Organic magnesium salts fortification in fermented goat’s milk

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ABSTRACT
The aim of this study was the production of a functional goat’s milk product fortified with organic magnesium salts and fermented by *Bifidobacterium Bb-12*. The best stimulator of probiotic bacteria growth was magnesium citrate. Fermented milk with citrate addition had a similar L*a*b* color parameters in comparison to the control milk sample. The addition of magnesium pidolate significantly favorably increased the hardness of the fermented milk; however, the fortification with magnesium lactate and citrate decreased the hardness. Moreover, fortification with magnesium citrate reduced the intensity of goaty taste and odor.

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Introduction

The increased interest in goat milk as functional food lies in the lower allergenicity in comparison to cow milk, especially for children. Nowadays, the goat’s milk is a part of the current trend of a healthy diet in developed countries.[1–3] The use of goat’s milk as an excellent source of food is undeniable, because it is known that it has a positive effect on maintaining health and physiological functions in nutrition, especially for children and the elder people. The combination of bacterial strains, probiotic properties, and fortification with magnesium salts of goat’s milk is an excellent proposal for the dairy industry in developing new trends for functional food. Probiotic strains are microorganisms that have a beneficial effect on the health and well-being of the consumer.[4] To achieve the declared health benefits, an important requirement in probiotic food production is a high survival rate of probiotic bacteria, at a minimum level of 7 log cfu g⁻¹ or mL⁻¹.[5,6]

The production of fermented products from goat’s milk encounters the problem of obtaining proper consistency of the curd in fermented goat’s milk. This may result from the low buffering capacity of goat’s milk[7] and the very low concentration or absence of α₁-casein.[8] These factors affect the rheological properties of goat’s milk coagulate which after the fermentation process is a semi-liquid product. To obtain a proper consistency of the curd in fermented goat’s milk, it is required to increase the nonfat dry matter content by, e.g., using whey or milk protein concentrates or isolates, as well as caseinates, stabilizers like pectins and inulin, or even the addition of lactic acid bacteria (LAB) as producers of exopolysaccharides.[9–14]

Some studies have reported that fortification of processing milk with certain minerals may contribute to obtaining a more compact curd in a finished fermented beverage, and increasing its hardness.[15,16] Haenlein[17] and Yangilar[18] reported that there is a lack in goat milk and goat milk product research and this needs more attention, especially for fortified goat products. The novelty of this study was to determine the properties of goat’s fermented milk enriched with organic magnesium salts: magnesium citrate, magnesium pidolate, and magnesium lactate. These studies, on fortification of goat milk with magnesium compounds, have not been published yet. However, there are presented some studies on goat milk enrichment with calcium, iron, and zinc. Moreover,
due to much lower than recommended daily intake of magnesium (300 mg per day) by the human body,\cite{19,21} dairy products fortified with magnesium could contribute to supplementing its dietary deficiencies\cite{22-24} and simultaneously improving the hardness of its curd. In medicine, many magnesium salts are used, both inorganic (chloride, sulfate, nitrate, carbonate) and organic (citrate, ascorbate, aspartate, gluconate, lactate). The soluble salts have better toleration and absorption than insoluble compounds. All inorganic salts of magnesium are significantly less absorbable by the human body in comparison to the organic magnesium salts. The aim of this study was to evaluate the possibility of using organic magnesium salts for the production of goat’s milk fermented by probiotic microflora \textit{Bifidobacterium animalis} ssp. \textit{lactis} Bb-12.

\section*{Materials and methods}

\subsection*{Material}

Material: goat’s milk was purchased in June 2018 in the organic farm “Zuza” (Zabratówka, Poland); magnesium L-pidolate $\text{C}_{10}\text{H}_{12}\text{N}_{2}\text{MgO}_{6}$ (Sigma, France); magnesium L-lactate hydrate $\text{C}_{6}\text{H}_{10}\text{MgO}_{6}\cdot\text{H}_{2}\text{O}$ (Sigma – Aldrich, Spain); magnesium citrate $\text{C}_{6}\text{H}_{6}\text{MgO}_{7}$ (Sigma – Aldrich, Polska); \textit{Bifidobacterium animalis} ssp. \textit{lactis} Bb-12 (Chr. Hansen, Denmark).

\subsection*{Quality assessment of goat’s milk}

The chemical composition (fat, protein, lactose, total solids) and freezing point of goat’s milk were determined using the Infrared Milk Analyzer B-150 (Bentley Instruments, USA). The total number of microorganisms was determined with using BactoCount IBC-m/SCC (Bentley Instruments, USA). The active acidity (pH) of milk was determined with the pH-meter FiveEasy (Mettler Toledo, Switzerland).

