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Effect of glucono delta lactone and potassium sorbate on the texture and stability of fresh goat milk cheese

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Abstract

This study investigated the impact of different concentrations of Glucono Delta Lactone (GDL) and the addition of potassium sorbate on the physicochemical and microbial properties, structure, and texture of cheese during a 28-day storage period. The results showed that higher concentrations of GDL led to increased acidity in the cheese, resulting in a softer and more hydrated texture. The addition of potassium sorbate effectively controlled microbial growth, reducing Total Plate Count (TPC) and extending the cheese's shelf life by up to 28 days. Texture analysis revealed that the samples with potassium sorbate had a better and more stable texture. GDL had concentration-dependent effects on cheese's adhesiveness, resilience, hardness, and cohesiveness. Fourier Transformed-Infra Red (FT-IR) analysis revealed shifts in the O-H, C-H, and C=O peaks, indicating that GDL caused changes in the cheese's chemical structure through acidification, while potassium sorbate contributed to stabilization by interacting with proteins and lipids. The combined analysis of yield percentages, moisture content, and color provides valuable insights for optimizing cheese production.

Keywords: Goat milk cheese, Glucono Delta Lactone (GDL), shelf-life, cheese yield, FT-IR, texture profile analysis

1. Introduction

Advancements in the industry have increased the popularity of dairy products worldwide. Goat milk, with its low casein percentage, promotes better digestion compared to cow milk [1]. Milk products make up a significant portion of liquid food intake in Malaysia [2]. Goat milk cheese, known for its taste and nutritional benefits, lacks hardness and coagulation efficiency. Glucono Delta Lactone (GDL) is a cost-effective additive used in cheese manufacturing to improve the texture of goat milk cheese by adjusting pH levels, enhancing milk coagulation, facilitating casein breakdown, promoting curd formation, and creating a softer cheese texture [3].

In light of these functions, this study hypothesized that different concentrations of GDL affect the pH, moisture content, and water activity of cheese, contributing to a variation in yield percentage and texture. Additionally, the presence of potassium sorbate extends the shelf life of cheese beyond 21 days. The interaction between GDL concentrations and potassium sorbate influences the quality, texture, and shelf life of the cheese.

Despite Goat milk's nutritional benefits, the impact of GDL and potassium sorbate on its cheese has not been thoroughly explored, particularly in terms of texture and preservation. Therefore, this study examines the effects of different concentrations of GDL and potassium sorbate on the physicochemical properties, yield, texture, and shelf life of goat milk cheese. FT-IR spectroscopy is used to identify the functional groups and molecular interactions in goat cheese samples with different levels of potassium sorbate and GDL. The findings seek to increase goat milk cheese's shelf life and quality, gain better knowledge of these elements, and help produce products that match customer expectations and industry requirements.

2. Materials and methods

2.1 Material

A farm in Semenyih, Selangor provided a total of 12 L of milk samples from the Saanen breed.

2.2 Cheese preparation from goat milk

The cheese-making process was followed by the procedures outlined by Djebli et al. [4], Altan et. al. [5], McMahon et al. [6], and Hamad [7]. A total of 12 L of milk was divided into eight portions of 1.5 L each to make cheese samples. The eight samples were then treated as shown in Table 1. The percentage addition was calculated on a w/w basis relative to the milk. Cheese was made by heating raw milk to 66 °C and cooling it to 35 °C. Every sample was treated with 3 g of calcium chloride and was stirred for one minute to ensure uniform dispersion. Next, 0.03 g of the starting culture was added to each sample and allowed to sit for 20 minutes to mature. After adding rennet for coagulation, each sample was then placed in a water bath at 38 °C for an hour. The cheese was cut into cubes by cutting it both horizontally and vertically. As shown in Table 1, GDL and potassium sorbate were given next. The treatment on each sample was sat for an hour in a 450-mL container. Curds from each sample were placed in a drainer to drain whey overnight. Each sample's whey and curds were weighted separately for yield calculation. Finally, cheese was submerged in 3% brine solutions in a 50-mL covered container at 4-5 °C for a month prior to shelf-life testing. Physicochemical, microbiological, and FT-IR tests were done during storage.

Table 1 Samples treated with different concentration of GDL and with/without addition of potassium sorbate.

No.	Sample	GDL conc. (%)	Potassium sorbate conc. (%)
1	Control XPS	0	0
2	XPS 0.5	0.5	0
3	XPS 1.0	1.0	0
4	XPS 1.5	1.5	0
5	Control PS	0	1.0
6	PS 0.5	0.5	1.0
7	PS 1.0	1.0	1.0
8	PS 1.5	1.5	1.0

CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbate. Notes: Conc. = concentration.

2.2.1 Physicochemical Properties Analyses

The physicochemical properties of the cheese samples were assessed for moisture content, water activity, pH, texture profile, and color. In all, there were around four analyses, performed weekly for a month or until deterioration started.

