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This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1718420> since 2019-12-05T12:08:22Z

Published version:

DOI:10.3390/fermentation5030055

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Article

Goat Milk with Different Alpha-s1 Casein Genotype (CSN1S1) Fermented by Selected *Lactobacillus paracasei* as Potential Functional Food

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Received: 29 April 2019; Accepted: 27 June 2019; Published: 1 July 2019



Abstract: The characteristics of fermented milk are affected by the type of milk used and the microorganisms involved in the fermentation process. Goat milk has been widely suggested as a possible alternative to cow milk in allergic subjects, because of the high genetic variability in alpha-s1 casein (CSN1S1) content, which is associated with different technological and nutritional properties of milk. The aim of the study was to evaluate the suitability of goat milk with low and high CSN1S1 to produce fermented milk. In addition, the performance as starter of selected *Lactobacillus paracasei* FS109 strain compared to no-selected *L. paracasei* strains was investigated. Initially, the selected *L. paracasei* FS109 strain was tested for adhesion ability to HT-29 and Caco-2 cells and immunomodulation effect. Then, the strain was used to produce fermented milk from goat milk with a low and high casein CSN1S1 genotype. The results indicated that greater acidifying activity was obtained for *L. paracasei* FS109 after 24 h of fermentation than the other two strains tested independently by the CSN1S1 genotype. *L. paracasei* FS109 grew well during fermentation, reaching a higher value (>8.5 log CFU/mL). Interestingly, the same strain maintained a high viable population (about 9 log CFU/mL) during the 30-day cold storage of the product. The present study shows for the first time the suitability of the goat milk with low CSN1S1 genotypes to produce fermented milk and highlight the importance of strain selection in determination of technological and beneficial traits. Combining goat milk with low CSN1S1 and selected strains could be a strategy of improving traditional and functional fermented milk market.

Keywords: *Lactobacillus paracasei*; immunomodulation; goat milk; casein genotype; fermented milk; functional food

1. Introduction

Fermented milk enhances sensorial and nutritional features when compared to the raw material and has always been perceived by consumers as a health food. These later traits are related to the type of milk used, the microorganisms involved, and the technology applied. Goat milk is widely used in many countries as an alternative to cow milk, especially for children showing cow milk intolerance (MCI) or cow milk allergy (CMA) [1]. Caseins (CN), and in particular alpha s-CN, are the major milk allergens [2]. Caseins are encoded by four well-known genes and characterized in goats by a

high genetic variability. Considering all variants described in the literature, CSN1S1, encoding for α S1-casein, is characterized by at least 23 variants (A, A2, A3, A', B1, B2, B3, B4, B', C, D, D1, E, F, G, H, I, L, M, N, 01, 02, and 04) as described by Chessa and Caroli [3]. Although on average, α S1-casein represents only the 10–13% of the total casein content in goat milk, the respective genes are the most studied because, depending on the genetic variant, the synthesis level of this casein varies greatly: The strong alleles (A, A2, A3, A', B1, B2, B3, B4, B', C, H, L, and M) produce about 3.5 g/L of α S1-casein each, the intermediate alleles (D1, E, and I) produce 1.1–1.8 g/L, the weak alleles (D, F, and G) 0.45–0.6 g/L, and the null alleles (01, 02, 04, and N) produce no α S1-casein [4,5].

The presence of particular α S1-variants can affect the composition and technological features of goat fermented milk. Perna et al. [6] reported the lowest phenolic compounds content in the yogurt from goats with weak alleles at CSN1S1 loci (FF) compared with yogurt from goats with strong alleles at CSN1S1 loci (AA, BB, AB). A study conducted on Norwegian goat breed shown as milk with high S1-CN evidenced a higher coagulant activity than milk with a weak α S1-CN [7]. The different nutritional value of milk from animals with a different CSN1S1 genotype has been evidenced by several studies. In guinea pigs, the anti-goat beta-Ig IgG1 antibodies and intestinal anaphylaxis were significantly decreased when animals were fed with goat milk with low (0.7 g/L) CSN1S1 content compared with those fed with milk with high (7 g/L) CSN1S1 [8]. Albenzio et al. [9] showed a lower production of pro-inflammatory cytokines (IL6, IL8 and TNF) from cultured peripheral blood mononuclear cells from infants with cow milk protein allergy after exposure to goat milk casein than after exposure to cow milk.