The concentration of magnesium in raw goat milk ($n = 5$) was determined by optical emission spectrometry with inductively coupled plasma optical emission spectrometry (ICP-OES) Thermo iCAP Dual 6500 (Thermo Fisher Scientific Inc., USA). For sample mineralization, the microwave digestion system Ethos Ultra-wave-One (Milestone SRL, Italy) was used. Samples of goat milk (2.5 g) were mineralized under high pressure in super pure 65% HNO$_3$ (Merck Millipore, Germany). Samples were placed in teflon vessels, filled with 8 mL of nitric acid and sealed tightly. During the microwave digestion rotor of the digestion system was filled with unknown samples and one blank sample, which consisted of 8 mL of nitric acid as well. The samples were mineralized for an hour with the algorithm of the temperature increase applied as specified for the type of biological samples, without exceeding 200°C. The vessels were opened after the completion of the process of digestion, after cooling down the samples with acid to the room temperature. The mixture was transferred equally to falcon tubes and it was replenished to 50 mL with deionized water. Before measuring, the method was calibrated to certified models with concentrations of 10000 ppm for magnesium (Merck, Germany). The measurement result for magnesium was adjusted to account for the measurement of elements in the blank sample. In each case, a three-point calibration curve was used for magnesium, with optical correction applying the method of internal models, in the form of yttrium and ytterbium ions, at concentrations of 2 mg l$^{-1}$ and 5 mg l$^{-1}$, respectively. The analytical methods were validated using Certified Reference Material and the recovery obtained for magnesium (102%). In order to identify the relevant measurement lines (279.553 nm) and avoid possible interferences, the method of adding an internal standard was applied.

\subsection*{Fermented milk manufacture}

Milk was divided into four parts to which was added, respectively: (1) magnesium L-lactate (30 mg Mg 100 g$^{-1}$), (2) magnesium citrate (30 mg Mg 100 g$^{-1}$), (3) magnesium L-pidolate (30 mg Mg 100 g$^{-1}$), (4) control (0 mg Mg 100 g$^{-1}$).
The milk mixtures were homogenized (20 MPa, 60°C) in a homogenizer (Nuoni GJJ-0.06/40, Zhejiang, China) and pasteurized in a water bath at 85°C for 15 min and then rapidly cooled in chilled water to 37°C. Then, the milk was inoculated with the previously revived probiotic cultures containing *Bifidobacterium* Bb-12 (*Bifidobacterium animalis* ssp. *lactis* Bb-12). The addition of bacteria was 10 mg/L (10% v/v) of starter cultures (in sterile milk). Bacteria inoculum was approx. 9 log CFU g⁻¹. After the exact combination of the substrate with microflora, the intermediate product was placed in 100 mL unit cups and fermented (acidified). All experimental milk were incubated at 37°C for 10 h and stored at 5°C (Cooled Incubator ILW 115, POL-EKO Aparatura, Poland).

**Physicochemical analysis**

The pH values of the samples were measured using a FiveEasy pH-meter (Mettler Toledo, Switzerland), total acidity was determined in g of lactic acid equivalent L⁻¹, syneresis with the centrifugal method (n = 10, for each group of fermented milk). Color measurements (n = 10, for each group of fermented milk) were performed using the CIELab system with a portable colorimeter Chroma Meter CR-400 (Konica Minolta Sensing, Inc., Osaka, Japan). Data were expressed in terms of L*, a*, and b* parameters, where L* represents the lightness (from 0 – black to 100 – white); a* and -a* redness and greenness, respectively; and b* and -b* yellowness and blueness, respectively. Before testing, the instrument was calibrated on a White Calibration Plate CR-A43.

**Instrumental texture**

The texture profile was determined by the TPA test using the CT3 Texture Analyzer (Brookfield, USA) with Texture Pro CT (Brookfield, USA) software. The sample dimensions were cylindrical 66 mm × 33.86 mm and the temperature of the sample was 8°C (n = 10, for each group of fermented milk). The test was performed using the acrylic probe TA 3/100 and the following settings: distance 15 mm, contact load 0.1 N, measurement speed 1 mm/s.

**Microbiological analysis**

Determination of the counts of *Bifidobacterium* was made by the plate method (n = 10, for each group of fermented milk). Viable counts of *Bifidobacterium animalis* ssp. *lactis* Bb-12 were determined on MRS Agar (Biocorp, Poland), after anaerobic incubation at 37°C for 72 h. Anaerobic conditions were obtained using the GENboxanaer sachets and were controlled by the Anaer indicator (Biomerieux, Poland). The grown colonies were counted using the TITRIPLAQUE instrument (LLME, Hungary). The results are given in log CFU g⁻¹.