2.2.2 Moisture content

The moisture content of each sample was measured using a Moisture Analyzer (Metler Toledo), and an average of 5–7 g of the cheese samples was taken for the analysis.

2.2.3 Water Activity, (a_w)

Approximately 3 g of each cheese sample were taken for water activity measurement using a water activity meter (Aqualab) at 25 °C.

2.2.4 pH Value

The pH value of each cheese sample was measured using the Seven Excellence pH meter S400-Std-Kit (Mettler Toledo). The pH meter's electrode contacted the cheese sample to determine the pH value.

2.2.5 Color

Each sample's cheese color was measured with a chroma meter (Konica Minolta Spectrophotometer CR-400 Model, Osaka, Japan) after instrument calibration. Lightness (L), redness (a), and yellowness (b) were assessed. Cheese samples were put on white A4 paper. Triplicate measurements were taken per manufacturer directions.

2.2.6 Texture Profile Analysis (TPA)

Using a texture analyzer, TA XT Plus (Ametek Lloyd Instruments Ltd., UK), at room temperature, the texture of the fresh goat cheese samples was evaluated. For homogeneous and consistent samples, cylindrical samples with diameters and heights of 20 mm were taken from various spots throughout the cheese. The cheese cylinder was doubly compressed with a 35-mm cylindrical compression probe (P35) to determine its textural profile. A steady speed of 2.0 mms^{-1} with a contact strength of 5 g compressed the sample to 10 mm (50%) of its initial height.

2.2.7 Microbial analyses: Total Plate Count (TPC) and Yeast & Mold (Y&M)

Each cheese sample was microbiologically analyzed for shelf life using Yilmaz and Kurdal [8] methods. Microbiological tests include TPC and Y&M. For both studies, 10 g of each sample was stomacher-dissolved in 90 ml of peptone water to achieve a 1 in 10 dilution (solution 10^{-1}). Next, 1 ml from the 10^{-1} solution was transferred to a sterile 100 ml universal bottle (10^{-2} solution), followed by 1 ml from the 10^{-2} solution to another sterile 100 ml universal bottle. For TPC and Y&M tests, a milliliter of each dilution was poured and dispersed over Plate Count Agar and Potato Dextrose Agar with a hockey stick. Then, TPC and Y&M agar plates were cultured in the range of 24-48 hours at 37°C and 5-7 days at 25–30°C, respectively.

2.2.8 FT-IR Analysis: Molecular structure identification

The analysis was conducted on a Perkin Elmer Spectrum 100 with an ATR detector. The spectra were obtained at 4.00 cm^{-1} resolution with 16 scans per sample from 4000 to 650 cm^{-1}. The cheese's functional group was determined using %T (percent transmittance) scan units and varied sample formulations.

2.3 Statistical analysis

The dependent variables show one interaction's primary effect. A generalized linear model (GLM) was used to find significant differences in all the data. GDL, potassium sorbate, and storage were fixed variables and replication random effects in the statistical design. The Tukey multiple comparison test examined significant average mean differences. Differences among mean values were considered significant at $P < 0.05$. The results were presented as mean values with standard errors from three replications. Statistical analysis was performed using Minitab® version 18 (Minitab Inc., USA, 2017).

3. Results and Discussion

3.1 Physicochemical Properties

3.1.1 Yield

Table 2 illustrates the effect of varying concentrations of GDL (glucono delta-lactone) and the presence of potassium sorbate on cheese yield. The results showed significant yield percentage differences across samples. The CXPS and CPS samples with no GDL or potassium sorbate had the greatest yields. Yield decreased at 0.5% and 1.0% GDL, then increased slightly with 1.5% GDL. The results align with previous study conducted by Hamad [7], who found that adding GDL to cheese mixtures raises acidity, greater expulsion of whey from curds, and reduces cheese yield. The decrease in yield may be attributed to reduces both calcium and protein recovery in the cheese due to the progressive reduction in moisture and salt adjusted cheese yield with increasing pre-acidification [7, 9]. At higher concentrations (1.5% GDL, 1.5 XPS), yield increases slightly, suggesting a more acidified composition with improved moisture. Adding potassium sorbate was another influence. The yield increased slightly, similar to the group lacking potassium sorbate, which had 1.5% GDL concentrations. Other parameters, including milk composition, casein content and genetic diversity, cheese water retention, and pasteurization could also play a role in the variations in yield cheese yield [7].

Table 2 Yield percentage of each cheese sample.

