveness [kg·s-1]	–0.21 ± 0.09 b	–0.24 ± 0.13 b	–0.03 ± 0.01 a	–0.09 ± 0.11 ab	–0.16 ± 0.19 ab	–0.16 ± 0.13 ab

Different small letter in superscript in the same row indicate statistically significant differences ($p < 0.05$).

Water activity is a property that determines the survival and growth of microorganisms in food. No significant differences in this parameter ($p > 0.05$) were observed between the examined samples of coconut plant-based yoghurt (Tab. 3). Grasso et al. [10] reported comparable findings regarding the chemical characteristics of a commercial coconut yoghurt.

Textural characteristics

Textural characteristics play a crucial role in the quality and sensory attributes of food. Tab. 4 shows data on firmness, consistency, stickiness and adhesiveness of coconut plant-based yoghurts.

Firmness, specifically, refers to the highest level of force required to break a gel. The firmness values of coconut plant-based yoghurts were similar except for Yog3 and Yog1. The same was noticed also regarding consistency. Yog3 had high firmness and consistency and Yog1 was less firm compared with other samples. High content of saturated fatty acids leads to high firmness and their low content leads to less firm yoghurt [22]. Homogenization of the milk before fermentation leads to increased interactions between lipids and proteins in milk accompanied by the formation of protein-coated lipid globules, which contribute to the firmness of the yoghurt [23]. Also, the presence of exopolysaccharides contributes to gel firmness in fermented food products [24] and this can be influenced by the microbial culture used [25].

Cohesiveness refers to the ability of a product to adhere or stay together. It can be measured by the maximum opposing force required to separate the sample, indicating its level of stickiness. Small differences between samples were noticed for beat stickiness parameter ($p < 0.05$). The measure of adhesiveness was ascertained by measuring the force exerted during the removal of a probe from the sample [6]. Only minor differences were determined in sample adhesion. The highest value for this parameter was found for Yog3 (–0.03 ± 0.01 kg·s^{-1}) and the lowest for Yog2 (–0.24 ± 0.13 kg·s^{-1}). Variations may be attributed to specific stabilizers in the formulation [6].

Fatty acids

Ten fatty acids were identified and quantified in plant-based coconut yoghurt samples (Tab. 5). Regarding short-chain saturated fatty acid (SCFA, C4–C10), the coconut yoghurt samples contained hexanoic, octanoic and decanoic acids. From medium-chain saturated fatty acids (MCFA, C12–C15), dodecanoic and tetradecanoic acid were found. From long-chain fatty acids (LCFA, C16–C24), the saturated hexadecanoic and octadecanoic acids were found. As presented in Tab. 5, saturated fatty acids predominated in coconut plant-based yoghurt samples. Notably, octanoic acid, decanoic acid, dodecanoic acid, tetradecanoic acid and hexadecanoic acid were present at highest levels among all fatty acids in the fermented product. Additionally, Tab. 5 underscores that dodecanoic acid was contained at the highest level of all fatty acids (from 454.70 ± 0.00 g·kg^{-1} to 541.80 ± 0.00 g·kg^{-1}) in all samples. These results are consistent with the findings of Mauro et al. [9], suggesting a correlation with the use of mature coconut pulp in the yoghurt production process. Moreover, the content of octadecanoic acid remained relatively consistent across the analysed samples, with higher contents observed in Yog3 and Yog6. In comparison with the results previously reported by Machado et al. [26], the results of this study showed an increased amount of all fatty acids. This could be due to different technological process used, different composition or different fermentation.

Organic acids

Organic acids have influence on the shelf life of the fermented foods, originating mainly from bacterial metabolism during fermentation and storage [18, 19]. LAB play a significant role in fermentation and preservation of foods by for-

Tab. 5. Content of organic and fatty acids in coconut plant-based yoghurts.