Currently, the high nutritional and therapeutic potential of caprine milk fermented with selected lactic acid bacteria (LAB) with functional features has been accentuated [10–12], as well as the opportunity to set up innovative products supplemented and/or fortified with different ingredients [13]. However, the counts of probiotic microorganisms in such food products decrease during cold storage, thus reducing or compromising the health value of the fermented milk. This is due to several factors, such as low pH, production of lactic and acetic acid [14] as well as storage conditions. In a previous study carried out by our research group, several autochthonous *Lactobacillus* (*L.*) *paracasei* strains showed interesting attributes, such as good survival in gastric and intestinal juice models, inhibition of undesirable bacteria growth, and susceptibility towards antibiotics, such as chloramphenicol, clindamycin, penicillin, amoxicillin, erythromycin, tetracycline, and ampicillin [15].

In the present study, we deepened some probiotic aspects, such as the adhesion ability of *L. paracasei* FS109 strain, as well as their immunomodulatory potential. Adhesion prolongs transition of bacteria through the gut, thus enhancing their health impact through antagonistic activities against enteropathogens [16] and stimulation of the immune responses [17], with those referring to upregulation of anti-inflammatory cytokines, such as Interleukin 10 (IL10) [18], reducing nitrite to nitric oxide [19], and downregulating the cyclooxygenase-2 (COX2) expression [20,21], being the most promising ones.

The objective of the present study was to evaluate the suitability of goat milk with low CSN1S1 to produce fermented milk. In addition, the ability of selected *L. paracasei* strain as a starter to produce fermented milk from low CSN1S1 milk has been also investigated.

2. Materials and Methods

2.1. Milk Samples Selection

The study was conducted at a private farm located in the northwest of Sardinia, Italy. Details on this study were reported by Caboni et al. [22]. Briefly, 14 goats were selected on the basis of the CSN1S1 genotype previously typed and divided into two groups: one group of 7 goats, including animals classified as heterozygous for weak or null alleles (low group; LCsM; goats with FF, 0101, and F01 genotype), and one group of 7 goats with strong homozygous genotypes (high group; HCsM; goats with AA genotype). Animals were kept on pens and milked twice a day (h 7:00 and 17:00). Each group of animals was fed alfalfa hay (on average 1.1 kg/day per goat, as fed), split into 2 feedings (morning

and evening), and each animal was individually fed a commercial concentrate (0.6 kg/day per goat, as fed) during both milkings, and beet pulp (0.11 kg/day per goat, as fed). Goats grazed on natural pasture during approximately 3 h after the morning milking every day. Pasture intake was estimated to be equal to 600 g of dry matter based on animal energy requirements. Milk was collected individually for each animal at the morning milking, and the bulk milk of each group was used for producing the experimental fermented milk. Bulk milk samples of the HCsM and LCsM groups were analyzed for fat, proteins, and lactose using a Milkoscan 6000 instrument (Foss Electric, Hillerød, Denmark).

