Utilization of two plant polysaccharides to improve fresh goat milk cheese: Texture, rheological properties, and microstructure characterization

Weizhe Wang,1 Rong Jia,1 Yuanyuan Hui,1 Fuxin Zhang,1 Lei Zhang,2 Yufang Liu,1 Yuxuan Song,2* and Bini Wang1*

1College of Food Engineering and Nutritional Science, Shaanxi Normal University, Xi’an, Shaanxi 710119, China
2College of Animal Science and Technology, Northwest A&F University, Yangling 712100, China

ABSTRACT

This study aimed to evaluate the effects of added jujube polysaccharide (JP) and Lycium barbarum polysaccharide (LBP) on the texture, rheological properties, and microstructure of goat milk cheese. Seven groups of fresh goat milk cheese were produced with 4 levels (0, 0.2, 0.6, and 1%, wt/wt) of JP and LBP. The goat milk cheese containing 1% JP showed the highest water-holding capacity, hardness, and the strongest rheological properties by creating a denser and more stable casein network structure. In addition, the yield of goat milk cheese was substantially improved as a result of JP incorporation. Cheeses containing LBP expressed lower fat content, higher moisture, and softer texture compared with the control cheese. Fourier-transform infrared spectroscopy and low-field nuclear magnetic resonance analysis demonstrated that the addition of JP improved the stability of the secondary protein structure in cheese and significantly enhanced the binding capacity of the casein matrix to water molecules due to strengthened intermolecular interactions. The current research demonstrated the potential feasibility of modifying the texture of goat milk cheese by JP or LBP, available for developing tunable goat milk cheese to satisfy consumer preferences and production needs. Key words: goat milk cheese, plant polysaccharides, texture, microstructure

INTRODUCTION

Goat milk is traditionally accepted as a wholesome and nutritious dairy drink rich in protein, calcium, minerals, phosphorus, niacin, and thiamine (Csapóné Riskó and Csapó, 2019). Given the smaller size of fat globules and caseins, goat milk is easier to digest and absorb by the human body compared with bovine milk (Razali et al., 2021). As a collection of goat milk nutrients, goat milk cheese is a value-added and popular gel dairy product in the world. In Europe, nearly all goat milk is processed into cheese, accounting for 35% of the world’s goat milk cheese production (Sepe and Argüello, 2019). However, goat milk shows poorer coagulation properties than cow milk due to the low casein content, especially the low αS1-CN ratio (leading to weaker casein aggregation behavior during the second stage of rennet; Clark and Sherbon, 2000). Therefore, cheese processed with goat milk presents poor renneting kinetics, which means less hardness and more fragility. The underlying reasons for this situation are not fully understood, but it is commonly linked to the defective allele (such as a single nucleotide deletion in exon 12 of the gene encoding CSN1S1) in the goat (Skeie et al., 2014). In addition, hydration and mineral status (both concentration and distribution) in the soluble and colloidal phases also have an effect on the coagulation performance of goat milk (Zhao et al., 2014). With these drawbacks, cheese processed with goat milk suffers from less textural integrity, imposing an obstacle to the consumption experience and even yield of goat milk cheese (Hovjec et al., 2022).

During the past decades, the cheese industry has been continuously looking for available physical and chemical methods, including heat treatment (Miroladovic et al., 2017), high-pressure treatment (Delgado et al., 2012), and transglutaminase cross-linking (Ardelean et al., 2013) to achieve a satisfactory textural response of goat milk cheese. However, these treatments are either high in cost (such as heat and high-pressure treatment) or involve certain side effects on goat milk cheese such as protein hydrolyzing and yield loss (e.g., transglutaminase). There is a growing awareness that many of the textural properties of cheese are dictated by its structure. Goat milk cheese could be regarded as a gel food based on the casein network, in which fat, water, minerals, and bacteria are distributed (Rovira
et al., 2013). Its structural features are determined by the interactions and spatial arrangement among these components (Van Hekken et al., 2004).

In recent years, polysaccharides have been gaining more and more attention due to the potential to improve the structure and texture of protein-based gel food (Alavarse et al., 2022). Several “gelling” polysaccharides (carrageenan, gellan, xanthan, and so on) are typically used as stabilizers, thickeners, or gelling agents in dairy products (Ouyang et al., 2022a) for their combined advantage in biopolymer system (Yang et al., 2021). At the same time, the interactions of protein-polysaccharide are widely studied, which provides a theoretical basis for its application in the design of cheese formulations. In low-fat or skim cheese, polysaccharides are used as alternative fat to meet both textural experience and health demands (Felix da Silva et al., 2016). Dai et al. (2018) found that 0.5% (wt/wt) of Konjac glucomannan could improve the moisture and hardness of low-fat or skim cheese to be close to those of full-fat cheese. Similar observations were made in low-fat mozzarella cheese, and the stringiness of the cheese was increased when adding 1% of (wt/wt) xanthan gum slurry (Oberg et al., 2015). Macků et al. (2008) proposed that the cheese would be more rigid, be less spreadable, and have higher storage ($G'$) and loss ($G''$) moduli with increasing pectin content (from 0 to 0.8%, wt/wt). Mende et al. (2020) found that the coagulation time was reduced and the hardness was increased with the incorporation of dextran (1–3%, wt/wt) in cheese. Studies confirmed that some anionic polysaccharides could induce a harder and more resistant-to-failure texture by creating a stronger structure and a denser microstructure in cheese (Benjamin et al., 2018). Although there are many advantages to adding polysaccharides to cheese, very little attention has been paid to their uses in cheese production, let alone to the examination of their effects on cheese texture. To our knowledge, the utilization of JP and LBP to modify goat milk cheese has not been reported yet.

In this paper, 2 plant polysaccharides (JP and LBP) were first adapted to goat milk production in an attempt to acquire texture-adjustable goat milk cheese and improve the consumption experience. More specifically, 4 concentrations of JP and LBP were added to goat milk to manufacture fresh cheese. The textural properties, rheological behavior, and microstructure of the fresh goat milk cheeses were characterized to evaluate the relations between the addition of JP and LBP and cheese textural properties. Furthermore, Fourier-transform infrared (FTIR) and low-field nuclear magnetic resonance (LF-NMR) analyses were carried out to analyze the potential drivers for these effects.