	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
Organic acids [g·kg⁻¹]						
Malic acid	0.80 ± 0.00	nd	1.10 ± 0.00	0.74 ± 0.00	nd	nd
Lactic acid	1.70 ± 0.00	3.90 ± 0.02	2.10 ± 0.01	0.40 ± 0.00	3.80 ± 0.01	3.90 ± 0.00
Acetic acid	≤ *LOD*	0.20 ± 0.00	≤ *LOD*	≤ *LOD*	0.20 ± 0.00	0.20 ± 0.00
Citric acid	0.45 ± 0.00	0.12 ± 0.00	0.20 ± 0.00	0.30 ± 0.00	≤ *LOD*	nd
Fatty acids [g·kg⁻¹]						
Hexanoic acid	4.60 ± 0.00	4.70 ± 0.00	5.00 ± 0.00	9.10 ± 0.00	6.80 ± 0.00	7.10 ± 0.00
Octanoic acid	124.30 ± 0.00	122.40 ± 0.00	111.10 ± 0.00	125.60 ± 0.00	146.90 ± 0.00	117.00 ± 0.00
Decanoic acid	71.30 ± 0.00	73.30 ± 0.00	70.20 ± 0.00	86.70 ± 0.00	78.60 ± 0.00	79.80 ± 0.00
Dodecanoic acid	511.20 ± 0.00	531.80 ± 0.00	500.00 ± 0.00	454.70 ± 0.00	541.80 ± 0.00	475.40 ± 0.00
Tetradecanoic acid	169.20 ± 0.00	163.60 ± 0.00	180.70 ± 0.00	191.10 ± 0.00	146.20 ± 0.00	178.30 ± 0.00
Hexadecanoic acid	60.90 ± 0.00	72.60 ± 0.00	78.60 ± 0.00	68.60 ± 0.00	46.90 ± 0.00	74.50 ± 0.00
Octadecanoic acid	10.00 ± 0.00	10.10 ± 0.00	18.10 ± 0.00	17.40 ± 0.00	8.70 ± 0.00	18.10 ± 0.00
Octadecenoic acid	41.20 ± 0.00	21.50 ± 0.00	34.30 ± 0.00	40.40 ± 0.00	24.10 ± 0.00	43.30 ± 0.00
Octadecadienoic acid	7.40 ± 0.00	nd	1.90 ± 0.00	6.50 ± 0.00	nd	6.50 ± 0.00
Octadecatrienoic acid	nd	nd	nd	nd	nd	nd

nd – not detected, *LOD* – limit of detection.

mation of organic acids, in particular lactic acid and acetic acid, and enhance the texture and taste of the product [18]. Yogurt is a cultured product derived from the fermentation of strains of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. In the initial stage of fermentation, Str. thermophilus exhibits rapid growth, releasing metabolites such as lactic acid, carbon dioxide or formic acid [27]. According to the data in Tab. 5, it can be observed that the content of lactic acid was higher in Yog2, Yog5, and Yog6. This was consistent with the results for acetic acid. The incorporation of additional ingredients, including coconut water, significantly impacted the production of organic acids, particularly malic and citric acid [28], as shown in the composition list (Tab. 1). Additionally, in fortified yoghurt with Ca/Vitamin D, calcium citrate can contribute to traces of citric acid from the coconut water [28].

Colour

The product's colour and appearance play a significant role in influencing the consumer's purchasing decision. According to the present study, the results of colour measurement of the samples are presented in Tab. 6. Significant variations were identified in the lightness (L^*) values among all samples, spanning from 61.94 ± 0.41 to 79.48 ± 1.05. The differences in L^* values between the samples could be ascribed to the light-scattering effect induced by lipid globules [7]. The most pronounced differences in colour were identified in Yog1, where the L^* value

Tab. 6. Colour parameters of the supernatant of coconut plant-based yoghurt samples.

	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
L^*	61.94 ± 0.41^{e}	79.48 ± 1.05^{ab}	73.47 ± 1.31^{d}	72.61 ± 0.47^{d}	76.59 ± 0.32^{c}	78.74 ± 0.18^{b}
a^*	0.80 ± 0.01^{a}	-1.01 ± 0.02^{e}	-0.34 ± 0.01^{b}	-0.60 ± 0.04^{c}	-0.77 ± 0.03^{d}	-0.63 ± 0.01^{c}
b^*	6.98 ± 0.03^{a}	2.08 ± 0.21^{c}	-0.11 ± 0.15^{f}	1.38 ± 0.06^{d}	0.94 ± 0.07^{e}	1.46 ± 0.06^{d}
H°	83.43 ± 0.09^{e}	116.00 ± 2.02^{c}	175.39 ± 11.93^{a}	113.68 ± 1.79^{c}	129.48 ± 1.08^{b}	113.43 ± 1.41^{c}
YI	25.08 ± 0.14^{a}	10.77 ± 0.37^{c}	7.15 ± 0.16^{f}	9.88 ± 0.14^{d}	8.69 ± 0.12^{e}	9.86 ± 0.14^{d}
WI	61.84 ± 0.90^{d}	78.99 ± 1.07^{a}	73.47 ± 1.50^{c}	72.52 ± 0.43^{c}	76.75 ± 0.40^{b}	78.36 ± 0.51^{a}

Different small letter in superscript in the same row indicate statistically significant differences ($p < 0.05$).
L^* – lightness, a^* – redness/greenness, b^* – blueness/yellowness, H – hue angle, YI – yellowness index, WI – whiteness index.