Sample	Cheese Weight (g)	Whey Weight (g)	Total Weight (g)	Yield (%)
CXPS	292.60	852.80	11454.40	25.55^{AB}
XPS 0.5	217.00	930.20	1147.20	18.92^{B}
XPS 1.0	200.90	995.8	1196.70	16.79^{B}
XPS 1.5	215.90	902.10	1118.00	19.31^{B}
CPS	361.30	862.20	1223.50	29.53^{A}
PS 0.5	254.90	1005.70	1260.6	20.22^{AB}
PS 1.0	243.00	1056.20	1299.20	18.70^{AB}
PS 1.5	260.10	925.70	11858.8	21.93^{AB}

3.1.2 pH

The pH level in cheese, indicating its acidity or alkalinity, significantly influences its quality and characteristics. Maintaining the correct drainage pH is crucial during production, as it affects the cheese's physicochemical, texture, and microstructural properties, and influences chemical reactions in the curd. This will ultimately determine the final product’s quality [10]. Table 3 presents the pH values with and without potassium sorbate and different concentrations of GDL were measured over a period of 21-28 days. The results align with previous studies, showing that the pH value of cheese decreased during storage with CXPS samples starting at 4.82 and dropping to 3.90 by day 21, indicating increased microbial activity and metabolic changes [7, 11]. The most substantial decrease in pH occurred within the first 14 days, highlighting that this period as critical for acidity development in cheese. When GDL was absent from the cheese samples, the pH was at its highest. However, as GDL concentrations increased, the pH gradually decreased due to the synergistic hydrolysis of GDL, which enhanced both the initial gelation time and the rate of network creation, resulting in a rapid pH drop. Potassium sorbate showed slower pH decline and delayed spoilage compared to those without potassium sorbate

Table 3 pH of the cheese samples over 28 days of storage.

Samples	Storage Time (day)				
	0	7	14	21	28
CXPS	4.82 ± 0.02^{A}	4.31 ± 0.01^{B}	4.08 ± 0.01^{C}	3.90 ± 0.02^{D}	*Spoiled
XPS 0.5	4.47 ± 0.02^{A}	4.25 ± 0.01^{AB}	3.99 ± 0.02^{AB}	3.67 ± 0.02^{AB}	*Spoiled
XPS 1.0	4.35 ± 0.02^{A}	4.15 ± 0.01^{B}	3.89 ± 0.01^{B}	3.39 ± 0.02^{B}	*Spoiled
XPS 1.5	4.12 ± 0.02^{A}	3.96 ± 0.02^{B}	4.01 ± 0.01^{B}	3.67 ± 0.03^{B}	*Spoiled
CPS	4.75 ± 0.02^{A}	4.21 ± 0.01^{B}	4.05 ± 0.02^{C}	3.96 ± 0.02^{D}	3.43 ± 0.02^{E}
PS 0.5	4.51 ± 0.02^{A}	4.28 ± 0.02^{AB}	3.99 ± 0.02^{AB}	3.97 ± 0.02^{B}	3.77 ± 0.03^{AB}
PS 1.0	4.27 ± 0.02^{A}	4.23 ± 0.01^{B}	3.99 ± 0.02^{B}	3.79 ± 0.02^{B}	3.56 ± 0.02^{AB}
PS 1.5	4.17 ± 0.02^{A}	4.15 ± 0.03^{B}	4.01 ± 0.03^{B}	3.87 ± 0.02^{B}	3.47 ± 0.02^{AB}

3.1.3 Moisture Content

The data in Table 4 outlines the moisture content trends in cheese samples over different storage periods. The PS 0.5 sample's moisture content significantly decreased by the end of storage, indicating ongoing moisture loss from protein binding during ripening and water evaporation, as seen in Ras cheese [12]. The moisture content of the CPS sample started at 75.30 %, dropped to 58.92 % on day 21, and rose to 65.85% on day 28. As a result of GDL's ability to reduce calcium levels in cheese, adding it to cheese milk initially results in increased moisture content. Lower calcium levels result in a lower Ca-to-casein ratio, which hydrates casein to keep the cheese moist. Calcium ions stabilize the casein matrix, reducing water absorption. As GDL lowers calcium levels, it indirectly makes cheese more hydrated and softer, hence increasing the initial moisture content [13]. Without GDL, acidification slows, leaving the curd with less whey, resulting in increased cheese moisture retention and moisture content [7].

Table 4 Moisture content of cheese sample over 28 days of storage.

Samples	Storage Time (day)				
	0	7	14	21	28
CXPS	65.00 ± 0.20^{A}	64.33 ± 0.25^{AB}	59.65 ± 0.20^{B}	57.82 ± 0.26^{B}	*Spoiled
XPS 0.5	64.63 ± 0.25^{A}	60.54 ± 0.20^{AB}	55.76 ± 0.20^{B}	52.81 ± 0.20^{B}	*Spoiled
XPS 1.0	62.10 ± 0.23^{A}	59.87 ± 0.20^{AB}	59.23 ± 0.21^{B}	63.90 ± 0.26^{AB}	*Spoiled
XPS 1.5	64.77 ± 0.20^{A}	60.54 ± 0.21^{AB}	58.63 ± 0.21^{B}	66.57 ± 0.20^{AB}	*Spoiled
CPS	75.30 ± 0.20^{A}	69.40 ± 0.20^{AB}	61.90 ± 0.20^{B}	58.92 ± 0.20^{B}	65.85 ± 0.20^{AB}
PS 0.5	65.70 ± 0.20^{A}	62.8 ± 0.21^{AB}	55.78 ± 0.26^{B}	53.76 ± 0.20^{B}	51.50 ± 0.25^{B}
PS 1.0	63.13 ± 0.25^{A}	60.54 ± 0.20^{AB}	58.63 ± 0.23^{B}	59.40 ± 0.21^{AB}	60.78 ± 0.23^{AB}
PS 1.5	63.90 ± 0.20^{A}	60.78 ± 0.20^{B}	58.37 ± 0.21^{B}	54.30 ± 0.25^{B}	63.40 ± 0.20^{AB}