**MATERIALS AND METHODS**

Because no human or animal subjects were used, this analysis did not require approval by an Institutional Animal Care and Use Committee or Institutional Review Board.

**Materials**

Fresh goat milk was obtained from a nearby dairy farm in Chang’an District (Xi’an, Shaanxi, China) on the day of cheese production. Milk pH was 6.62 ± 0.005, and chemical composition included 3.38 ± 0.02% wt for protein and 3.68 ± 0.05% wt for fat. Composition of goat milk is shown in Supplemental Table S1.
Cheese Polysaccharides and Lycium Polysaccharides were purchased from a local supplier (Shaanxi Jiahe Phytochem Co. Ltd.). Other chemicals and reagents included calcium chloride, mesophilic starter R-704 (Chr. Hansen), and calf rennet (Renco New Zealand) with an activity of 20,000 U/g⁻¹. All chemicals and reagents were of analytical grade. We used distilled water for the experiments.

**Cheese Manufacture**

On the day of cheese production, the bulk goat milk (chemically analyzed) obtained from the dairy farms was divided into 7 batches of 5 kg each for manufacturing cheese with different polysaccharides. Every batch of cheese was produced in triplicate.

The goat milk cheeses were made according to the method of Jia et al. (2021) with a few modifications. Cheese manufacture flow is shown in Supplemental Figure S1 (https://doi.org/10.6084/m9.figshare.22346965.v1; Wang, 2023b). Briefly, the raw milk was pasteurized at 63°C for 30 min and then cooled to 32°C. The JP and LBP were added to the goat milk at the following concentrations (wt/wt): 0% (control), 0.2% (JP 0.2%, LBP 0.2%), 0.6% (JP 0.6%, LBP 0.6%), and 1.0% (JP 1%, LBP 1%). After stirring for 10 min to mix well, 0.5 g of mesophilic starter was inoculated. After 1 h of fermentation at 32°C, 1 g of food-grade calcium chloride was added, and then a 0.25 g of calf rennet enzyme was added 5 min later. Next, the coagulation was cut into 1-cm³ cubes after 50 min and stirred for 10 min while the temperature was raised to 42°C (from 32°C) at a rate of 1°C/min⁻¹. Then, the cheese was removed to a cylindrical mold (15.6 cm diameter) and pressed (at 6.43 kg) for 3 h. Pressing temperature was maintained at 10°C using a thermostatic test chamber (CSH-250SD-C). At last, cheeses were divided into different pieces, vacuum-sealed in sterile polyethylene bags, and stored at 4°C for subsequent analysis. Cheese without polysaccharides was considered as the control sample. All analyses for cheese were carried out over 3 d after processing.

**Color Measurement**

The color of the fresh goat milk cheese was measured using a portable colorimeter (NS800). We recorded the redness (a*), yellowness (b*), and lightness (L*) values of the samples. The total color change (ΔE) was determined according to Ramírez-López and Vélez-Ruiz (2018). Three measurements were taken in different areas for each sample.

**Cheese Yields and Physicochemical Analysis**

The moisture, protein, and fat content in the cheese were analyzed according to AOAC International (1997) standards. Protein content was measured according to the Kjeldahl method and calculated using a conversion factor of 6.38. Fat content was measured by the Rose-Gottlieb method. The cheese moisture content was determined by heating them to a constant weight at 105°C. The pH was measured using a pH meter (632 pH meter, Metrohm). The yield was calculated using the following formula:

\[
yield = \frac{\text{cheese produced (g)}}{\text{goat milk used (g)} + \text{additives (g)}} \times 100.
\]

Taking into account the differences in moisture content between treatments, the yield of dry matter (YDM) was calculated using the following formula:

\[
YDM = \frac{Y(100 - MD)}{100},
\]

where MD is the moisture content of the cheese and Y is yield (Diamantino et al., 2014). The WHC was evaluated through centrifugation of 3-g samples at 3,000 × g for 20 min at room temperature (25°C) and determined using the following formula:

\[
\text{WHC} = \frac{W_0 - W_1}{W_1} \times 100,
\]

where \(W_0\) is serum separated after centrifugation and \(W_1\) is mass of cheese before centrifugation (Harte et al., 2003). Each sample was taken for analysis in triplicate.

**Cheese Texture Measurements: Texture Profile Analysis**

The cheese textural characteristics were analyzed by the TA.XT Plus Texture Analyzer. The unvacuumed packaged cheeses were cut into 20 × 20 × 15-mm rectangles before analysis. Samples were compressed twice to 30% of the original height by a stainless-steel cylindrical probe (diameter 36 mm) at a speed of 1 mm/s and the trigger force was set to 15 g. Hardness, cohesiveness, springiness, chewiness, and resilience were recorded according to the texture profile analysis indicators. For each cheese sample, 6 measurements were analyzed.

**Dynamic Rheological Properties**

The mechanical spectra of the cheese were recorded for the further effect of polysaccharides on cheese. The
small dynamic rheological properties of cheeses were determined using a stress-controlled rheometer (AR-G2). Cheese samples were cut into 40-mm diameter and 2-mm height to fit the rough-surfaced parallel plate (40-mm diameter) and the 2-mm space in the instrument. The low-density silicone oil was smeared onto the periphery of the cheese to prevent water from evaporating. A strain sweep (0.01–10%) was carried out from 0.01 to 100% deformation to determine the linear viscoelastic region (LVR) at 1 Hz and 25°C. The frequency sweep test was applied using 0.01 to 100 Hz at 25°C, and the strain applied was 0.05 (within the LVR). The frequency dependence of $G'$ and $G''$ were evaluated as follows using power-law equations:

$$G' = k'(f)^{n'},$$  
$$G'' = k''(f)^{n''},$$

where $k'$ and $k''$ coefficients are indicative of the viscoelastic behavior of the material, whereas the $n'$ and $n''$ values reflect the dependency of viscoelastic properties on the frequency variation.