(61.94 ± 0.41), whiteness index (61.84 ± 0.90) and hue angle (83.43 ± 0.09) were the lowest. This was accompanied by a significantly increased yellowness (b^*) value (6.98 ± 0.03) and yellowness index (25.08 ± 0.14), indicating distinct yellowish characteristics. Comparable findings were reported by CHETACHUKWU et al. [7], where the retention of coconut testa in the coconut meat correlated with an elevated b^* value of the samples. Furthermore, PACHEKREPAPOL et al. [5] reported a slight decrease in whiteness, possibly due to the Maillard reaction gradually occurring in heat-treated coconut milk during storage. Additionally, the size of lipid globules, protein particles and the content of stabilizers significantly contribute to the brightness level [6]. Moreover, minor variations were observed in other coconut plant-based samples concerning colour parameters ($p < 0.05$).

Antioxidant characteristics

Phenolic compounds found in coconut milk originate from the brown coconut testa and the white coconut kernel. These compounds in food play a role in enhancing pleasant flavours, exhibiting antimicrobial activity, contributing to sensory properties and extending the shelf life of food products [29]. Some statistically significant differences were noticed in *TPC* values between the samples. Yog2 had the highest *TPC* of 91.17 ± 0.84 mg·l^{-1} (Fig. 1A) and *TFC* of 37.91 ± 0.73 mg·l^{-1}, which was associated with improvement of the antioxidant activity of the sample. At the same time, this sample had the lowest pH among all samples, pH 3.98 ± 0.00. According to the literature, LAB-induced acidification is responsible for enhancing the solubilization and extractability of polyphenols. This is primarily attributed to specific enzymatic activities of LAB, such as feruroyl esterases [30], or may also be attributed to the metabolic activity of microorganisms [31]. Furthermore, antioxidant activity can be measured using ABTS$^{\bullet+}$ radical-scavenging activity to assess total antioxidant activity. Compared to $^{\bullet}$DPPH radical-scavenging activity, all samples had a higher ABTS$^{\bullet+}$ radical-scavenging activity (Fig. 1B). This may be attributed to the increased levels of aromatic amino acids, which possess the ability to donate hydrogen and potentially impede the radical-mediated peroxidation process [32]. This phenomenon may be a result of the bioactivity of the protein fraction derived from the raw material.

Microbiological characteristics

The potentially beneficial lactic acid bacteria and metabolites can be present in plant-based products if they are fermented with starter cultures. These are believed to provide positive health effects to consumers due to the presence of live lactic acid bacteria in the products. The results of the microbiological analysis are shown in Tab. 7. The viable counts of presumptive *Lactobacillus* spp. were significantly different ($p < 0.05$) in all tested samples. Low counts were determined in the two samples (Yog1 and Yog4). The reduction in microbial culture counts could be influenced by a decline in lactose levels, a primary energy source for LAB [33]. Additionally, plant-based milk environment can induce stress on the yogurt starter *Lactobacillus delbrueckii* subsp. *bulgaricus* resulting in deformities and segmentation of cells [34].