3.1.4 Water Activity, (a_w)

Table 5 reveals that most cheese samples' a_w increased throughout storage, demonstrating that storage days had a significant influence on a_w ($F = 12.48$, $p = 0.00$). Early a_w readings varied from 0.964 to 0.985, with the XPS 1.5 sample having the highest by day 21 and spoilage by day 28, suggesting greater a_w related to microbial development and deterioration. The PS samples in the group exhibited greater stability, with a_w values that fell below the spoilage threshold. The correlation between GDL content and a_w suggests that GDL may influence the water-binding properties of cheese matrices by keeping a_w below a certain critical level. GDL concentration has minimal impact on a_w, suggesting it modifies the flavor and texture rather than water binding. This will indirectly influence a_w by changing cheese composition, such as calcium content and protein structure [13]. Increases in a_w and moisture retention in cheese samples are predicted to accompany increases in GDL content.

Table 5 Water activity of the cheese samples over 28 days of storage.

Samples	Storage Time (day)				
	0	7	14	21	28
CXPS	0.966 ± 0.014^{B}	0.988 ± 0.003^{A}	0.990 ± 0.002^{A}	0.992 ± 0.001^{A}	*Spoiled
XPS 0.5	0.964 ± 0.027^{B}	0.986 ± 0.002^{A}	0.990 ± 0.002^{A}	0.993 ± 0.002^{A}	*Spoiled
XPS 1.0	0.969 ± 0.021^{B}	0.989 ± 0.004^{A}	0.990 ± 0.002^{A}	0.995 ± 0.004^{A}	*Spoiled
XPS 1.5	0.982 ± 0.014^{B}	0.989 ± 0.005^{A}	0.993 ± 0.004^{A}	0.998 ± 0.001^{A}	*Spoiled
CPS	0.984 ± 0.003^{B}	0.991 ± 0.002^{A}	0.992 ± 0.002^{A}	0.988 ± 0.004^{A}	0.991 ± 0.001^{A}
PS 0.5	0.982 ± 0.001^{B}	0.988 ± 0.002^{A}	0.984 ± 0.005^{A}	0.984 ± 0.001^{A}	0.985 ± 0.001^{A}
PS 1.0	0.984 ± 0.002^{B}	0.988 ± 0.002^{A}	0.988 ± 0.004^{A}	0.988 ± 0.005^{A}	0.989 ± 0.001^{A}
PS 1.5	0.985 ± 0.001^{B}	0.990 ± 0.003^{A}	0.986 ± 0.004^{A}	0.987 ± 0.003^{A}	0.987 ± 0.001^{A}

*Means that do not share letters are significantly different
*CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbate

3.1.5 Color

Cheese color varies depending on the type of milk used, maturation, and processing methods during ripening or storage [14]. Table 6 displays the color of cheese (L* for brightness, a* for green to red, and b* for blue to yellow). According to studies conducted by Jo et al. [15] on Gouda cheeses, the most popular color preferences among US customers fall within the 85 to 67 L* range. Initially, the lightness is highest for CXPS and lowest for CPS. Lightness changed greatly throughout time. Storage days ($p = 0.000$) and potassium sorbate ($p = 0.001$) significantly affected L* levels, but GDL concentration did not ($p = 0.538$). The cheese samples without potassium sorbate (XPS group) exhibited a higher L* than those with it. This suggests that the absence of potassium sorbate causes a lighter appearance and decreases lightness in the cheese samples. Lightness decreases over time, declining most before spoiling.

Cheese samples without potassium sorbate (XPS) shifted toward negative values (indicating greener colors) or minor positive changes after storage. The GDL concentrations had a less significant effect (p = 0.136), hence indicates that varying concentrations of GDL do not significantly alter the redness of the cheese. Compared to PS samples, XPS samples without potassium sorbate had higher b* values. The findings showed that storage days, GDL concentration, and potassium sorbate significantly affected yellowness values (p = 0.000, 0.012, and 0.000). GDL concentration significantly influenced yellowness, with higher yellowness observed in samples with a 0.5% GDL concentration and potassium sorbate. The samples without potassium sorbate (XPS) showed higher mean b* values, which affected yellowness. The addition of potassium sorbate reduced the cheese's yellow hue.

Table 6 Color parameters (L*, a*, and b*) of cheese samples over 28 days storage time.