**Cheese Microstructure Analysis**

**Scanning Electron Microscope Observations.** The cheese scanning electron microscopy (SEM) observation was carried out according to Soltani et al. (2016) with few modifications. The cheeses were diced into rectangular blocks of approximately $1 \times 1 \times 2$ mm and fixed in 2.5% glutaraldehyde in cacodylate buffer (pH 7.2) for 3 to 4 h at 4°C. After rinsing 3 times in cacodylate buffer, the samples were washed with buffer again and subjected to a dehydration cycle with a graded series of alcohol (10 min 50%, 10 min 70%, 10 min 80%, 10 min 90%, 10 min 95%, and 15 min 100% alcohol twice). Subsequently, the samples were extracted with chloroform for 2 h and post-fixed using 100% alcohol for 10 min, 100% ethanol and tert-butanol (1:1) for 6 min, and tert-butanol for 6 min. Then, the processed samples were dried by freeze-dryer (FDU 1200) and subsequently sputter-coated with gold to enable it conductive. The samples were photographed with 1,200× and 3,000× magnifications under a SEM (TM 3030) with a high voltage of 15 kV.

**Confocal Laser Scanning Microscopy Observations.** A confocal laser scanning microscopy (CLSM; FV 1200) was applied to analyze the microstructure of cheese. The cheese samples were cut to 20 μm using a freezing microtome (CM 1950), and then placed on a glass microscope slide, dyed with 2 mL of Nile Red (0.04 mg/mL in deionized water), which stained the oil phase, and 2 mL of fluorescein isothiocyanate (0.2 mg/mL in deionized water), which stained the protein. The dyed cheese sample was mounted on a glass slide, covered by a coverslip. After keeping the samples at 4°C for 12 h, the cheese sample was observed using the CLSM under the bright field and the fluorescence modes. Excitation was provided by an argon laser at 488 nm and a helium/neon laser at 633 nm with emission windows of 500 to 545 nm for fluorescein isothiocyanate and 570 to 625 nm for Nile Red (Yu et al., 2021). The final overlaid images were obtained from 2 different wavelengths at a 40× magnification objective.

**FTIR Analysis.** The FTIR spectra were measured using an infrared spectrometer (Tensor 27). The freeze-dried cheese samples were crushed and then pressed with KBr at a 1:150 ratio. Thirty scans were co-added at a normal resolution of 4 cm$^{-1}$ within a 4,000 to 400 cm$^{-1}$ region with OMNIC software (OMNIC). The atmospheric background was deducted automatically to minimize the disruption of the atmosphere during measurement. Each sample was analyzed in triplicate and the final results are presented as the mean spectrum. Furthermore, the secondary structure of cheese protein was analyzed according to the FTIR spectrum. To remove the interference of moisture and distinguish between the helix and random coil structures, the amide III spectra were selected to analyze the secondary protein structure. Data of the amide III spectra were pretreated according to Wang et al. (2011) by Peakfit (v4.12) software. We used the following criteria to identify the secondary structure corresponding to peaks in amide III: 1,290 to 1,330: α-helix, 1,220 to 1,250: β-sheet, 1,265 to 1,295: β-turn, 1,245 to 1,270: random coil (Cai and Singh, 1999).

**LF-NMR Analysis.** The spin-spin relaxation time ($T_2$) of cheese samples was measured using an nuclear magnetic resonance analyzing system (NMII20–025V) operating at 20 MHz. The magnetic field strength was 0.5 ± 0.03 tesla. The cheese samples (approximately 1.0 g) cut from the central part of the cheese were transferred into a 25-mm diameter nuclear magnetic tube. The $T_2$ was analyzed by Carr-Purcell-Meiboom-Gill sequence with 5,000 echoes and 4 scan repetitions. The simultaneous iterative reconstruction technique (SIRT) algorithm was used to invert the decay curve, and the resulting spectrum was normalized according to the weight of the sample (Khanal et al., 2018). All the measurements were performed in triplicate.

**Statistical Analysis**

The data were analyzed using SPSS software (version 17.0, SPSS Inc.). We used a one-way ANOVA to
RESULTS AND DISCUSSION

Cheese Appearance and Color

The appearance of cheese is a vital criterion attribute that affects consumer preference and even changes the consumer perception of flavor (Wadhwani and McMahon, 2012). The appearance and color parameters of fresh goat milk cheese at different concentrations of JP and LBP are presented in Figure 1 and Table 1, respectively. As shown, the incorporation of both JP and LBP had a remarkable effect on the $L^*$, $b^*$, and $a^*$ of goat milk cheese compared with control cheese. Most notably, the control goat milk cheese appeared milky white, whereas the red and yellow color of cheese increased with the concentration of polysaccharides used, as shown by a significant increase ($P < 0.01$) in both $a^*$ and $b^*$ values. Among them, cheese containing 1% LBP has the highest $a^*$ and $b^*$ of 3.93 and 21.71, respectively. According to visual observations, the cheese samples showed a deepening in brightness with an increasing level of JP or LBP, which corresponds to the low values of $L^*$. The reduction of $L^*$ was commonly related to the opaque gel structure formed by the aggregation of polysaccharides and proteins. As an indicator of the degree of color change, a higher $\Delta E$, indicating a greater change in cheese color, is considered to be obvious to the human eye when greater than 3 (Koca et al., 2011). The changes in $\Delta E$ values are consistent with visual observations; higher $\Delta E$ was found as the JP or LBP increased, which was more significant in cheese with added LBP (reaching 19.9 ± 0.19 at 1% LBP). These color changes depended more on the pigment in polysaccharides such as carotenoids, which occurred co-colored when a stable complex formed between polysaccharide and cheese matrix, affecting the appearance of goat milk cheese. According to the observations of appearance and color, JP and LBP were incorporated into cheese via interaction with components in goat milk cheese, and the darker the cheese is, the more polysaccharides it contains. For these changes in cheese color, consumer acceptance might depend more on individual preferences. A color that is too light or too dark will have an effect; for example, people in the United States prefer light-colored Gouda (Milovanovic et al., 2020), whereas yellow-orange Prato cheese is more popular in Brazil (Sobral et al., 2016). Therefore, a thorough sensory evaluation is needed to fully understand the various consumer acceptance levels for goat milk cheese with JP and LBP.