2.2. *Lactobacillus Paracasei* FS109 Strain Probiotic Selection

To be used as culture starter to produce the experimental fermented milk, autochthonous *L. paracasei* strain, namely *L. paracasei* FS109, already characterized in a previous work [15], was further tested for adhesion ability and immunomodulation effect. The adenocarcinoma cell lines HT-29 and Caco-2 cells were used to determine the adhesion ability of the *Lactobacillus* strains, as previously described [23]. Briefly, cells were seeded (1×10^5 cells per well) in 12-well tissue culture plates and cultured in Dulbecco's modified Eagle medium (DMEM) supplemented with 4 mM L-glutamine, 100 U mL⁻¹ penicillin, 100 µg/mL streptomycin, and 10 or 15% (*v/v*) fetal bovine serum (FBS) for HT-29 or Caco-2, respectively. Cells were incubated (37 °C, 5% CO₂) for either 3 days (HT-29) or 5 days (Caco-2). Overnight cultures of *Lactobacillus* strains (8–9 log CFU/mL) were washed with PBS (pH 7.4) and re-suspended in the cell-line medium, without antibiotics and FBS, to achieve a final concentration of 10⁸ CFU mL⁻¹. After medium removal, cell monolayers were also washed twice, and 1 mL of the *Lactobacillus* suspensions was added. Adhesion experiments were carried out for 2 h at 37 °C, 5% CO₂. The bacterial suspension was then aspirated, and cell monolayers were washed twice with PBS and detached using a trypsin solution (0.25% *w/v*). Bacterial enumeration was determined at t₀ (starting time) and t₂ (after 2 h) using appropriate dilutions plated on MRS agar medium and incubated at 37 °C for 48 h.

Immunomodulation was tested according to Zoumpopoulou et al. [21]. A relative expression of IL10, inducible nitric oxide synthase (iNOS), and COX2 genes was calculated using the 2^{-ΔΔCt} method, and glyceraldehyde-3-phosphate dehydrogenase (GAPDH) was used as the reference gene. Sequences of primers used are presented in Table 1.

Table 1. Sequences of primers used in the immunomodulation experiment.

| Primer | Sequence |
|-----------|---------------------------|
| IL10 (F) | CACCCACTTCCCAGGCAACC |
| IL10 (R) | TCTCAGACAAGGCTTGGCAACC |
| iNOS (F) | CCCAGCCTCAAGTCTTATTTTCCTC |
| iNOS (R) | GCACTCAGCAGCAAGTCCATC |
| COX2 (F) | CCTGTGCCTGATGATTGC |
| COX2 (R) | CTGATGCGTGAAGTGCTG |
| GAPDH (F) | GAGTCCACTGGCGTCTTC |
| GAPDH (R) | GCATTGCTGATGATCTTGAGG |

2.3. Experimental Fermented Milks Production from Different Genotypes

The performance of this *Lactobacillus* strain has been compared to *L. paracasei* CF4, isolated from Casizolu cheese [24] and to *L. paracasei* ATCC 393^T reference strain.

Strains were subcultured twice in MRS (Oxoid, Milan, Italy), and incubated at 30 °C for 12 h. Before fermented milk production, strains were grown separately in sterile goat milk at 30 °C until they reached approximately 6 log CFU/mL.

For the production of experimental fermented milks, 45 L of milk from each goat group were heated at 90 °C for 10 s, then cooled down to 30 °C and divided in three batches: Batch 1 was inoculated with *L. paracasei* FS109; batch 2 with *L. paracasei* CF4; and batch 3 with *L. paracasei* ATCC 393^T. In all

cases, an inoculum of 1% (*w/v*) was used. The inoculated batches were incubated for 24 h at 30 °C. Afterward, the products were cooled and kept at 4 °C for 30 days.

2.4. *Lactobacillus* Strains viable Counts and Physicochemical Parameters Determination

For microbiological analysis, all samples (10 g) were carefully homogenized in 90 mL sterile Ringer’s solution for 2 min in a Stomacher Lab Blender 80 (PBI, Milan, Italy). Aliquots of 1 mL were 10-fold diluted in Ringer’s solution and inoculated on MRS agar to quantify lactobacilli. Plates were incubated under anaerobiosis (Anaerobic System Anaerogen, Oxoid) at 30 °C for 48 h. pH value was determined with a pH-meter (Crison Instruments SA, Barcelona, Spain). Acidity determination was carried out in 10 mL of fermented milk titrated with 0.1 N NaOH, with phenolphthalein as an indicator and expressed as a percentage of lactic acid. All samples at 0, 3, 6, 9, and 24 h of incubation were collected and analyzed immediately. The same microbiological and physicochemical parameters were evaluated at 15 and 30 days during storage at 4 °C. All analyses were carried out in triplicate in fermented milk samples from each batch (*n* = 3).