Lab Colour	Samples	Storage Time (day)				
		0	7	14	21	28
L*	CXPS	69.06 ± 0.05^{B}	57.83 ± 2.58^{C}	73.05 ± 0.91^{A}	72.03 ± 0.21^{A}	*Spoiled
	XPS 0.5	67.92 ± 0.24^{B}	59.47 ± 1.79^{C}	73.23 ± 1.09^{A}	72.60 ± 0.10^{A}	*Spoiled
	XPS 1.0	67.98 ± 0.72^{B}	60.41 ± 1.61^{C}	72.94 ± 1.15^{A}	73.00 ± 0.10^{A}	*Spoiled
	XPS 1.5	66.71 ± 1.72^{B}	61.60 ± 3.22^{C}	77.13 ± 0.60^{A}	76.90 ± 0.10^{A}	*Spoiled
	CPS	63.79 ± 3.24^{B}	59.01 ± 1.27^{C}	72.31 ± 0.02^{A}	65.10 ± 0.10^{B}	65.51 ± 4.81
	PS 0.5	64.65 ± 0.71^{B}	60.28 ± 1.09^{C}	74.89 ± 0.02^{A}	64. 10 ± 0.10^{B}	64.18 ± 0.03
	PS 1.0	65.61 ± 0.07^{B}	59.56 ± 1.52^{C}	73.51 ± 0.03^{A}	64.50 ± 0.10^{B}	64.26 ± 0.10^{B}
	PS 1.5	65.61 ± 0.07^{B}	59.61 ± 1.90^{C}	72.56 ± 0.29^{A}	65.50 ± 0.10^{B}	65.52 ± 0.06^{B}
a*	CXPS	-0.21 ± 0.01^{A}	-0.01 ± 0.07^{A}	-0.82 ± 0.04^{B}	-0.78 ± 0.03^{B}	*Spoiled
	XPS 0.5	0.14 ± 0.02^{A}	0.25 ± 0.03^{A}	-0.75 ± 0.08^{B}	-0.72 ± 0.03^{B}	*Spoiled
	XPS 1.0	0.02 ± 0.03^{A}	0.12 ± 0.06^{A}	-0.58 ± 0.04^{B}	-0.57 ± 0.03^{B}	*Spoiled
	XPS 1.5	-0.03 ± 0.07^{A}	-0.16 ± 0.10^{A}	-1.03 ± 0.05^{B}	-0.99 ± 0.04^{B}	*Spoiled
	CPS	0.05 ± 0.13^{A}	0.31 ± 0.01^{A}	-0.67 ± 0.01^{B}	0.03 ± 0.03^{A}	-0.06 ± 0.18^{A}
	PS 0.5	0.47 ± 0.04^{A}	0.26 ± 0.03^{A}	-0.83 ± 0.03^{B}	0.08 ± 0.03^{A}	0.08 ± 0.01^{A}
	PS 1.0	0.31 ± 0.03^{A}	0.35 ± 0.03^{A}	-0.58 ± 0.02^{B}	0.28 ± 0.03^{A}	0.27 ± 0.03^{A}
	PS 1.5	0.26 ± 0.05^{A}	-0.57 ± 0.06^{B}	-0.02 ± 0.03^{A}	0.03 ± 0.01^{A}	0.26 ± 0.05^{A}
b*	CXPS	-0.21 ± 0.01^{A}	-0.01 ± 0.07^{A}	-0.82 ± 0.04^{B}	-0.78 ± 0.03^{B}	*Spoiled
	XPS 0.5	0.14 ± 0.02^{A}	0.25 ± 0.03^{A}	-0.75 ± 0.08^{B}	-0.72 ± 0.03^{B}	*Spoiled
	XPS 1.0	0.02 ± 0.03^{A}	0.12 ± 0.06^{A}	-0.58 ± 0.04^{B}	-0.57 ± 0.03^{B}	*Spoiled
	XPS 1.5	-0.03 ± 0.07^{A}	-0.16 ± 0.10^{A}	-1.03 ± 0.05^{B}	-0.99 ± 0.04^{B}	*Spoiled
	CPS	0.05 ± 0.13^{A}	0.31 ± 0.01^{A}	-0.67 ± 0.01^{B}	0.03 ± 0.03^{A}	-0.06 ± 0.18^{A}
	PS 0.5	0.47 ± 0.04^{A}	0.26 ± 0.03^{A}	-0.83 ± 0.03^{B}	0.08 ± 0.03^{A}	0.08 ± 0.01^{A}
	PS 1.0	0.31 ± 0.03^{A}	0.35 ± 0.03^{A}	-0.58 ± 0.02^{B}	0.28 ± 0.03^{A}	0.27 ± 0.03^{A}
	PS 1.5	0.26 ± 0.05^{A}	-0.57 ± 0.06^{B}	-0.02 ± 0.03^{A}	0.03 ± 0.01^{A}	0.26 ± 0.05^{A}

*Means that do not share letters are significantly different

*CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbate

GDL concentration significantly affected yellowness but had a minimal effect on lightness and redness. Potassium sorbate consistently reduces lightness and yellowness and stabilizes redness. Ismail et al. [13] discovered that GDL, pH, and cheese composition indirectly affect mozzarella cheese color stability. Acidity alters the structure and appearance of cheese proteins. GDL is an acidulant; therefore, adding more makes cheese yellower [13]. Storage days and potassium sorbate make cheese appealing, whereas GDL affects yellowness.