**Organoleptic analysis**

The analysis of organoleptic parameters was made for three fermented milk samples fortified with magnesium salts and the control. The organoleptic analysis was performed by a trained panel that consisted of 10 women and 10 men at the age of 25–30. The panelists were served seven samples at a time (in three-digit random number coded plastic cubs) and asked to rinse their mouths with water between samples. The panelists evaluated the presence of creamy-milky taste, sour taste, sweet taste, goaty taste, off-taste, fermentation odor, goaty odor, and off-odor on a 9-point rating scale with edge markings (from 1 = not perceptible to 9 = extremely strong).
Statistical analysis

The obtained results were given as the mean and standard deviation and were calculated statistically using the Statistica v. 13.1 software (StatSoft, USA). Significance of differences between the averages was estimated with Tukey’s test ($P<0.05$).

Results and discussion

Goat’s milk quality

The physicochemical and microbiological composition of raw goat’s milk from hybrids with the Carpathian goats is presented in Table 1. The protein, lactose, fat and magnesium content were similar to the literature data. The protein and fat content are mainly influenced by diet and race.\cite{29,30} Goats were fed with local organic fodder. However, the fat content of goat milk was very low compared with normal cows’ milk. The milk was characterized by a low total number of bacteria and somatic cell count, which proves a good hygienic and microbiological quality (Table 1).

The addition of magnesium to goat’s milk had a significant influence on the pH value of milk after pasteurization, depending on the type of salt added (Table 2). The addition of magnesium lactate most intensively reduced the pH of milk as compared with the control sample ($P<0.05$). Lactate is characterized by a good solubility and reduces the pH of milk immediately after adding. In Znamirowska et al.\cite{31} study, the addition of magnesium lactate to cow’s milk at a dose of 30 mg/100g of milk decreased the pH value by 0.37 unit.

Fortification with magnesium pidolate also significantly reduced the pH of milk in comparison to the control milk sample. The carried out study has shown that magnesium citrate acidified goat’s milk the least. The citrate producer indicates that it is slightly soluble in water (Sigma-Aldrich). Therefore, in goat’s milk, citrate did not cause such a large decrease in pH as magnesium lactate and magnesium pidolate.

Microbiological analysis

The number of Bifidobacterium Bb-12 cells was determined 24 h after the end of fermentation (Figure 1). The highest number of bacterial cells was found in milk with magnesium citrate addition and this number was significantly higher (by 0.16 log cfu g$^{-1}$) than that determined in the control

**Table 1.** Characteristic of raw goat’s milk used for the production of fermented milk ($n = 5$).

| Characteristic                  | Value                  |
|--------------------------------|------------------------|
| Total bacterial counts, CFU/ml | 120,500.00 ± 111.15    |
| Somatic cells count in 1 ml    | 299,200.00 ± 13,190.00 |
| pH                             | 6.78 ± 0.02            |
| Fat, g 100g$^{-1}$             | 2.66 ± 0.01            |
| Protein, g 100g$^{-1}$         | 2.97 ± 0.00            |
| Lactose, g 100g$^{-1}$         | 4.53 ± 0.00            |
| Total solid, g 100g$^{-1}$     | 11.30 ± 0.02           |
| Freezing point, °C             | −0.623 ± 0.01          |
| Magnesium, mg 100 g$^{-1}$     | 22.11 ± 0.60           |

Values are means ± standard deviation.

**Table 2.** The pH of control milk and milk enriched with magnesium after the pasteurization ($n = 10$).

| pH     | Control | Lactate | Citrate | Pidolate |
|--------|---------|---------|---------|----------|
| 6.56 ± 0.01 | 6.32 ± 0.02 | 6.44 ± 0.01 | 6.35 ± 0.01 |

Values are means ± SD.

a, b, c – mean values in lines denoted by different letters differ significantly ($P<0.05$).
milk sample. It was noticeable that magnesium citrate positively affects the growth of \textit{Bifidobacterium} Bb-12 in goat’s milk. In milk enriched with magnesium pidolate, the number of \textit{Bifidobacterium} Bb-12 cells was not significantly different from in the control milk sample. The least favorable growth conditions for \textit{Bifidobacterium} Bb-12 were found in goat’s milk fortified with magnesium lactate, because the number of bacterial cells was lower by 0.3 log cfu g$^{-1}$ as compared with the control sample.