Cheese Yields and Physicochemical Properties

The yields and part of physicochemical properties of goat milk cheese fortified with different concentrations (0, 0.2, 0.6, or 1.0%) of JP or LBP are presented in Table 2. According to Table 2, the yield, moisture, protein, and fat demonstrated varied characteristics among the cheese samples. Yield is a crucial factor for cheese production, and the crude yield of goat milk cheese was significantly increased when incorporated with polysaccharides ($P < 0.05$), except for 1% LBP. The YDM for cheeses with JP significantly increased compared with control cheese ($P < 0.01$), especially at 0.6% concentration (reach 7.08%). The difference in yield was related mainly to the moisture retention of
cheese and the destabilization rate of goat milk protein during curdling (Pandey et al., 2000). Cheese with 0.6% JP seemed to destabilize casein more rapidly at a given renneting time, resulting in more casein micelle coalescence. More specifically, cheese yield is linked to coagulation (Vacca et al., 2020), and the polysaccharides might destabilize rennet-induced casein aggregate due to competition with rennet (Olsen, 1989) depending on the type and concentration of polysaccharides. When LBP was incorporated (especially at 1%), the rennet action seems to be limited, making the YDM impaired. Conversely, when the charge of polysaccharides is appropriate, more casein occurred in syneresis during the rearrangement of bonds between protein aggregates (Silva et al., 2021), and the yield increased as well. In addition, the level of carbohydrates in cheese also has an effect on the total composition and the yield due to the addition of polysaccharides, which needs further study to understand.

The moisture contents of cheeses with LBP were significantly increased compared with the control sample (P < 0.01), up to 53 to 54%. Instead, we found a reduction in the moisture content of cheese with high levels of JP (>0.2%) compared with the control sample, only 46.41% at 0.6% JP. Similar lower moisture levels were found in cheese with rennet gels containing konjac glucomannan, which was attributed to the higher rates of syneresis of the gels caused by the certain concentration of konjac glucomannan (Ouyang et al., 2022b). Another speculation is that this may be related to the hydrophobic micro-regions by hydrophobic groups of JP in the aqueous solutions. The formation of hydrophobic regions was based on intermolecular aggregations (Yang et al., 2019), depending on the polysaccharide concentration and structure (including chemical structures and conformational features). In addition, the carbohydrate level and mineral status in cheese with JP might also have an effect on moisture under the action of polysaccharides. More studies should be carried out to determine the cause. Meanwhile, the protein and fat content of cheese appeared to decrease with the addition of JP and LBP. In general, the lower protein concentration is often attributed to the high level of moisture caused by polysaccharides, which leads to a low DM concentration and causes a decrease in the concentration of protein and fat. However, we also found a

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Fat (%)</th>
<th>pH</th>
<th>WHC (%)</th>
<th>Yield (%)</th>
<th>YDM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>49.91 ± 1.07a</td>
<td>23.29 ± 0.03a</td>
<td>22.89 ± 2.71a</td>
<td>5.48 ± 0.09a</td>
<td>92.92 ± 2.07a</td>
<td>11.89 ± 0.10a</td>
<td>5.96 ± 0.13a</td>
</tr>
<tr>
<td>JP0.2%</td>
<td>50.87 ± 0.54b</td>
<td>21.76 ± 0.02c</td>
<td>20.63 ± 0.45ab</td>
<td>5.44 ± 0.05b</td>
<td>88.50 ± 2.65b</td>
<td>12.86 ± 0.11b</td>
<td>6.32 ± 0.07b</td>
</tr>
<tr>
<td>JP0.6%</td>
<td>46.41 ± 0.72d</td>
<td>21.66 ± 0.00b</td>
<td>20.02 ± 0.96abc</td>
<td>5.54 ± 0.02b</td>
<td>94.50 ± 0.78ab</td>
<td>13.21 ± 0.14a</td>
<td>7.08 ± 0.09a</td>
</tr>
<tr>
<td>JP1%</td>
<td>49.21 ± 0.78d</td>
<td>21.80 ± 0.01b</td>
<td>22.00 ± 0.47b</td>
<td>5.57 ± 0.01b</td>
<td>97.41 ± 1.81a</td>
<td>12.57 ± 0.12a</td>
<td>6.39 ± 0.10a</td>
</tr>
<tr>
<td>LBP0.2%</td>
<td>54.13 ± 0.41a</td>
<td>22.43 ± 0.06ab</td>
<td>16.37 ± 1.60cd</td>
<td>5.68 ± 0.02b</td>
<td>92.52 ± 0.82c</td>
<td>11.96 ± 0.15b</td>
<td>5.48 ± 0.05d</td>
</tr>
<tr>
<td>LBP0.6%</td>
<td>53.43 ± 0.47a</td>
<td>21.30 ± 0.004ab</td>
<td>15.18 ± 0.87a</td>
<td>5.32 ± 0.02b</td>
<td>94.61 ± 2.42ab</td>
<td>12.62 ± 0.18a</td>
<td>5.88 ± 0.06c</td>
</tr>
<tr>
<td>LBP1%</td>
<td>54.59 ± 0.09a</td>
<td>22.21 ± 0.001ab</td>
<td>15.54 ± 0.36cd</td>
<td>5.31 ± 0.04b</td>
<td>86.21 ± 1.95a</td>
<td>11.82 ± 0.20a</td>
<td>5.37 ± 0.01d</td>
</tr>
</tbody>
</table>

a–d Mean values with different superscript letters in a column differ significantly (P < 0.05).

Table 1. Color of fresh goat milk cheese with different concentrations of jujube polysaccharide (JP) and Lycium barbarum polysaccharide (LBP)1

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>∆E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>93.66 ± 0.36a</td>
<td>−1.47 ± 0.05f</td>
<td>9.19 ± 0.05f</td>
<td>—</td>
</tr>
<tr>
<td>JP0.2%</td>
<td>92.17 ± 0.05b</td>
<td>−0.69 ± 0.01e</td>
<td>10.75 ± 0.15e</td>
<td>2.5 ± 0.17i</td>
</tr>
<tr>
<td>JP0.6%</td>
<td>90.47 ± 0.07f</td>
<td>0.86 ± 0.02d</td>
<td>11.56 ± 0.11d</td>
<td>4.77 ± 0.10e</td>
</tr>
<tr>
<td>JP1%</td>
<td>88.53 ± 0.02c</td>
<td>1.6 ± 0.01c</td>
<td>13.32 ± 0.04c</td>
<td>7.59 ± 0.04c</td>
</tr>
<tr>
<td>LBP0.2%</td>
<td>89.87 ± 0.22a</td>
<td>0.89 ± 0.04d</td>
<td>12.55 ± 0.23d</td>
<td>5.95 ± 0.33d</td>
</tr>
<tr>
<td>LBP0.6%</td>
<td>85.74 ± 0.04e</td>
<td>2.51 ± 0.02d</td>
<td>17.68 ± 0.09b</td>
<td>13.32 ± 0.10b</td>
</tr>
<tr>
<td>LBP1%</td>
<td>81.27 ± 0.11e</td>
<td>3.93 ± 0.03a</td>
<td>21.71 ± 0.17b</td>
<td>19.9 ± 0.19a</td>
</tr>
</tbody>
</table>

a–g Mean values with different superscript letters in a column differ significantly (P < 0.05).

1JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP. All values are mean ± SD (n = 3).

2L* = lightness; a* = redness; b* = yellowness; ∆E = total color change.
significant reduction in protein content in cheeses with lower moisture content such as cheese with 0.6% JP ($P < 0.05$). Correspondingly, Kim and Kang (2015) found the addition of 0.8% solution of carboxymethylchitosan (1% wt/vol) neither improved yield nor whey protein retention of cheese, which was attributed to the weakening in polysaccharide-protein binding capacity at critical concentration. Moreover, the transferring of protein and fat in cheese was controlled by the syneresis process involving curd fusion during shaping and pressing (Dejmek and Walstra, 2004). It seems that more fat in LBP cheese enters into the whey compared with JP cheese (as shown in Supplemental Table S2, https://doi.org/10.6084/m9.figshare.22346956.v1; Wang, 2023c), which leads to a major reduction in the fat content of LBP cheese. Therefore, in the presence of polysaccharides, the rearrangement and movement of casein and fat determined whether they are retained in the cheese matrix or discharged into the whey, and further study is needed to understand this change.

Additionally, the WHC of goat milk cheese significantly increased with increasing JP concentration, whereas the WHC of cheese with 1% LBP decreased significantly ($P < 0.05$) compared with the control cheese. It was reported that polysaccharides had a certain ability to enclose water and reduce syneresis by their long backbone, which depends mainly on their molecular weight, branching degree, and polarity (Gannasin et al., 2012). Therefore, the difference in WHC was partly affected by the water retention capacity of the JP and LBP themselves. However, the ability of the cheese to absorb water was determined ultimately by the hydrophobic interactions maintained by the 3-dimensional casein network due to the limited water entrapped by polysaccharides. Thus, the highest WHC of cheese with 1% JP might be associated with the enhanced capacity in forming the casein network.

As for pH, most goat milk cheese samples remained at 5.3 to 5.5. In general, cheeses with higher moisture content (cheese with 0.6 and 1% LBP) tended to have lower pH, but the cheese with 0.2% LBP showed the highest pH (up to 5.68) among cheese samples. This might be attributed to the subsequent fermentation of lactic acid bacteria inhibited by additions (Li et al., 2019). However, higher pH might be linked to the lower H$^+$ concentration resulting from electrostatic interaction between polysaccharides and protein in the cheese system, which requires further study.

**Cheese Textural Properties: Texture Profile Analysis**

As shown in Table 3, we observed significantly poor hardness values for the cheeses with higher moisture (cheese with added LBP) compared with the control cheese, which suggests softer cheeses. Dey et al. (2020) found the comparable weakening in hardness of polysaccharide-added paneer and attributed it to the adequate entrainment of polysaccharides in the cheese matrix. Another reason for this decrease in hardness was the lower fat content, which could stabilize the gel network as a filler component. It is worth noting that cheese containing 1% JP had significantly higher hardness, gumminess, and chewiness values than other cheese samples ($P < 0.05$). It is reported that the rigid structure formed by casein in cheese plays a determining role in cheese texture (Lamichhane et al., 2018), which seemed to be enhanced by 1% JP.

As for springiness, cheese containing LBP and 1% JP showed higher springiness compared with the control cheese but no statistically significant difference was observed. In addition, all cheeses samples with JP or LBP demonstrated significantly lower cohesiveness and resilience compared with the control cheeses ($P < 0.05$). Such declines were reported as less relative casein concentration and a low fat/protein ratio, leading to a fragile structure in goat milk cheese (Hesarinejad et al., 2021; Amiri et al., 2022). However, we still found a significant drop in cohesiveness and resilience, even
in cheeses with a high fat/protein ratio (1.01 in cheese containing 1% JP) compared with control cheese. This phenomenon may occur due to structural inconsistencies when creating a new protein network (Shan et al., 2020). Therefore, the key could be the formation of a compact and ordering casein network during the interaction between JP or LBP and proteins to make cheese more resistant to fracture, considering the similar type of interactions between JP or LBP and casein matrix (mainly electrostatic, accompanied by hydrogen bonds and hydrophobic interactions; Černíková et al., 2008; Corredig et al., 2011). According to texture profile analysis results, 1% JP performed better in keeping goat milk cheese resistant to solid deformation and giving it firmness.

**Dynamic Rheological Behavior**

Dynamic rheological tests based on molecular and microstructural considerations contribute to our understanding of the texture differences (Rogers et al., 2009). Fresh goat milk cheese could be described as a bicontinuous protein gel interspersed with localized domains of fat and water (which act as lubricants). The rheological properties of cheese will be affected by the interactions between the polymers when mixed with polysaccharides.

Small dynamic oscillatory tests were carried out to evaluate the mechanical properties of goat milk cheese at different levels of JP and LBP. Strain sweep and frequency sweep measurements of fresh goat cheese affected by JP and LBP are shown in Figure 2. The storage modulus (G‘) is used to describe the ability of the gel to recover its original state from deformation, whereas the loss modulus (G″) represents the energy lost against viscous resistance (Feng et al., 2020). As shown in strain sweep (Figure 2a), goat milk cheeses containing 1% JP and 0.6% LBP had higher storage modulus (G‘) compared with other samples, which suggested a stronger elastic behavior in interconnected network structures than other cheese samples. This change was related to the favorable integrity of the cheese structure and, more specifically, related to the increased amount of present intact protein (Moghiseh et al., 2021). In addition, all the LVR of goat milk cheeses were extended toward higher strain values with increased concentrations of JP and LBP, suggesting that deformation is less likely to occur at a lower force. It is worth noting that cheese with 1% LBP appeared to have the longest LVR among cheese samples. On the one hand, the extended LVR region of cheese samples was attributed mainly to the formation of stronger casein network structures, which demonstrates enhanced structural stability of the viscoelastic solid. On the other hand, it is accepted that the more fluid the gel is, the longer its LVR is for viscoelastic fluid. When strain scanning, the water in the cheese (especially cheese with high moisture content and poor water retention) tends to seep out to the surface, which may cause the cheese to exhibit certain fluid characteristics while expressing a viscoelastic solid. Therefore, the larger LVR region in cheese with 1% LBP was possibly related to the high moisture content and low WHC, which needs further analysis to understand.