Additionally, storage temperature may sig-

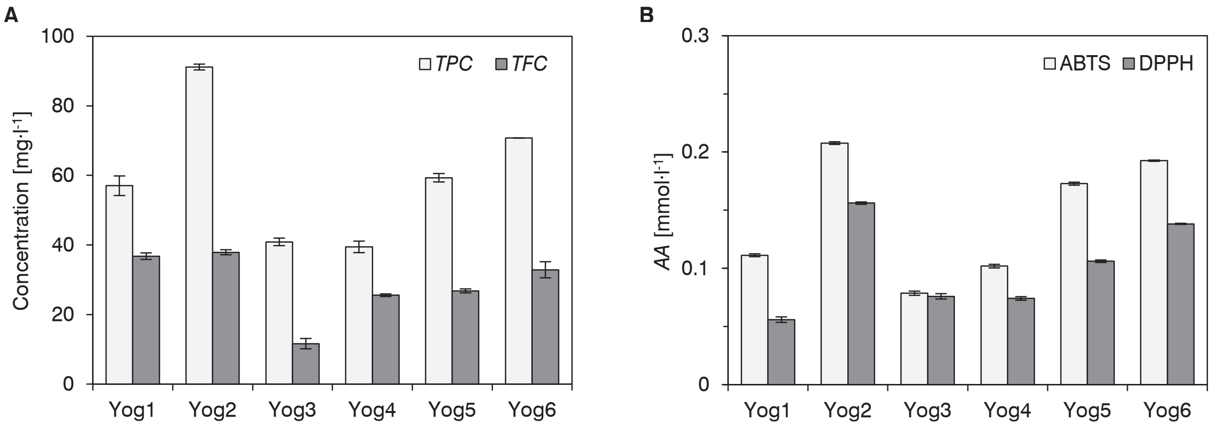

Fig. 1. Antioxidant characteristics of the supernatant of coconut plant-based yoghurts.

A – total polyphenols and total flavonoids concentration, B – antioxidant activity.
TPC – total polyphenols concentration (expressed as milligrams of gallic acid equivalent), *TFC* – total flavonoids concentration (expressed as milligrams of rutin equivalent), *AA* – antioxidant activity (expressed as Trolox equivalents), ABTS – antioxidant activity determined by ABTS assay, DPPH – antioxidant activity determined by DPPH assay.

Tab. 7. Counts of presumptive lactobacilli and thermophilic streptococci in coconut plant-based yoghurts.

Viable cell count [CFU·g-1]	Yog1	Yog2	Yog3	Yog4	Yog5	Yog6
Presumptive lactobacilli	$< 4.6 \times 10^1$	1.6×10^8	2.8×10^4	$<4.6 \times 10^1$	1.8×10^8	3.1×10^8
Thermophilic streptococci	$< 4.6 \times 10^1$	1.6×10^8	6.6×10^5	$<4.6 \times 10^1$	1.3×10^8	3.3×10^8

Tab. 8. Panelist description of sensory parameters of the coconut plant-based yoghurts.

	Appearance	Taste
Yog1	Light brown, "gelatinous"	Disgusting
Yog2	White, thick to stiff, denser than the reference sample	Tasty, pleasant acidity
Yog3	White, thick	Less tasty than Yog2
Yog4	Greyish-white, separated aqueous component, like 'clotted cream'	Taste watery to soapy
Yog5	White, thick and creamy, aroma coconutty, pleasant, acidic	Watery to tasteless
Yog6	White, thick to stiff, denser than the reference sample, aroma coconutty, sour pleasant	Sour

nificantly affect viability of LAB and physicochemical characteristics of the final product [35]. Some of the samples were not within the acceptable standard range regarding counts of LAB in coconut plant-based yoghurt, where the minimum counts need to be $> 10^6$ CFU·g^{-1} and if intended as probiotics, then counts need to be at least 10^7 CFU·g^{-1} [18].

Sensory evaluation

Sensory acceptability is affected by various factors like composition and quality of the product [4]. The results of sensory evaluation were statistically different among coconut yoghurt samples for all parameters (Fig. 2). The highest score for overall acceptability had Yog2 (89.8 %), followed by sample Yog5 (72.7 %). The panellist description of sensory parameters is shown in Tab. 8. It can be noted that Yog2, which contained the highest amount of added sugar (Tab. 2) was evaluated as tasty with pleasant acidity. The second choice Yog5 was described as watery to tasteless. Besides the composition of the formulation, using different starter cultures can affect the quality of the product and the sensory perception of fermented plant-based products [25], influencing their acceptability.