Probiotic bacteria remained viable after 24 h of cold storage (5°C) with a number of cells (Figure 1) not less than the minimum value (7.0 log cfu g$^{-1}$) recommended by the International Dairy Federation.$^{32}$ It is worth mentioning that a count higher than 7 log cfu g$^{-1}$ will guarantee an adequate number of viable cells during the useful life of the product.

The lower content of bacterial cells in milk with magnesium lactate showed that the addition of lactate creates less favorable growth conditions for \textit{Bifidobacterium} Bb-12, resulting in a higher pH value in this milk compared with the control sample (Table 3). Fortification of goat’s milk with magnesium citrate and magnesium pidolate did not significantly affect the pH value of fermented milk. Higher total acidity was found in fermented milk fortified with magnesium compounds than in the control fermented milk sample, but only the acidity of milk with lactate differed significantly ($P<.05$).

**Physicochemical properties**

Syneresis is one of the most visible and significant defects in fermented milk, which is due to the accumulation of whey on the surface of the milk gels creating a negative impact on the consumer acceptability.$^{33}$ The certainty behind the syneresis occurrence is due to the shrinkage of the gel that leads to the whey separation.

| Table 3. Total acidity [g/L], pH and syneresis [%] of fermented goat’s milk with magnesium (n = 10). |
|---------------------------------------------------------------|
| **Parameter** | **Control** | **Lactate** | **Citrate** | **Pidolate** |
| pH             | 4.78$^a$ ± 0.05 | 4.87$^b$ ± 0.17 | 4.74$^c$ ± 0.05 | 4.80$^b$ ± 0.11 |
| Total acidity  | 0.59$^a$ ± 0.01 | 0.77$^b$ ± 0.16 | 0.64$^a$ ± 0.03 | 0.63$^a$ ± 0.04 |
| [g of lactic acid L$^{-1}$] | | | | |
| Syneresis [%]  | 59.05$^a$ ± 1.89 | 58.69$^a$ ± 2.20 | 70.02$^b$ ± 2.10 | 70.11$^b$ ± 0.77 |

Values are means ± SD.
a, b – mean values in lines denoted by different letters differ significantly ($P<0.05$).
According to Stelios and Emmanuel\textsuperscript{34}, syneresis values may be associated with a higher calcium content in goat’s milk and the water-holding capacity in calcium due to the presence of ionic interactions between caseins in the protein network. The process of whey separation is also related to the rigidity and stability of the protein network and other factors, such as protein denaturation, low pH, high acidity as well as the type and intensity of heat treatment.\textsuperscript{35} Moschopoulou et al.\textsuperscript{36} suggest that a higher fat content in goat’s milk also contributes to an increase in WHC (water-holding capacity) because the film material of the fat globule improves the WHC of the yoghurt gels. In our study, only milk with magnesium lactate addition was characterized by syneresis comparable to the control sample. However, in milk with magnesium citrate and magnesium pidolate, syneresis was lower than in the control by about 11%. The syneresis was found to be positively and significantly correlated with pH value ($r = 0.7989$, $P < 0.05$).

Color is another important sensory characteristic of goat’s milk and its dairy products. Goat’s milk shows white color, since all the $\beta$-carotene content is converted into retinol and it is devoid of that pigment. In the CIELAB color coordinates, coordinates $a^*$ and $b^*$ depend on the natural pigment concentration of goat’s milk.\textsuperscript{37} Therefore, $L^*$ value depends on the dispersion of casein micelles and fat globules that affect the diffusion of the incident light.\textsuperscript{38} In the study by Znamirowska et al.\textsuperscript{31}, fermented milk fortified with magnesium and calcium lactate gave a significantly darker color than the control ones. With an increase in the dose of these micronutrients, the darkening color of fermented milk was detected.

The results shown in Figure 2 indicate that the color lightness $L^*$ of the control sample was significantly higher than that of milk with magnesium pidolate and magnesium lactate. Fermented milk with magnesium citrate was not different in terms of $L^*a^*b^*$ color parameters compared with the control. All milk were green/yellow, but the intensity was significantly differentiated. The addition of magnesium lactate decreased the proportion of yellow and green, while the addition of magnesium pidolate decreased the proportion of yellowness and increased greenness. Also, the study conducted by Moschopoulou et al.\textsuperscript{36} demonstrated the green-yellow color of goat’s milk yoghurts.