3.1.6 Textural Characteristics

Cheese's physical characteristics are mostly felt, and these are referred to as its texture. Ingredients, production procedures, and chemical composition (water, protein, fat, pH, and minerals) affect cheese texture [16].
Table 7 details the TPA components, including hardness, springiness, adhesiveness, cohesiveness, gumminess, chewiness, and resilience. When GDL raises acidity, it weakens the protein network and decreases hardness in goat cheese [7]. A reduction in GDL concentrations leads to a higher degree of cheese hardening over time, as seen by the significant increase in hardness in control compared to 0.5 XPS. Nevertheless, the hardness of XPS 1.0 and 1.5 diminishes. PS samples in both groups and its control lost hardness after 28 days. Due to moisture loss and proteolytic breakdown of the protein matrix, cheese softens with time [17]. Hardness is significantly impacted by potassium sorbate (P-value = 0.013, $p < 0.05$), while GDL and storage days had no influence except for PS group samples.

Springiness measures a cheese's bounciness by how effectively it recovers from compression. Because it contains a firmly cross-linked protein, beginning cheese is frequently more elastic [18]. The wide range of springiness in cheese samples suggests that formulations and storage conditions can greatly influence its texture and quality, affecting customer acceptance. Since it includes firmly cross-linked protein, initial cheese is usually more elastic [18]. Long-term storage can cause cheese to lose its stretchy properties due to metabolic changes and moisture loss. Although springiness changed, the general linear model showed no significant effect on GDL concentration, storage days, or potassium sorbate (P-values = 0.807, 0.699, and 0.329). GDL in milk cheese enhances its stickiness due to its softer, moist texture, resulting in a higher adhesiveness or tendency to stick to surfaces. Most experiments revealed that negative adhesiveness increased with age, making cheese stickier. Cheese becomes softer and stickier as GDL acidity damages the protein network [7]. Table 8 shows that XPS 1.5 was the stickiest sample from day 0 (-36.29, -71.85), confirming that GDL improves cheese stickiness.

Cohesiveness reflects how well cheese holds together under stress and affects the mouthfeel. Cheese with high cohesiveness stays together and appears smoother, whereas one with low cohesiveness crumbles [19]. In CXPS, cohesiveness increased, indicating better texture stability with decreased crumbliness. Despite slight decreases, XPS 0.5 cheese stays cohesive, showing outstanding texture stability. However, XPS 1.0 shows a minor loss in cohesiveness, indicating a decrease in texture stability, whereas XPS 1.5 has a slight improvement but is still low value and crumbles easily. The gumminess and chewiness of the cheese samples appear to follow a hardness-related trend. Over storage days, control XPS and XPS 0.5 were gummier and chewier. Both the PS and control groups showed consistent decreases in gumminess and chewiness. Meanwhile, the use of GDL softened and weakened the cheese due to increased acidity, further weakening the protein network, making cheese less firm and less likely to hold together [7].

Resilience investigates how GDL addition affects cheese's capacity to recover from deformation. With increasing storage days, resilience scores decline, with the most stable sample decreasing somewhat on day 28. Higher GDL concentrations reduce resilience, making cheese less springy. The study indicated that potassium sorbate substantially affects cheese texture, with PS group samples being more stable and better than XPS group samples. GDL had significant effects on adhesiveness, resilience, hardness, and cohesiveness, suggesting its role is concentration dependent. Table 8 depicts the texture changes in cheese samples between days 0–7 and 21–28.

Table 7 Texture profile of the cheese samples over 28 days storage time.