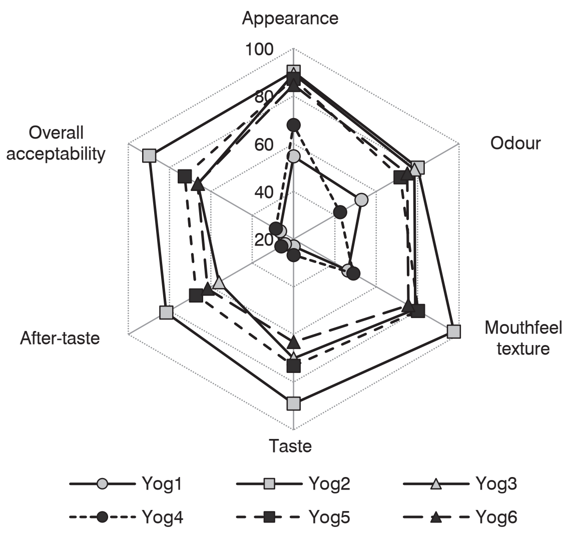

Fig. 2. Sensory evaluation of coconut plant-based yoghurts.

CONCLUSIONS

Selected quality parameters of commercial coconut plant-based yoghurt were studied. The results showed that all of the products differed in quality parameters probably as a result of differences in the technological process and the raw material used. Generally, one of the major attributes affecting the taste of the product panellist described some of the samples as watery and soapy. The sensory analysis showed that some of the coconut plant-based samples were more appreciated than others, which are strongly related with compositional factor, such as sugar content in the sample. We found also reduced microbiological quality in some samples manifested as bacterial cultures present at unacceptably low levels. The sample with the highest overall acceptance score had better overall quality characteristics. The results obtained in this study allowed identification of the important quality attributes of commercial coconut-based yoghurt-like products. At developing a new product, structural and textural parameters should be considered to meet consumer preferences.

Acknowledgements

Biljana Trajkovska would like to acknowledge the direct support of COST (European Cooperation in Science and Technology) in the framework of COST Action CA20128 (Promoting Innovation of fermented foods, PIMENTO).