2.5. Statistical Analysis

Mean values of microbiological and physicochemical data from different milk genotypes, various *L. paracasei* strains, and storage time of fermented milk were compared using the Student’s T test, and differences were considered statistically significant at *p* < 0.05. Statistical analysis was performed using MINITAB® software (Version 16.1.0, Minitab, State College, PA, USA).

3. Results

3.1. Milk Composition

The average milk yield was higher in high compared to low goats (2610 vs. 2129 g/day). Overall, the average of the milk fat, protein, and lactose content obtained was 3.19%, 3.21%, and 4.41% for the HCsm and 3.18%, 3.24%, and 4.31% for the LCsm bulk milk, respectively.

3.2. *Lactobacillus Paracasei* FS103 Strain Probiotic Features

The *L. paracasei* strain showed poor adhesion capacity to HT-29 and Caco-2 cells, namely, less than 1%. The cell counts binding to adenocarcinoma cells were estimated at 4.92 ± 0.12 and 5.13 ± 0.01 log CFU/mL (for HT-29 cells) and 5.59 ± 0.08 and 5.30 ± 0.86 CFU mL⁻¹ (for Caco-2 cells), respectively, after 2 h of incubation. Regarding immunomodulation results (Table 2), the IL10 expression, was numerically higher than control, even if did not reach the level of significant difference (*p* > 0.05). The iNOS expression was significantly (*p* < 0.05) downregulated when THP-1 cells were co-cultured with FS109, while COX2 mRNA level remained unaffected with *L. paracasei* FS109 (*p* > 0.05).

Table 2. Immunomodulation properties of *L. paracasei* FS109 strain in human THP-1 cells. after co-culture for 4 h.

| | Min | Max | Average | SD | <i>p</i> Value |
|---------|------|-------|---------|------|-----------------|
| IL10 | 0.96 | 17.31 | 6.83 | 6.69 | <i>p</i> > 0.05 |
| COX2 | 0.79 | 1.49 | 1.23 | 0.31 | <i>p</i> > 0.05 |
| iNOS | 0.56 | 0.96 | 0.67 | 0.15 | <i>p</i> < 0.05 |
| Control | 1 | 1 | 1 | 0 | |

IL10, interleukin 10; COX2, cyclooxygenase-2; iNOS inducible nitric oxide synthase; SD, standard deviation; significant differences (*p* < 0.05) were considered in comparison to the untreated control.

3.3. Experimental Fermented Milks from Different Genotypes

3.3.1. pH and Titratable Acidity Values

The genetic polymorphisms in *CSN1S1* did not affect pH (Table 3) and titratable acidity (Table 4) values in both types of goat milk inoculated with the three different *L. paracasei* strains, apart from a difference after 24 h of fermentation with strain ATCC 393^T. More precisely, the pH was lower in the LCsM sample than in the HCsM one. Moreover, higher acidifying activity was obtained for *L. paracasei* FS109 compared to *L. paracasei* CF4 and ATCC 393^T strains as at 24 h of fermentation, the pH value decreased to 4.41 and 3.93 for HCsM and LCsM milk, respectively ($p < 0.05$). At the same incubation time, both HCsM and LCsM milk fermented with *L. paracasei* FS109 showed a higher value of lactic acid percentage ($p < 0.05$) than those determined in the fermented with the other two *Lactobacillus* strains. Overall, for each *L. paracasei* strain tested, the evolution of pH and lactic acid (Tables 3 and 4) over time did not show any difference between high and low genotype fermented milks ($p > 0.05$), except for the *L. paracasei* ATCC 393^T, where pH at the end of fermentation was lower in LCsM.