Sample/ Storage Days	Hardness			Springiness			Adhesiveness			Cohesiveness			Gumminess			Chewiness			Resilience		
	0	14	28	0	14	28	0	14	28	0	14	28	0	14	28	0	14	28	0	14	28
CXPS	513.01 ± 156.44	755.71 ± 150.40	*S	0.66 ± 0.15	0.83 ± 0.19	*S	-12.00 ± 8.00	-26.74 ± 11.48	*S	0.42 ± 0.06	0.47 ± 0.05	*S	207.64 ± 37.95	357.42 ± 38.81	*S	137.27 ± 42.07	296.40 ± 6.56	*S	0.16 ± 0.02	0.12 ± 0.01	*S
XPS 0.5	701.79 ± 330.83	1459.06 ± 297.87	*S	0.76 ± 0.07	0.77 ± 0.08	*S	-5.72 ± 4.41	-8.14 ± 5.37	*S	0.53 ± 0.07	0.49 ± 0.05	*S	374.42 ± 182.43	716.34 ± 209.18	*S	292.10 ± 158.47	550.25 ± 112.84	*S	0.24 ± 0.05	0.17 ± 0.03	*S
XPS 1.0	566.84 ± 42.09	470.59 ± 41.01	*S	0.70 ± 0.08	0.48 ± 0.04	*S	-19.57 ± 13.74	-31.01 ± 18.31	*S	0.40 ± 0.03	0.38 ± 0.03	*S	224.46 ± 0.09	177.32 ± 0.14	*S	156.36 ± 17.61	83.86 ± 5.11	*S	0.16 ± 0.01	0.13 ± 0.01	*S
XPS 1.5	385.39 ± 62.38	313.18 ± 61.18	*S	0.48 ± 0.04	0.78 ± 0.04	*S	-36.29 ± 21.65	-71.85 ± 29.75	*S	0.32 ± 0.04	0.33 ± 0.04	*S	122.42 ± 6.88	102.40 ± 5.32	*S	58.06 ± 2.71	80.31 ± 0.99	*S	0.13 ± 0.02	0.06 ± 0.01	*S
CPS	973.81 ± 407.41	924.92 ± 400.50	-42.29 ± 39.28	0.76 ± 0.04	0.66 ± 0.05	0.73 ± 0.15	-7.03 ± 9.31	-21.05 ± 17.27	-42.29 ± 39.28	0.57 ± 0.07	0.45 ± 0.06	0.460 ± 0.10	536.76 ± 151.98	420.08 ± 134.65	340.97 ± 142.70	409.57 ± 134.48	278.31 ± 85.37	260.31 ± 156.15	0.24 ± 0.07	0.16 ± 0.03	0.18 ± 0.06
PS 0.5	1173.23 ± 460.99	833.30 ± 400.12	-7.05 ± 1.48	0.78 ± 0.04	0.69 ± 0.03	0.67 ± 0.05	-8.45 ± 4.12	-1.27 ± 2.88	-7.05 ± 1.48	0.53 ± 0.08	0.52 ± 0.08	0.50 ± 0.03	629.71 ± 289.51	434.66 ± 302.10	536.84 ± 94.62	484.44 ± 201.09	292.99 ± 72.34	360.18 ± 92.07	0.25 ± 0.07	0.25 ± 0.03	0.23 ± 0.04
PS 1.0	1497.00 ± 419.48	1289.94 ± 416.85	-6.38 ± 1.16	0.82 ± 0.08	0.68 ± 0.04	0.75 ± 0.09	-4.50 ± 2.26	-3.15 ± 2.00	-6.38 ± 1.16	0.51 ± 0.07	0.52 ± 0.05	0.39 ± 0.01	773.87 ± 310.54	665.13 ± 300.21	481.09 ± 35.04	650.36 ± 308.11	453.67 ± 159.41	358.27 ± 14.87	0.25 ± 0.05	0.24 ± 0.03	0.18 ± 0.01
PS 1.5	1236.55 ± 441.50	1061.15 ± 432.16	-16.87 ± 20.90	0.84 ± 0.20	0.72 ± 0.40	0.61 ± 0.10	-13.82 ± 11.67	-13.78 ± 4.89	-16.87 ± 20.90	0.56 ± 0.11	0.49 ± 0.10	0.50 ± 0.06	723.89 ± 401.47	520.28 ± 452.34	435.33 ± 208.88	629.71 ± 444.85	395.85 ± 373.51	254.74 ± 81.91	0.27 ± 0.06	0.19 ± 0.03	0.24 0.01

Table 7 Visual comparison of cheese samples during storage over days 0–7 and 21–28.

Day	Control XPS	XPS 0.5	XPS 1.0	XPS 1.5	Control PS	PS 0.5	PS 1.0	PS 1.5
0-7								
21-28								

*CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbat

3.2 Microbiological Analysis and Shelf Life Evaluation

3.2.1 Total Plate Count (TPC)

The total plate count, or TPC is an important indicator of microbial load in food products, and is a standard method used to estimate the total number of viablemicroorganisms in a sample. It provides a general overview of the microbial load, which is crucial for assessing the overall quality and safety of cheese as high TPC can indicate potential spoilage or contamination [20].