The G‘ and the G″ changes during increasing frequency for goat milk cheese samples with or without polysaccharides are presented in Figure 2b and 2c. All cheese samples showed an increasing G‘ and G″ with increasing frequency, and higher G‘ than G″, suggesting a predominance of the elastic behavior in cheese. Interestingly, cheeses with JP and LBP demonstrated a different concentration-dependent behavior in the frequency sweep. The G‘ and G″ of goat milk cheese increased significantly with the increasing JP concentration and reached the highest value at 1% JP. Apparently, the incorporation of 1% JP might produce a more intensive casein network to strengthen the elastic force of cheeses, which is partly consistent with the hardness and springiness results obtained by the texture profile analysis analyses given above. On the contrary, cheese containing 1% LBP exhibited a poor value of modulus, which was suggested as a destructive effect on gel formation at a relatively high LBP concentration. Previous studies associated this negative behavior simply with high water absorption of cheese and low protein content caused by polysaccharides (Alinovi and Mucchetti, 2020). Nevertheless, it is reasonable to believe that a fortified casein network structure played a determining role in contributing to the better mechanical properties of the cheese, which could improve the cheese quality and texture perception during eating (Fu and Nakamura, 2018).

The power-law equations allow us to better understand the relationship between the structure and frequency-dependent behavior in the goat milk cheese matrix. According to the parameters given by the power-law equations (Table 4), it can be seen that G‘ increased at a faster rate than G″ among all cheeses (k″ < k‘), in which JP1% had the highest values of k‘ and k″, indicating the formation of entangled polymer networks or physical gels (Tidona et al., 2021). However, both k‘ and k″ of the cheese were decreased compared with the control cheese except for 1% JP, which was associated with a lowering of the para-casein network and a reduction of cheese firmness or rheological elasticity as previously discussed. Moreover, cheeses, except for those with 0.2 and 1% LBP, showed a low-frequency dependence (n′ < 0.2), which is considered a high pseu-
doplastic gel with permanent covalent bonds (Sharma et al., 2016). It is worth mentioning that the value of $n'$ was significantly increased for cheese added JP and LBP compared with the control cheese ($P < 0.05$), implying a higher frequency dependence. This change is thought to be related to the discontinuous protein phase and extended serum phase of cheese (Song et al., 2022b), affecting the form and order of the cheese matrix structure, which requires further characterization to determine.

**Cheese Microstructure**

**SEM.** The application of SEM allows us to understand the changes in texture and rheological properties of goat milk cheese in visualization. Figure 3 shows the different microstructure of the fresh goat milk cheese in the absence and presence of JP or LBP. Most noticeably, large inhomogeneous protein aggregation was formed in cheeses with both 0.6% JP and 0.6% LBP, which is likely related to decreased electrostatic repulsion and increased hydrophobic interaction. The coacervates in the mixed system were driven by the charge density and the degree of charge neutrality between polysaccharides and casein micelles (Schmitt and Turgeon, 2011), depending on the types and concentrations of polysaccharides. That means higher charge neutrality and more electrostatic aggregation arose at this concentration level (0.6%), producing more aggregates in the cheese system (Klassen et al., 2011). The protein solubility was reduced by these aggregations, which might be an explanation for the increased YDM. As expected, the cheese containing 1% JP appeared to have the most intensive protein gel network and the
Table 4. Power law rheological parameters (k’ and k” coefficients indicate viscoelastic behavior; n’ and n” values reflect the dependency of viscoelastic properties on the frequency variation) of fresh goat milk cheeses with different concentrations of jujube polysaccharide (JP) and Lycium barbarum polysaccharide (LBP)1

<table>
<thead>
<tr>
<th>Sample</th>
<th>k’ (Pa)</th>
<th>n’</th>
<th>k” (Pa)</th>
<th>n”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>11,921 ± 142b</td>
<td>0.110 ± 0.004e</td>
<td>4,124 ± 46b</td>
<td>0.147 ± 0.0044</td>
</tr>
<tr>
<td>JP0.2%</td>
<td>6,885 ± 31c</td>
<td>0.172 ± 0.001d</td>
<td>2,341 ± 27c</td>
<td>0.185 ± 0.004d</td>
</tr>
<tr>
<td>JP0.6%</td>
<td>10,913 ± 49f</td>
<td>0.174 ± 0.002d</td>
<td>3,357 ± 39f</td>
<td>0.169 ± 0.004f</td>
</tr>
<tr>
<td>JP1%</td>
<td>46,926 ± 253a</td>
<td>0.163 ± 0.002d</td>
<td>14,651 ± 211a</td>
<td>0.182 ± 0.005b</td>
</tr>
<tr>
<td>LBP0.2%</td>
<td>5,853 ± 192f</td>
<td>0.252 ± 0.010b</td>
<td>1,887 ± 25e</td>
<td>0.188 ± 0.005b</td>
</tr>
<tr>
<td>LBP0.6%</td>
<td>8,149 ± 47f</td>
<td>0.187 ± 0.002f</td>
<td>2,495 ± 28d</td>
<td>0.170 ± 0.004f</td>
</tr>
<tr>
<td>LBP1%</td>
<td>5,758 ± 313f</td>
<td>0.310 ± 0.016c</td>
<td>2,063 ± 28f</td>
<td>0.199 ± 0.004a</td>
</tr>
</tbody>
</table>

*a–gMean values with different superscript letters within a column differ significantly (P < 0.05).
1JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP. All R² >0.996. All values are mean ± SD (n = 3).