Greater acidifying activity (pH and titratable acidity) of *L. paracasei* FS109 was observed throughout the storage period. At 5 °C, pH values further decreased while lactic acid percentage increased in both genotype groups even if it did not reach the level of significance ($p > 0.05$), except for the *L. paracasei* CF4 and ATCC 393^T strains, for which pH value was higher at 15 and 30 days of storage in both low and high *CSN1S1* fermented milk (Tables 3 and 4).

Table 3. Evolution of pH values in HC_{SM} and LC_{SM} bulk milk fermented with *L. paracasei* strains during fermentation time and cold storage.

| Strain | Fermentation Time (h) | | | | | | | | | | | | Cold Storage (Day) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------|-----------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|--------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|
| | 0 | | 3 | | 6 | | 9 | | 24 | | 15 | | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FS109 | HC _{SM} | 6.63 ^{aA} | 0.05 | LC _{SM} | 6.46 ^{aA} | 0.1 | HC _{SM} | 6.88 ^{aA} | 0.17 | LC _{SM} | 6.60 ^{aA} | 0.11 | HC _{SM} | 6.44 ^{aA} | 0.2 | LC _{SM} | 6.60 ^{aA} | 0.19 | HC _{SM} | 6.15 ^{aA} | 0.15 | LC _{SM} | 6.10 ^{aA} | 0.27 | HC _{SM} | 4.41 ^{aA} | 0.17 | LC _{SM} | 3.93 ^{aA} | 0.31 | HC _{SM} | 3.85 ^{aA} | 0.12 | LC _{SM} | 3.73 ^{aA} | 0.12 | HC _{SM} | 3.79 ^{aA} | 0.2 | LC _{SM} | 3.62 ^{aA} | 0.13 | | | | | | | | | | | | | | |
| | CF4 | 6.67 ^{aA} | 0.23 | 6.53 ^{aA} | 0.16 | 6.95 ^{aA} | 0.07 | 6.78 ^{aA} | 0.16 | 6.68 ^{aA} | 0.13 | 6.82 ^{aA} | 0.17 | 6.50 ^{aB} | 0.12 | 6.33 ^{aA} | 0.07 | 6.63 ^{aC} | 0.06 | 6.23 ^{aC} | 0.14 | 4.00 ^{aA} | 0.23 | 4.18 ^{aB} | 0.21 | 4.07 ^{aB} | 0.11 | 4.13 ^{aB} | 0.10 | 3.93 ^{aT} | 0.15 | 6.5 ^{aA} | 0.2 | 6.90 ^{aA} | 0.16 | 6.75 ^{aA} | 0.12 | 6.54 ^{aA} | 0.07 | 6.67 ^{aA} | 0.16 | 6.45 ^{aB} | 0.06 | 6.35 ^{aA} | 0.19 | 6.28 ^{bB} | 0.06 | 5.94 ^{aB} | 0.11 | 5.42 ^{aB} | 0.04 | 5.31 ^{aC} | 0.16 | 5.07 ^{aC} | 0.16 | 5.36 ^{bC} |

HC_{SM} and LC_{SM}, goat milk with high and low casein CSN1S1 genotype, respectively; different superscript lower case (a, b, c) letters on the same row indicate significant differences ($p < 0.05$) between HC_{SM} and LC_{SM}; different superscript upper case (A, B, C) letters on the same column and or each time indicate significant differences ($p < 0.05$) between *L. paracasei* strains.

Table 4. Evolution of titratable acidity (% lactic acid) of HC_{SM} and LC_{SM} bulk milk fermented with *L. paracasei* strains during fermentation time and cold storage.