**Parameters of texture**

Textural properties are one of the most essential attributes of fermented milk quality. According to Walia et al.\textsuperscript{39}, the structural arrangement of the network determines the textural characteristics of

![Figure 2. Color parameters of fermented goat’s milk with magnesium (n = 10).](image)

Values are means for $n = 10$. $a,b$ – means values between magnesium salts denoted by different letters differ statistically significantly ($P < .05$).
fermented milk, which is influenced by factors such as composition and manufacturing processes. However, it should be noted that the mineral compounds in milk and milk products play an important role in the stability of the proteins and in some of their characteristics. Although protein is a significant contributor to development of texture in fermented milk, changes in minor components of milk that mediate changes in protein and mineral equilibria of milk may also alter fermented milk texture.  

Table 4 presents the results of a texture profile parameters of goat’s milk fermented with the addition of organic magnesium salts. Goat-fermented milk, compared with cow milk products, have weaker body and poorer texture that are dependent on the seasonal variations of milk composition. Various studies showed different methods to improve the texture of fermented goat milk products, such as the addition of skim milk powder. However, despite this already known characteristic, researchers are continually seeking to further improve texture. Therefore, the improving of hardness of goat-fermented milk is more favored.

A significantly lower hardness was demonstrated in milk with the addition of magnesium lactate and magnesium citrate than in the control milk (P<0.05). However, fortification with magnesium pidolate resulted in a significantly higher hardness of acid goat’s milk gel. Higher hardness of fermented milk fortified with magnesium pidolate could be explained by a higher addition of this salt in comparison to other magnesium compounds used, since it contains the least of magnesium (8.66% Mg). A higher addition of this magnesium salt presumably increased significantly the dry matter content and a hardness of gel. According to Szajnar et al. the introduction of various magnesium salts could affect the ability of the strain to produce EPS, which can explain differences in the hardness of the samples tested. Earlier studies showed that the addition of calcium chloride to goat’s milk also increased the hardness of yoghurts. Moatsou and Park showed that the abundance of goat β-casein and αs1-casein polymorphisms is the main feature of casein from goat’s milk. Low casein content in goat’s milk, low proportion of αs1-casein, the lower sedimentation rate of casein micelles, higher β-casein solubility, higher content of calcium and phosphorus and lower thermal stability as compared with cow’s milk causes poor texture of yoghurt. Yoghurt from milk of goat breeds with high casein content, and in particular, with αs1-casein content, shows higher firmness than that from milk of international breeds with low casein content.

Adhesiveness is the force necessary to remove the material that adheres to the mouth during eating. The adhesiveness of the control milk was comparable with fermented milk with the addition of magnesium pidolate and significantly lower than in milk with magnesium lactate. Gels of milk fermented with the addition of magnesium lactate and magnesium citrate were characterized by higher values of stringiness length and cohesiveness than milk with magnesium pidolate (P<0.05). Cohesiveness is an indication of a strong bond and it affects the structural integrity of fermented milk. In this study, we found that the adhesiveness, cohesiveness and stringiness length of fermented goat milk can be changed by using different magnesium compounds. Springiness is the rate at which the sample returns to its original shape when the deforming force is removed. Moreover, springiness depends on different agents such as heat treatment, protein interaction,
elasticity, and degree of the unfolding of the protein.[47] No significant differences in springiness were found in fermented goat’s milk with the addition of magnesium and in the control sample.

**Organoleptic parameters**

The trained panel evaluated milk samples in terms of flavor and odor (Table 5). According to the panelists opinion, the fortification of milk with magnesium did not significantly affect the consistency, color, milky-creamy taste, sour-yoghurt taste and sweet taste as compared with the control sample. The intense goaty taste and odor is not accepted by most consumers. A significantly weaker goaty taste was found in goat’s milk with magnesium citrate in comparison with the control. The average values of goaty taste in milk with magnesium lactate and magnesium pidolate were not significantly different from in the control milk sample. In previous studies, it was shown that the addition of magnesium chloride also reduces the intensity of goaty taste and odor.[43] Park et al.[30] stated that the two biggest barriers in marketing of goat milk products are negative public perception of goaty flavor and odor and seasonal milk production. The conducted studies showed that some magnesium salts, such as citrate, by reducing the intensity of goat’s flavor and odor may increase the acceptability of fermented goat’s milk.

Goat’s milk fermented with magnesium lactate and citrate obtained lower marks for consistency than the control milk. A significant correlation coefficient ($r = 0.8044, P < .05$) between consistency and hardness was calculated. Our study showed that the addition of magnesium lactate and magnesium pidolate may result in an off-taste and a slight off-odor. According to Gahruie et al.[24] the properties of fortified dairy products are influenced by the type of mineral source and the amount of component which is added to the product. In our study was shown that the addition of 30 mg of magnesium (in 100 g$^{-1}$ of milk), in the form pidolate and lactate, was too high. All around the world, especially in Europe, where health claims on products are regulated by the new EFSA (European Food Safety Authority) health claim regulation, magnesium offers various options for new fortified product concepts As technological problem will increase with higher fortification levels of mineral, magnesium citrate will be able to prove superior application in dairy products, especially goat.