Figure 3. Scanning electron microscopy images of fresh goat milk cheese microstructure with different concentrations of jujube polysaccharide (JP) and Lycium barbarum polysaccharide (LBP). The amplification level was set to 1,200× (A–G) and 3,000× (a–g). A, a (control); B, b (JP0.2%); C, c (JP0.6%); D, d (JP1%); E, e (LBP0.2%); F, f (LBP0.2%); G, g (LBP1%). JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP.
The smallest pores compared with other cheese samples. In a sense, this observation indicated a more intense interaction between the particles affected by 1% JP. In contrast, larger pores and coarse matrices were observed in cheese samples with 1% LBP, implying the loss of the casein network. According to Aminifar and Emam-Djome (2016), the generation of these large voids could be considered an inconsistent structure induced by the incorporation of charged polysaccharides into the protein network. These cavities in cheese were instead filled with the available water and fat to cover the vacancies in the casein structure.

As shown at a higher magnification (3,000×), a more fibrous and uniform structure was observed in cheese with 1% JP compared with other cheese samples. This phenomenon was regarded as a conversion from a more fractured casein network to a cross-linking state of cheese as JP concentration increased. Such positive changes in the cheese casein structure seemed to be the probable cause for the desirable textural and rheological properties described earlier. As for LBP, 1% LBP appeared to exceed the critical concentration, and cause the instability and phase separation of the cheese system, which is considered a reflection of the depletion flocculation mechanism (Bulut-Solak and O’Mahony, 2015). These observations revealed the existing segregated or associated casein micelles induced by JP or LBP in a real system of goat milk cheese. Likewise, the rigid structures in cheeses with 1% JP might also be associated with protein polymerization to an extreme degree during such phase equilibrium (Domagała et al., 2022). Thus, the relative phase concentrations of JP or LBP played an integral role in improving the casein structure of goat milk cheese.

**CLSM.** Confocal lasing scanning microscopy is widely used in studying food protein gel systems to obtain the microstructural information of multi-system gel food, which could assist in analyzing the texture and functional properties of cheese. The microstructures of fresh goat milk cheese affected by the JP or LBP are illustrated by the CLSM micrographs (Figure 4).

As shown in Figure 4, different states of fat (yellow) and pore space (black) are distributed over the protein matrices (green) in goat milk cheese. It can be observed that the fat globules were dispersed in the casein matrix randomly, presenting a regular spherical shape in the absence of polysaccharides. The coalescence of larger fat domains occurred when adding JP; however, large fat globules were difficult to observe as JP increased, which were replaced by a more dense and homogeneous casein matrix. This finding was in agreement with the observations by SEM. In addition, the density of the cheese casein gel network was enhanced with increasing JP concentration. Interestingly, the rearrangement of fat globules in cheese added LBP showed an opposite trend to cheeses with JP as the concentration increased. The fat globules in cheese containing 1% LBP coalesced into several large fat domains that partially occupied the holes. Such coalescence of fat was related to the movement of the fat globules, depending on the

Figure 4. Confocal laser scanning microscopy images of fresh goat milk cheese slices with different concentrations of jujube polysaccharide (JP) and *Lycium barbarum* polysaccharide (LBP) at 40× magnification. Fat is shown in yellow and protein in green. JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP.
formation rate of protein network structures during curdling (Ong et al., 2012). It was also reported that fat globule size is associated with the protein network strength in cheese (Feng et al., 2021). In cheese with 1% JP, structural casein aggregates were formed more quickly and with higher intensity, and more fat globules would not have sufficient time to coalesce, whereas the opposite was true in cheese containing 1% LBP. Correspondingly, these pores provided more space for fat to accumulate, shaping the different structured states of goat milk cheese. According to CLSM images, the aggressive rescheduling behavior in the goat milk cheese system (including casein, fat, and water) affected by 1% JP might play a critical role in the improvement of cheese structure and texture. It is widely associated with the large aggregation and solidification of cheese fat particles with an increase in fat content (Logan et al., 2017), which seems to be inconsistent with the lower fat content given above. However, it is easy to find that the stacking level and porosity of the cheese matrix differ despite the same thickness of the samples (20 μm). A large number of small fat domains might be embedded in the tighter structure of cheese with 1% JP, which are not merely those we observed. Therefore, 2-dimensional images present in CLSM were analyzed preliminary to determine the structural states (area, size, and so on) of goat milk cheese modified by JP and LBP, and other factors such as the volume of fat in the 3-dimensional network structure of cheese require comprehensive study to understand.

**FTIR Analysis.** In goat milk cheese, the structure of the casein matrix is maintained by a series of interactions such as electrostatic interactions (major interactions), hydrophobic interactions, and hydrogen bonds (Foegeding and Drake, 2007). The characteristic absorption peaks of fat and protein functional groups in FTIR spectra could reveal the possible changes in intermolecular interaction of goat milk cheese. The FTIR spectra of goat milk cheese with or without JP and LBP are shown in Figure 5. It can be found that 4 major adsorption peaks (at 3,450, 2,930, 2,850, and 1,740 cm$^{-1}$, respectively) occurred in the FTIR spectra. As reflected, a stronger vibrational peak occurred at 3,450 cm$^{-1}$ of cheese added polysaccharides compared with control cheese, except for cheese with 1% JP, which was attributed to the enhanced $-\text{OH}$ and $-\text{NH}$ stretching in protein. Yang et al. (2022) reported this change as a rightward shift of the peak at 3,500 cm$^{-1}$ due to more intermolecular hydrogen bonds. Thus, the hydrogen bonds involved in the complex formation might be weakened and stronger electrostatic interactions dominate in cheeses containing 1% JP compared

![Figure 5. Infrared spectra of fresh goat milk cheese with different concentrations of jujube polysaccharide (JP) and *Lycium barbarum* polysaccharide (LBP), using Fourier-transform infrared spectroscopy in the 4,000 cm$^{-1}$ to 400 cm$^{-1}$ range.](image-url)
with other polysaccharide-added cheese. In addition, the major absorption peaks that occurred at 2,930 and 2,850 cm\(^{-1}\) were related to \(\nu(\text{C–H})\) stretching vibrations of methyl (−CH\(_3\)) and methylene (−CH\(_2\)) groups in proteins and lipids (Ong et al., 2020). The absorption peak located at 1,740 cm\(^{-1}\) was correlated with the C=O stretching vibration of methylated and nonmethylated carboxyl (Tarapoulouzi et al., 2020). Among all cheeses, the intensity of these peaks was higher in presence of JP or LBP, which confirms the stronger interaction between them and the casein matrix.