| Strain | Fermentation Time (h) | | | | | | | | | | | | Cold Storage (Day) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------|-----------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|--------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|--------------------|--------------------|------------------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|------|--------------------|
| | 0 | | 3 | | 6 | | 9 | | 24 | | 15 | | 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FS109 | HC _{SM} | 0.21 ^{aA} | 0.01 | LC _{SM} | 0.21 ^{aA} | 0.03 | HC _{SM} | 0.25 ^{aA} | 0.01 | LC _{SM} | 0.22 ^{aA} | 0.05 | HC _{SM} | 0.26 ^{aA} | 0.03 | LC _{SM} | 0.25 ^{aA} | 0.01 | HC _{SM} | 0.30 ^{aA} | 0.09 | LC _{SM} | 0.31 ^{aA} | 0.07 | HC _{SM} | 0.97 ^{aB} | 0.13 | LC _{SM} | 0.90 ^{aB} | 0.09 | HC _{SM} | 1.13 ^{aC} | 0.11 | LC _{SM} | 1.20 ^{aC} | 0.18 | HC _{SM} | 1.37 ^{aB} | 0.32 | LC _{SM} | 1.43 ^{aB} | 0.13 | | | | | | | | | | | | | |
| | CF4 | 0.19 ^{aA} | 0.01 | 0.20 ^{aA} | 0.02 | 0.21 ^{aA} | 0.03 | 0.20 ^{aA} | 0.03 | 0.21 ^{aA} | 0.02 | 0.23 ^{aA} | 0.10 | 0.24 ^{aA} | 0.02 | 0.23 ^{aA} | 0.02 | 0.22 ^{aA} | 0.01 | 0.21 ^{aA} | 0.08 | 0.33 ^{aA} | 0.08 | 0.28 ^{aA} | 0.01 | 0.70 ^{aA} | 0.11 | 0.73 ^{aA} | 0.33 | 3.93 ^{aT} | 0.18 ^{aA} | 0.02 | 0.18 ^{aA} | 0.02 | 0.21 ^{aA} | 0.03 | 0.23 ^{aA} | 0.01 | 0.21 ^{aA} | 0.02 | 0.24 ^{aA} | 0.03 | 0.23 ^{aA} | 0.02 | 0.25 ^{aA} | 0.08 | 0.28 ^{aA} | 0.02 | 0.50 ^{aB} | 0.03 | 0.52 ^{aB} | 0.21 | 0.67 ^{aA} | 0.17 | 0.58 ^{aA} |

HC_{SM} and LC_{SM}, goat milk with high and low casein CSN1S1 genotype, respectively; Different superscript lower case (a, b, c) letters on the same row indicate significant differences ($p < 0.05$) between HC_{SM} and LC_{SM}; different superscript upper case (A, B, C) letters on the same column and or each time indicate significant differences ($p < 0.05$) between *L. paracasei* strains.

3.3.2. Viable Count *Lactobacillus Paracasei* Strains

Microbial analysis (Table 5) showed that in the first 6 h of fermentation, *L. paracasei* FS109 and ATCC 393^T strains reached a viable count of 7 log CFU/mL, while lower count was observed for *L. paracasei* CF4 (of about 1 log CFU/mL). In this first part of fermentation, any differences in the *L. paracasei* strains counts were revealed between HC_sM and LC_sM milk, while *L. paracasei* CF4 at 9 h and *L. paracasei* ATCC 393^T count at 24 h were higher ($p < 0.05$) in LC_sM than HC_sM. However, after 24 h of fermentation, *L. paracasei* FS109 count reached a value significantly higher (>8.5 log CFU/mL) than the other two strains tested. During the first 15 days of storage, all lactobacilli counts increased about 1 log and remained quite constant until 30 days of storage, evidencing low mortality during incubation at 5 °C. At 15 days and 30 days, the viable counts were higher in HC_sM milk fermented with *L. paracasei* FS109 and *L. paracasei* CF4 ($p < 0.05$), whilst the opposite behavior was observed for *L. paracasei* ATCC 393^T. These results suggest that the genetic polymorphisms in CSN1S1 did not affect the growth of lactobacilli during fermentation and their viability during cold storage. However, it is interesting to underline that *L. paracasei* FS109 counts were always higher than those of the other two lactobacilli tested and that the high number (>9 log CFU/mL) at 30 days of cold storage has been detained.