**Conclusion**

Organic magnesium salts (citrate, lactate, and pidolate) can be used to produce functional milk. Magnesium salts used for milk fortification lowered pH, which is important in determining the parameters of pasteurization due to possible thermal denaturation of proteins. Magnesium citrate caused the smallest decrease in the pH value compared with the control sample, as well as the best growth stimulation of *Bifidobacterium* Bb-12. All fermented milk was characterized by the

| Properties                  | Control         | Lactate         | Citrate         | Pidolate        |
|-----------------------------|-----------------|-----------------|-----------------|-----------------|
| Creamy-milky taste          | 5.60$^{a} ± 1.52$ | 5.40$^{a} ± 1.34$ | 5.40$^{a} ± 1.67$ | 4.60$^{a} ± 0.89$ |
| Sour taste                  | 7.00$^{b} ± 0.71$ | 7.20$^{b} ± 1.10$ | 7.00$^{b} ± 0.71$ | 7.40$^{b} ± 0.89$ |
| Goaty taste                 | 1.70$^{c} ± 0.55$ | 1.60$^{ab} ± 0.60$ | 1.20$^{c} ± 0.25$ | 1.60$^{ab} ± 0.55$ |
| Sweet taste                 | 2.20$^{c} ± 1.30$ | 2.40$^{c} ± 1.14$ | 3.20$^{c} ± 2.28$ | 2.20$^{c} ± 1.30$ |
| Off-taste                   | 1.00$^{d} ± 0.00$ | 1.20$^{d} ± 0.10$ | 1.00$^{d} ± 0.00$ | 1.20$^{d} ± 0.10$ |
| Fermentation odor           | 5.80$^{a} ± 2.17$ | 5.20$^{a} ± 2.28$ | 6.00$^{a} ± 1.41$ | 4.60$^{a} ± 2.07$ |
| Goaty odor                  | 1.60$^{a} ± 0.55$ | 1.20$^{a} ± 0.19$ | 1.00$^{a} ± 0.00$ | 1.20$^{a} ± 0.15$ |
| Off-odor                    | 1.00$^{d} ± 0.00$ | 1.60$^{d} ± 0.67$ | 1.00$^{d} ± 0.00$ | 1.40$^{d} ± 0.52$ |

Values are means ± SD.

a, b, c, d – mean values in lines denoted by different letters differ significantly ($P < 0.05$).
number of bacterial cells higher than 7 log cfu g\(^{-1}\) ensuring the appropriate therapeutic effect. In fermented milk fortified with magnesium citrate and pidolate, total acidity and syneresis were estimated at a similar level. Milk fortified with magnesium citrate had L*a*b* color parameters similar to the control milk. Therefore, fortification with magnesium pidolate and lactate resulted in a decrease in the color lightness and a decrease in the intensity of yellowness. When designing functional products with magnesium, it should be considered that their texture can be shaped depending on the type of salt added. The addition of magnesium pidolate significantly increased the hardness of the milk gel, while the addition of magnesium lactate and citrate significantly reduced it in comparison with the control sample. Fortification with magnesium salts reduced the intensity of goaty taste and odor. The carried out study shows that magnesium citrate reduced the most a goaty taste and odor which is not always acceptable by the consumer. In this study, it was indicated that the best magnesium salt for the fortification of goat’s milk was magnesium citrate due to the organoleptic characteristics and the number of *Bifidobacterium* Bb-12 cells in the product.

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**References**

[1] Olalla, M.; Ruiz-López, M.-D.; Navarro, M.; Artacho, R.; Cabrera, C.; Giménez, R.; Rodríguez, C.; Mingorance, R. Nitrogen Fractions of Andalusian Goat Milk Compared to Similar Types of Commercial Milk. *Food Chem.* 2009, 113, 835–838. DOI: 10.1016/j.foodchem.2008.10.022.

[2] Bevilacqua, C.; Martin, P.; Candalh, C.; Fauquant, J.; Piot, M.; Roucayrol, A.-M.; Pilla, F.; Heyman, M. Goat’s Milk of Defective As1-casein Genotype Decreases Intestinal and Systemic Sensitisation to B-lactoglobulin in Guinea Pigs. *J. Dairy Res.* 2001, 68, 217–227. DOI: 10.1017/S0022029901004861.