REFERENCES

1. Crittenden, R. G. – Bennett, L. E.: Cow's milk allergy: a complex disorder. Journal of the American College of Nutrition, *24*, 2005, pp. 582S–591S. DOI: 10.1080/07315724.2005.10719507.
2. Tangyu, M. – Muller, J. – Bolten, C. J. – Wittmann, C.: Fermentation of plant-based milk alternatives for improved flavour and nutritional value. Applied Microbiology and Biotechnology, *103*, 2019, pp. 9263–9275. DOI: 10.1007/s00253-019-10175-9.
3. Jeske, S. – Zannini, E. – Arendt, E. K.: Evaluation of physicochemical and glycaemic properties of commercial plant-based milk substitutes. Plant Foods for Human Nutrition, *72*, 2017, pp. 26–33. DOI: 10.1007/s11130-016-0583-0.
4. Gupta, M. K. – Torrico, D. D. – Ong, L. – Gras, S. L. – Dunshea, F. R. – Cottrell, J. J.: Plant and dairy-based yoghurts: a comparison of consumer sensory acceptability linked to textural analysis. Foods, *11*, 2022. article 463. DOI: 10.3390/foods11030463.
5. Pachekrepapol, U. – Kokhuenkhan, Y. – Ongsawat, J.: Formulation of yoghurt-like product from coconut milk and evaluation of physicochemical, rheological, and sensory properties. International Journal of Gastronomy and Food Science, *25*, 2021, article 100393. DOI: 10.1016/j.ijgfs.2021.100393.
6. Góral, M. – Kozłowicz, K. – Pankiewicz, U. – Góral, D. – Kluza, F. – Wójtowicz, A.: Impact of stabilizers on the freezing process, and physicochemical and organoleptic properties of coconut milk-based ice cream. LWT – Food Science and Technology, *92*, 2018, pp. 516–522. DOI: 10.1016/j.lwt.2018.03.010.
7. Chetachukwu, A. S. – Thongraung, C. – Yupanqui, C. T.: Development of reduced-fat coconut yoghurt: physicochemical, rheological, microstructural and sensory properties. International Journal of Dairy Technology, *72*, 2019, pp. 524–535. DOI: 10.1111/1471-0307.12600.
8. Naibaho, J. – Butula, N. – Jonuzi, E. – Korzeniowska, M. – Chodaczek, G. – Yang, B.: The roles of brewers' spent grain derivatives in coconut-based yogurt-alternatives: Microstructural characteristic and the evaluation of physico-chemical properties during the storage. Current Research in Food Science, *5*, 2022, pp. 1195–1204. DOI: 10.1016/j.crfs.2022.07.011.
9. Mauro, C. S. I. – Fernandes, M. T. C. – Farinazzo, F. S. – Garcia, S.: Characterization of a fermented coconut milk product with and without strawberry pulp. Journal of Food Science and Technology, *59*, 2022, pp. 2804–2812. DOI: 10.1007/s13197-021-05303-1.
10. Grasso, N. – Alonso-Miravalles, L. – O'Mahony, J. A.: Composition, physicochemical and sensorial properties of commercial plant-based yoghurts. Foods, *9*, 2020, article 252. DOI: 10.3390/foods9030252.
11. AOAC 925.10-1925. Solids (total) and loss on drying (moisture) in flour. Air oven method. Gaithersburg : AOAC International, USA, 2014.
12. Tobolková, B. – Polovka, M. – Kajdi, F. – Suhaj, M. – Bitterová, M.: A comparative study of quality and colour characteristics of organically and conventionally produced spelt flours by means of UV-Vis reflectance spectroscopy and multivariate analysis. Journal of Food and Nutrition Research, *62*, 2023, pp. 212–223. ISSN: 1336-8672 (print), 1338-4260 (online). <https://www.vup.sk/download.php?bulID=2198>
13. Hirschler, R.: Whiteness, yellowness, and browning in food colorimetry: a critical review. In: Caivano, J. L. – del Pilar Buera, M. (Eds.): Color in food, technological and psychophysical aspects. Boca Raton : Imprint CRC Press, 2012, pp. 118–129. ISBN: 9781138199644.
14. Tobolková, B. – Polovka, M. – Belajová, E. – Koreňovská, M. – Suhaj, M.: Possibilities of organic and conventional wines differentiation on the basis of multivariate analysis of their characteristics (EPR, UV–Vis, HPLC and AAS study). European Food Research and Technology, *239*, 2014, pp. 441–451. DOI: 10.1007/s00217-014-2237-5.
15. Polovka, M.: EPR spectroscopy: A tool to characterize stability and antioxidant properties of foods. Journal of Food and Nutrition Research, *45*, 2006, pp. 1–11. ISSN: 1336-8672 (print), 1338-4260 (online). <https://www.vup.sk/download.php?bulID=1>
16. Saito, Y. – Tonouchi, A. – Harada, Y. – Ogino, R. – Toba, T.: Isolation of *Steptococcus thermophilus* strains from plant in Japan and their application to milk fermentation. Food Science and Technology Research, *26*, 2020, pp. 1–8. DOI: 10.3136/fstr.26.1.
17. Deshwal, G. K. – Tiwari, S. – Kumar, A. – Raman, R. K. – Kadyan, S.: Review on factors affecting and control of post-acidification in yoghurt and related products. Trends in Food Science and Technology, *109*, 2021, pp. 499–512. DOI: 10.1016/j.tifs.2021.01.057.
18. Qadi, W. S. M. – Mediani, A. – Benchoula, K. – Wong, E. H. – Misnan, N. M. – Sani, N. A.: Characterization of physicochemical, biological, and chemical changes associated with coconut milk fermentation and correlation revealed by ^{1}H NMR-based metabolomics. Foods, *12*, 2023, article 1971. DOI: 10.3390/foods12101971.
19. da Costa, M. P. – da Silva Frasao, B. – da Costa Lima, B. R. C. – Rodrigues, B. L. – Conte Jr., C. A.: Simultaneous analysis of carbohydrates and organic acids by HPLC-DAD-RI for monitoring goat's milk yoghurts fermentation. Talanta, *152*, 2016, pp. 162–170. DOI: 10.1016/j.talanta.2016.01.061.
20. Gawai, K. M. – Mudgal, S. P. – Prajapati, J. B.: Stabilizers, colorants, and exopolysaccharides in yoghurt. In: Shah, P. N. (Ed.): Yoghurt in health and disease prevention. Amsterdam : Academic Press, Elsevier, 2017, pp. 49–68. ISBN: 9780128051344. DOI: 10.1016/B978-0-12-805134-4.00003-1.