Table 5. Growth kinetic (log CFU/ml) of *L. paracasei* strains in HCsm and LCsm milk during fermentation and cold storage.

| Strain | Fermentation Time (h) | | | | | | | | | | | | Cold Storage (Day) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------------|-----------------------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|--------------------|--------------------|--------------------|--------------------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|--------------------|--------------------|--------------------|------|--------------------|------|------|--------------------|------|
| | 0 | | | 3 | | | 6 | | | 9 | | | 24 | | | 15 | | 30 | | | | | | | | | | | | | | | | | | | | | | | | |
| FS109 | HCsm | 5.75 ^{aA} | 0.14 | LCsm | 5.89 ^{aA} | 0.09 | HCsm | 6.54 ^{aA} | 0.02 | LCsm | 6.39 ^{aA} | 0.17 | HCsm | 7.14 ^{aB} | 0.02 | LCsm | 7.08 ^{aB} | 0.06 | HCsm | 7.34 ^{aB} | 0.36 | LCsm | 7.43 ^{aB} | 0.17 | HCsm | 8.57 ^{aC} | 0.06 | LCsm | 8.78 ^{aC} | 0.07 | HCsm | 9.48 ^{aC} | 0.31 | LCsm | 9.33 ^{aB} | 0.20 | HCsm | 9.30 ^{bC} | 0.08 | LCsm | 9.06 ^{aB} | 0.10 |
| | CF4 | 5.80 ^{aA} | 0.12 | 5.79 ^{aA} | 0.13 | 6.19 ^{aB} | 0.16 | 6.07 ^{aA} | 0.10 | 6.46 ^{aA} | 0.11 | 6.40 ^{aA} | 0.05 | 6.68 ^{aA} | 0.07 | 7.35 ^{bB} | 0.19 | 7.93 ^{aB} | 0.19 | 7.85 ^{aA} | 0.06 | 8.55 ^{aB} | 0.05 | 8.29 ^{aA} | 0.04 | 8.24 ^{aA} | 0.08 | 8.22 ^{aA} | 0.05 | 8.46 ^{bA} | 0.02 | 8.44 ^{aA} | 0.01 | 8.44 ^{aA} | 0.01 | 8.44 ^{aA} | 0.01 | 8.44 ^{aA} | 0.01 | | | |
| 393 [†] | HCsm | 5.93 ^{aA} | 0.06 | LCsm | 5.97 ^{aA} | 0.15 | HCsm | 6.58 ^{bA} | 0.10 | LCsm | 6.24 ^{aA} | 0.12 | HCsm | 7.06 ^{aB} | 0.20 | LCsm | 7.18 ^{aB} | 0.26 | HCsm | 6.98 ^{aB} | 0.01 | LCsm | 6.95 ^{aA} | 0.02 | HCsm | 7.65 ^{aA} | 0.06 | LCsm | 7.98 ^{bA} | 0.07 | HCsm | 8.30 ^{aA} | 0.04 | LCsm | 8.24 ^{aA} | 0.08 | HCsm | 8.22 ^{aA} | 0.05 | LCsm | 8.46 ^{bA} | 0.02 |

HCsm and LCsm, goat milk with high and low casein CSN1S1 genotype, respectively; different superscript lower case (a, b, c) letters on the same row indicate significant differences ($p < 0.05$) between HCsm and LCsm; different superscript upper case (A, B, C) letters on the same column and or each time indicate significant differences ($p < 0.05$) between *L. paracasei* strains.

4. Discussion

The composition of bulk milk did not evidence any difference in milk protein content in the group with high compared with low CSN1S1 genotype. By contrast, previous research reported a higher protein content in the milk of animals with a strong rather than weak genotype [25,26]. However, the similar content in protein could be partly explained by the lower milk yield of the low group at the sampling date, which may have caused a concentration of protein fraction. The differences in milk yield suggest greater intake of nutrient from goats of high genotype compared to low, during grazing activity. This is supported by previous observations [27,28], where goats with strong alleles evidenced greater intake and a superior diet efficiency than animal with low casein.