The variation of amides I and II (1,590–1,690 cm\(^{-1}\)) in FT-IR spectra was associated mainly with different combinations of vibrations of −C=O and −NH, indicating different peptide bonds and the secondary structure of the protein in cheeses. As the foundation of protein structure, the secondary protein structures play an essential role in cheese structure and function. Preliminarily, the possible composition of secondary protein structures in the fresh goat milk cheeses was investigated using the amide III (1,220–1,330 cm\(^{-1}\)) bands.

The diverse content of α-helix, β-turn, β-sheet, and random coil structural conformation among cheeses proteins are shown in Figure 6. As the primary organized secondary structure, α-helix and β-sheet are increased in total (accounting for about 60%) when adding JP and 0.2% LBP, suggesting more stability in the cheese secondary protein structure (Song et al., 2022a). The level of β-sheet was significantly increased \((P = 0.04)\) in cheese added 1% JP compared with control cheese, which is associated with the folding of the protein. It reported that the formation of this folding might create a more ordered structure, giving different coagulation properties to the protein (Lancelot et al., 2021). Additionally, the cheese containing a 1% LBP had the highest content of random coil, indicating poor structural stability which may be due to the highly denatured. Cheese with added JP 1% contained a large number of β-sheet structures, which were linked to the structural basis for better protein gel (Gao et al., 2022). However, we detected a decrease in α-helix (from 28.57 to 19.11%) and an increase in random coil (from 10.21 to 23.41%) in cheese with 1% JP, which seems to be detrimental to structural stability. Similar results were reported in

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**Figure 6.** Estimated quantitation of the secondary protein structures of fresh goat milk cheese with different concentrations of jujube polysaccharide (JP) and *Lycium barbarum* polysaccharide (LBP) by amide III spectra in Fourier-transform infrared spectroscopy. JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP.
cheese treated with high-intensity ultrasound (Ragab et al., 2020). Such changes were interpreted as the unfolding of the protein, leading to the exposure of hydrophobic groups and weakening hydrogen bonds, followed by the α-helix break to the β-sheet and random coil (Guo et al., 2019). These transformations in cheese secondary protein structure further proved that the complexation of JP or LBP with casein is an extreme behavior affected by concentration, manifesting as the unification of ordered and disordered structures. At the same time, these conversions of secondary structure might be intrinsic to triggering changes in casein structure and textural properties of goat milk cheese.

**LF-NMR Analysis.** In the case of adding JP or LBP, the state of the water molecules dispersed in the casein matrix was affected by interactions between water and other macromolecules, contributing to the heterogeneity of cheese. The LF-NMR technique allowed us to evaluate the availability of water in cheese modified by JP and LBP. The water spin-spin relaxation times $T_2$ (0.1–1,000 ms) of fresh goat milk cheese with or without polysaccharides are shown in Figure 7. The values and time to peak of $T_2$ were considered to describe the dynamics of molecules in bulk and bound water fractions (Tomaszewska-Gras et al., 2019). According to reports, a shorter $T_2$ relaxation time implies more bound hydrogen protons or less freedom in the system, which appears the more leftward the peak on the $T_2$ spectrum (Luo et al., 2020). The delay of the first peak $T_{21}$ (0–1 ms) was observed in cheese with added JP or LBP, which could be attributed to the less bound water connected to the casein structure by a strong H-bond. As the main population of water present in fresh goat milk cheese, the third peak $T_{23}$ (20–235 ms) was related to immobilized water. As shown, the peak $T_{23}$ significantly shifted toward lower relaxation times as JP concentration increased, implying the JP, especially 1% JP, could increase the binding force of goat milk cheese matrix to water and reduce the degrees of freedom of water. Damez and Clerjon. (2008) believed that the more evident variation in $T_{23}$ indicates the higher stability of tight binding to the protein. Among all samples, cheese containing 0.2% LBP had a remarkably shorter $T_2$ relaxation time, indicating an increase in bound hydrogen protons and less free $H^+$ in the system, which could explain its high pH. In contrast, a significant increase in the absolute peak value and longer relaxation times ($T_{23}$) was observed as LBP concentration increased, which was attributed to more water with stronger mobility in the protein and lipids meshes (Tidona et al., 2021). The binding level of casein matrix to water in cheese was determined by

![Figure 7](image_url). The spin-spin relaxation time ($T_2$) curves of fresh goat milk cheese water with different concentrations of jujube polysaccharide (JP) and *Lycium barbarum* polysaccharide (LBP). JP0.2% = cheese with 0.2% JP; JP0.6% = cheese with 0.6% JP; JP1% = cheese with 1% JP; LBP0.2% = cheese with 0.2% LBP; LBP0.6% = cheese with 0.6% LBP; LBP1% = cheese with 1% LBP.
the concentration of JP and LBP, which is consistent with the results in WHC of cheese. In other words, it was JP or LBP that interfered with the binding of the cheese matrix with water, driving the changes of WHC, which affected the texture of goat milk cheese in turn. The process of such interaction needs further study for a better understanding due to the complexity of the multiphase components in the goat milk cheese system.

CONCLUSIONS

Our study demonstrated the textural, rheological, and microstructural properties of goat milk cheese were considerably altered by the JP and LBP, which is strongly dependent on their phase concentration. Cheese containing 1% JP presented the best characteristics of WHC, hardness, and rheology by creating a stronger and more stable network structure. Different molecular interactions between JP or LBP and goat milk cheese matrix lead to changes in protein conformational and moisture-binding capacity, which were the intrinsic dynamics for the corresponding modifications of the cheese texture. Overall, 0.6% JP also significantly increased the YDM of goat milk cheese. The inclusion of LBP produced softer goat milk cheese, which is owing mainly to the higher moisture content and fragile structures. Different molecular interactions between JP or LBP and goat milk cheese matrix lead to changes in protein conformational and moisture-binding capacity, which were the intrinsic dynamics for the corresponding modifications of the cheese texture. Overall, 1% JP showed great potential to improve the texture of goat milk cheese. Therefore, it is feasible to develop fresh goat milk cheese with improved texture and advanced rheological properties based on the role of JP and LBP in the goat milk cheese system, facilitating the development of the goat milk cheese industry.

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**ORCIDs**

Weizhe Wang  
https://orcid.org/0000-0001-5404-4154

Rong Jia  
https://orcid.org/0000-0002-0408-7487

Yuanyuan Hui  
https://orcid.org/0000-0002-8411-5205

Bini Wang  
https://orcid.org/0000-0002-4157-8795