[3] Villoslada, F. L.; La Leche De Cabra En Nutrición Infantil: Una Fuente De Nuevos Ingredientes Alimentarios [In Spanish]. Goat’s Milk in Infant Nutrition: A New Source of Functional Ingredients. Doctoral thesis, Universidad de Granada, 2005.

[4] Salminen, S.; Ouwehand, A.; Benno, Y.; Lee, Y. K. Probiotics: How Should They Be Defined? *Trends Food Sci. Tech.* 1999, 10, 107–110. DOI: 10.1016/S0924-2244(99)00027-8.

[5] Altérez, M.-J.; Barrionuevo, M.; Lopez-Aliaga, I.; Sanz-Sampelayo, M. R.; Lisboa, F.; Robles, J. C.; Campos, M. S. Digestive Utilization of Goat and Cow Milk Fat in Malabsorption Syndrome. *J. Dairy Res.* 2001, 68, 451–461. DOI: 10.1017/S0022029901004903.

[6] Barrionuevo, M.; Altérez, M. J.; Lopez-Aliaga, I.; Sanz-Sampelayo, M. R.; Campos, M. S. Beneficial Effect of Goat Milk on Nutritive Utilization of Iron and Copper in Malabsorption Syndrome. *J. Dairy Sci.* 2002, 85, 657–664. DOI: 10.3168/jds.S0022-0302(02)74120-9.

[7] Barac, M.; Pescic, M.; Zilic, S.; Smiljanic, M.; Sredojevic Ignjatovic, I.; Vucic, T.; Kostic, A.; Milinovic, D. The Influence of Milk Type on the Proteolysis and Antioxidant Capacity of White-Brined Cheese Manufactured...
from High-Heat-Treated Milk Pretreated with Chymosin. *Foods*. 2019, 8(128), 1–14. DOI: 10.3390/foods8040128.

[8] Vegarud, G. E.; Devold, T. G.; Opheim, R.; Loeding, E.; Svenning, C.; Abrahamsen, R. K.; Lien, S.; Langsrud, T. Genetic Variants of Norwegian Goat’s Milk Composition, Micellar Size and Renneting Properties. *Int. Dairy J*. **1999**, 9, 367–368. DOI: 10.1016/S0958-6946(99)00090-4.

[9] Martin –Diana, A. B.; Peláez, C.; Requena, T. Rheological and Structural Properties of Fermented Goat’s Milk Supplemented with Caseinomacropeptide and Whey Protein Concentrate. *Milchwissenschaft*. 2004, 59(7–9), 383–386.

[10] Herrero, A. M.; Requena, T. The Effect of Supplementing Goats Milk with Whey Protein Concentrate on Textural Properties of Set-type Yoghurt. *Int. J. Food Sci. Technol.* **2006**, 41(1), 87–92. DOI: 10.1111/j.1365-2621.2005.01045.x.

[11] Tratnik, L.; Božanić, R.; Herceg, Z.; Drgalić, I. The Quality of Plain and Supplemented Kefir from Goat’s and Cow’s Milk. *Soc. Dairy Technol.* **2006**, 59(1), 40–46. DOI: 10.1111/j.1471-0307.2006.00236.x.

[12] Kearney, N.; Stack, H. M.; Tobin, J. T.; Chaurin, V.; Fenelon, M.; Fitzgerald, G. F.; Ross, P.; Stanton, C. *Lactobacillus Paracasei* NFBC 338 Producing Recombinant Beta-glucan Positively Influences the Functional Properties of Yoghurt. *Int. Dairy J*. 2011, 21(8), 561–567. DOI: 10.1016/j.idairyj.2011.03.002.

[13] Prasanna, P. H. P.; Grandison, S.; Charalamopoulos, D. Effect of Dairy – Based Protein Sources and Temperature on Growth, Acidification and Exopolysaccharide Production of Bifidobacterium Strains in Skim Milk. *Food Res. Int.* **2012**, 47(1), 6–12. DOI: 10.1016/j.foodres.2012.01.004.

[14] Karam, M. C.; Gaiani, C.; Hosri, C.; Burgain, J.; Scher, J. Effect of Dairy Powders Fortification on Yogurt Textural and Sensorial Properties: A Review. *J. Dairy Res.* 2013, 80(4), 400–409. DOI: 10.1017/S0022029913000514.

[15] Ocak, E.; Köse, S. The Effects of Fortifying Milk Cu, Fe and Zn Minerals on the Production and Texture of Yoghurt. *J. Sci. Food Agr.* 2010, 8(2), 122–125.