Strains of *L. paracasei* are isolated from various ecological niches, such as plant, milk, and animal gut, and are largely applied as starter cultures in the dairy industry. Some *L. paracasei* strains are highly valued for their probiotic properties being able to improve clinical outcomes [29].

In this study, low adhesion ability to intestinal epithelium cell lines was detected for the *L. paracasei* FS109 strain, but in some cases, in vitro experiments for adherence ability of strains have limited predictability for the real in vivo situation [30]. Regarding immunomodulation, FS109 strain was capable of decreasing iNOS expression, exhibiting the best antioxidant properties. iNOS produces large amounts of nitric oxide (NO), one of the most important signaling molecules in inflammation [31].

In order to select a starter suitable to fermented milk production, technological evaluation of strain includes the acidifying activity as well as the ability to survive during the storage of the product. Overall, this study revealed that different genetic polymorphisms in CSN1S1 of goat milk fermented by *L. paracasei* FS109 did not affect both abovementioned technological parameters, whereas significant differences between strains have been found. The selected *L. paracasei* FS109 showed higher acidifying activity compared to the other lactobacilli strains tested. The low pH value reached at the end of fermentation is considered optimal, as it makes the substrate unsuitable for the growth of spoilage and/or pathogenic microorganisms [32]. More generally, an adequate acidification during fermented milk production can positively affect the rheological and sensory properties of the final product [33]. Moreover, the high viable count determined at 24 h of fermentation, independently from milk polymorphisms of CSN1S1, highlights a remarkable adaptability of *L. paracasei* FS109 to both substrates.

The same strain has also led to a further increase of the acidity level during cold storage, due to post-acidification, which occurs from the continuous production of organic acid by the added starter. Post-acidification can affect the growth and viability of starter and/or probiotic microorganisms and consequently reduce the health benefit of milk fermented product [34]. For instance, in yogurt added with probiotics, *L. acidophilus* strain counts decreased, maintaining the minimum concentration for a beneficial effect only until 3 weeks of storage, as reported by Damin et al. [35].

In this study, although pH value of fermented milk further decreases (about 3.7) during storage, a high viable number of *L. paracasei* FS109 (about 9 log CFU/mL) throughout the 30 days of storage was observed. These data confirmed the results of previous research [15], where the same *L. paracasei* strain showed a high acid tolerance after 3 h of incubation in the synthetic medium at pH 2.5.

The ability of *L. paracasei* FS109 strain to resist acid stress leads us to suppose that it could withstand the acidic conditions of the stomach, the first barrier that a probiotic microorganism must overcome to exert a health effect [36]. In addition, our strains could be a potential in vivo colonizer as suggested by Wang et al. [37] for *L. paracasei* FM-LP-4, a strain able to resist under the same in vitro conditions (pH 2.5 per 3 h).

No specific information is available in fermented goat milk, but in cow milk, a strong influence of genetic variant of milk protein was evidenced on the fermentative ability with the yoghurt culture [38], indicating that fermentation tests together with milk proteins genotype could contribute to improving nutritional values of fermented milk and highlight new perspectives in dairy goat production system.

5. Conclusions

An appropriate selection of the type of milk and the culture starter used could be a potential strategy to produce fermented milk with added nutritional value. The present study shows that milk with a low CSN1S1 genotype is suitable to produce fermented milk product. *L. paracasei* FS109 strain evidenced features to be a beneficial culture starter. Finally, combining the positive characteristics of both CSN1S1 genotype goat milk and a selected *L. paracasei* strains can be a good strategy for improving the traditional and functional fermented milk market.

Author Contributions: N.P.M. and A.N. conceived the experimental design; G.Z., R.A., I.K., D.S., and L.S. performed strains probiotic characterization; E.T. conceived the probiotic experimental design; A.N. performed the identification of experimental animals, based on their genotype; S.C. performed genotypic characterization of casein variants; N.P.M. and L.S. performed all microbiological analysis; N.P.M. and A.N. drafted the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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