21. Maajid, H. S. – Nurliyani, N. – Widodo, W.: Exopolysaccharide production in fermented milk using *Lactobacillus casei* strains AP and AG. AIMS Microbiology, *8*, 2022, pp. 138–152. DOI: 10.3934/microbiol.2022012.
22. Mehta, A. – Kumar, L. – Serventi, L. – Schlich, P. – Torrico, D. D.: Exploring the textural dynamics of dairy and plant-based yoghurts: A comprehensive study. Food Research International, *171*, 2023, article 113058. DOI: 10.1016/j.foodres.2023.113058.
23. Nguyen, H. T. – Ong, L. – Kentish, S. E. – Gras, S. L.: Homogenisation improves the microstructure, syneresis and rheological properties of buffalo yoghurt. International Dairy Journal, *46*, 2015, pp. 78–87. DOI: 10.1016/j.idairyj.2014.08.003.
24. Buldo, P. – Benfeldt, C. – Folkenberg, D. M. – Jensen, H. B. – Amigo, J. M. – Sieuwerts, S. – Thygesen, K. – van den Berg, F. – Ipsen, R.: The role of exopolysaccharide-producing cultures and whey protein ingredients in yoghurt. LWT – Food Science and Technology, *72*, 2016, pp. 189–198. DOI: 10.1016/j.lwt.2016.04.050.
25. Masiá, C. – Geppel, A. – Jensen, P. E. – Buldo, P.: Effect of *Lactobacillus rhamnosus* on physicochemical properties of fermented plant-based raw materials. Foods, *10*, 2021, article 573. DOI: 10.3390/foods10030573.
26. Machado, M. – Rodríguez-Alcalá, L. M. – Gomes, A. M. – Pintado, M.: Does the nature of added bioactive lipids affect the biological properties of yoghurts? — Case study coconut and avocado oils. Applied Sciences, *13*, 2023, article 3101. DOI: 10.3390/app13053101.
27. Chandan, R. C. – Kilara, A. (Ed.): Manufacturing yoghurt and fermented milks. Hoboken : Wiley and Sons, 2013. ISBN: 9781119967088. DOI: 10.1002/9781118481301.
28. Yong, J. W. H. – Ge, L. – Ng, Y. F. – Tan, S. N.: The chemical composition and biological properties of coconut (*Cocos nucifera* L.) water. Molecules, *14*, 2009, pp. 5144–5164. DOI: 10.3390/molecules14125144.
29. Sun, J. – Chu, Y.-F. – Wu, X. – Liu, R. H.: Antioxidant and antiproliferative activities of common fruits. Journal of Agricultural and Food Chemistry, *50*, 2022, pp. 7449–7454. DOI: 10.1021/jf0207530.
30. Verni, M.– Verardo, V. – Rizzello, C. G.: How fermentation affects the antioxidant properties of cereals and legumes. Foods, *8*, 2019, article 362. DOI: 10.3390/foods8090362.
31. Zhao, Y.-S. – Eweys, A. S. – Zhang, J.-Y. – Zhu, Y. – Bai, J. – Darwesh, O. M. – Zhang, H.-B. – Xiao, X.: Fermentation affects the antioxidant activity of plant-based food material through the release and production of bioactive components. Antioxidants, *10*, 2021, article 2004. DOI: 10.3390/antiox10122004.
32. Li, Y. – Zheng, Y. – Zhang, Y. – Xu, J. – Gao, G.: Antioxidant activity of coconut (*Cocos nucifera* L.) protein fractions. Molecules, *23*, 2018, article 707. DOI: 10.3390/molecules23030707.
33. Madureira, A. R. – Amorim, M. – Gomes, A. M. – Pintado, M. E. – Malcata, F. X.: Protective effect of whey cheese matrix on probiotic strains exposed to simulated gastrointestinal conditions. Food Research International, *44*, 2011, pp. 465–470. DOI: 10.1016/j.foodres.2010.09.010.
34. Jan, G. – Tarnaud, F. – do Carmo, F. L. R. – Illikoud, N. – Canon, F. – Jardin, J. – Briard-Bion, V. – Guyomarc'h, F. – Gagnaire, V.: The stressing life of *Lactobacillus delbrueckii* subsp. *bulgaricus* in soy milk. Food Microbiology, *106*, 2022, article 104042. DOI: 10.1016/j.fm.2022.104042.
35. Durec, J. – Smorádková, K. – Tobolková, B.: Evaluation of *Lactibacillus rhamnosus* LGG and *Bifidobacterium* BB-12 growth in mixed plant-based beverages in industrial pilot production. Journal of Food and Nutrition Research, *62*, 2023, pp. 270–276. ISSN: 1336-8672 (print), 1338-4260 (online). <https://www.vup.sk/download.php?bulID=2203>

Received 8 November 2023; 1st revised 15 January 2024; accepted 17 January 2024; published online 10 March 2024.