[16] Szajnar, K.; Znamirowska, A.; Kalicka, D.; Kuźniar, P. Fortification of Yoghurts with Various Magnesium Compounds. *J. Elem.* 2017, 22(2), 559–568. DOI: 10.1056/jelem.2016.21.3.1226.

[17] Haenlein, G. F. H.; Goat Milk in Human Nutrition. *Small Ruminant Res.* 2004, 51(2), 155–163. DOI: 10.1016/j.smallrumin.2003.08.010.

[18] YANGILAR, F.;. As a Potentially Functional Food: Goats’ Milk and Products. *J. Food Nutr. Res.* 2013, 1(4), 68–81. DOI: 10.12691/jfnr-1-4-6.

[19] Welch, R.; Graham, R. Breeding Crops for Enhanced Micronutrient Content. *Plant Soil* 2005, 245, 205–214. DOI: 10.1023/A:1020668100330.

[20] White, P.; Broadley, M. Biofortifying Crop with Essential Mineral Elements. *Trends Plant Sci.* 2005, 20(12), 586–593. DOI: 10.1016/j.tplants.2005.10.001.

[21] Żbikowska, A.; Żbikowski, Z. Porównanie Cech Jakościowych Bio-jogurtu Produkowanego Metodą Termostatową z Dodatkiem Soli Wapnia i Magnesu [in Polish]. Comparison of Qualitative Features of Bio-yoghurt Produced with the Thermostat and Accelerated Method with the Addition of Calcium and Magnesium Salts. *Inz. Ap. Chem.* 2012, 51(1), 16–17.

[22] Gerhart, M.; Schottenheimer, M. Mineral Fortification in Dairy. *Wellness Foods Eur*. 2013, Nuremberg, Germany, 1, 30–36.

[23] Szelesczuk, Ł.; Kuras, M. The Importance of Calcium in the Human Metabolism and Factors Affecting the Bioavailability of Dietary. *Biul. Wydz. Farm. WUM*. 2014, 3, 16–22.

[24] Gahruie, -H.-H.; Eskandari, M. H.; Mesbahi, G.; Hanifpour, M. A. Scientific and Technical Aspect of Yogurt Fortification: A Review. *Food Sci. Hum. Wellness*. 2015, 4, 1–8. DOI: 10.1016/j.fshw.2015.03.002.

[25] Jemaa, M.-B.; Falleh, H.; Neves, M. A.; Isoda, H.; Nakajima, M.; Ksouri, R. Quality Preservation of Deliberately Contaminated Milk Using Thyme Free and Nanoemulsified Essential Oils. *Food Chem.* 2017, 217, 726–734. DOI: 10.1016/j.foodchem.2016.09.030.

[26] Zhao, L. L.; Wang, X. L.; Liu, Z. P.; Sun, W. H.; Dai, Z. Y.; Ren, F. Z.; Mao, X. Y. Effect of α-lactalbumin Hydrolysate-calcium Complexes on the Fermentation Process and Storage Properties of Yogurt. *LWT-Food Sci. Technol*. 2018, 88, 35–42. DOI: 10.1016/j.lwt.2017.09.006.

[27] Lima, K.-G.; Kruger, M.-F.; Behrens, J.; Destro, M.-T.; Landgraf, M.; Franco, B. D. G. Evaluation of Culture Media for Enumeration of *Lactobacillus Acidophilus*, *Lactobacillus Casei* and *Bifidobacterium Animalis* in the Presence of *Lactobacillus Delbrueckii Subsp Bulgaricus* and *Streptococcus Thermophilus*. *LWT-Food Sci. Technol*. 2009, 42, 491–495. DOI: 10.1016/j.lwt.2008.08.011.

[28] Baryło-Pikielna, N.; Matuszewska, I. Sensoryczne Badania Żywności. Podstawy – Metody – Zastosowania [in Polish]. Sensory Food Testing. Fundamentals – Methods – Applications. *Wyd. Naukowe PTTZ*. Krakow. 2014, 66, 150–157. ISBN 978-83-935421-3-0.

[29] Albenzio, M.; Santillo, A. Biochemical Characteristics of Ewe and Goat Milk: Effect on the Quality of Dairy Products. *Small Ruminant Res*. 2011, 101(1–3), 33–40. DOI: 10.1016/j.smallruminres.2011.09.023.

[30] Park, Y. W.; Juarez, M.; Ramos, M.; Haenlein, G. F. W. Physico-chemical Characteristics of Goat and Sheep Milk. *Small Ruminant Res*. 2007, 68(1–2), 88–113. DOI: 10.1016/j.smallrumin.2006.09.013.