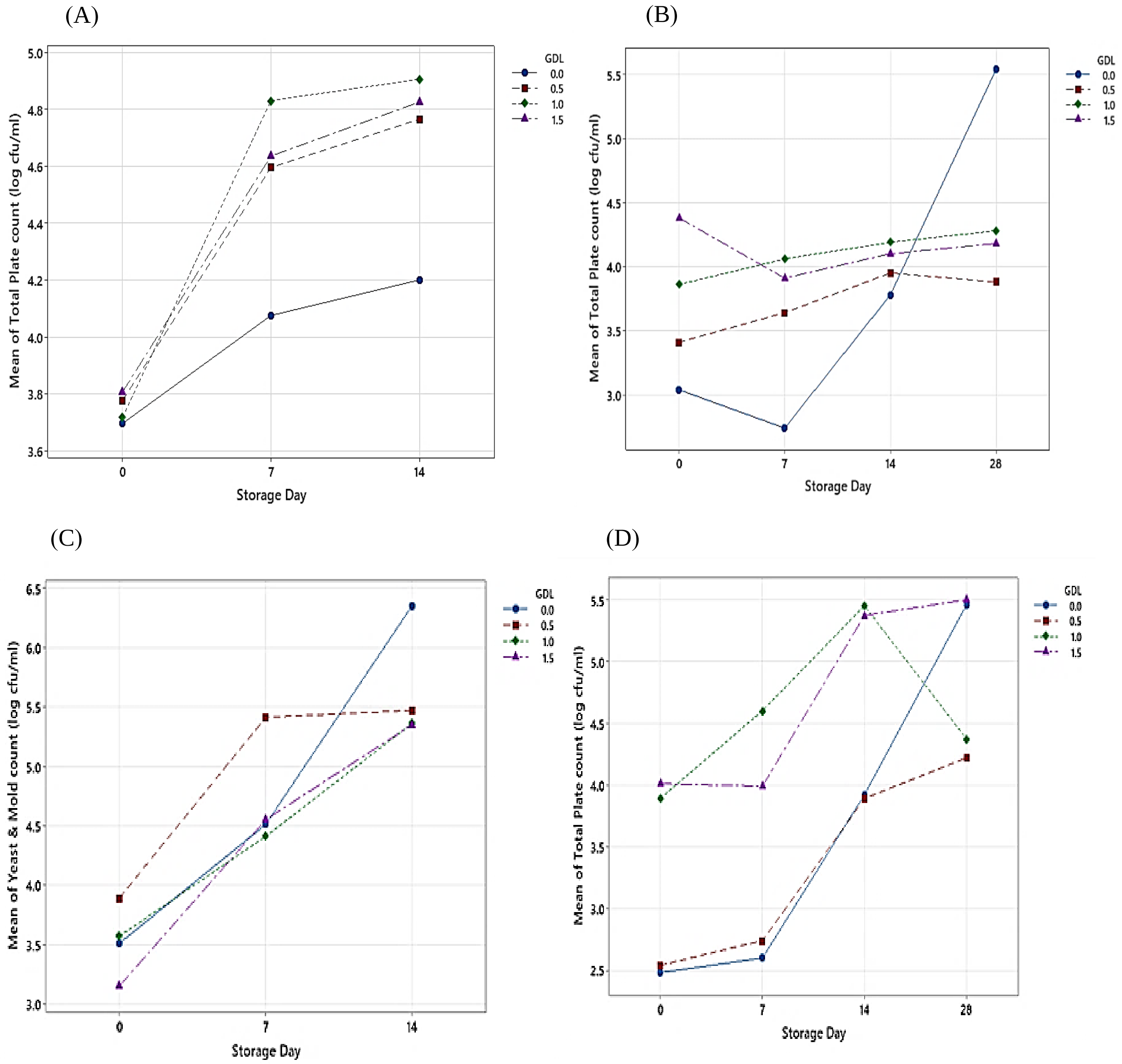

Figure 1 Trend of total plate count (log CFU/mL) without potassium sorbate (A), with potassium sorbate (B) and trend of Yeast & Mold Count (log CFU/mL) without potassium sorbate (C), with potassium sorbate (D).

The addition of potassium sorbate and control reduced the initial load, but the difference was not significant (Table 9). Control samples showed the most decrease, while samples without potassium sorbate increased. In Figure 1(A), the TPC shows an upward trend in TPC over the 14-day period, indicating a less effective microbial control while Figure 1(B) shows the TPC growth rate is slowed. Although there is some fluctuation in TPC across GDL concentrations, the overall microbial growth remains stable and lower up to day 28. Potassium sorbate effectively controls microbial growth in cheese samples, preventing spoilage within 28 days. It inhibits total aerobic mesophilic bacteria, which commonly grow at moderate temperatures, thus reducing the TPC. Its high water solubility ensures uniform distribution and better antimicrobial action [8]. The rate of increase and final microbial load were significantly influenced by the presence of potassium sorbate, which highlights its effectiveness in controlling microbial growth over time than the concentration of GDL alone.

Table 9 The total plate count, log_{10} CFU/mL over 28 days of storage.

Samples	Storage Time (day)			
	0	7	14	28
CXPS	4.35± 48.79	5.41 ± 24.75	4.62 ± 21.21	*Spoiled
XPS 0.5	4.14 ± 9.90	5.55 ± 29.70	5.58 ± 9.19	*Spoiled
XPS 1.0	3.57 ± 9.90	5.60 ± 27.58	5.62 ± 43.84	*Spoiled
XPS 1.5	3.23 ± 2.83	5.36 ± 98.29	5.55 ± 43.84	*Spoiled
CPS	3.04 ± 1.41	2.74 ± 3.54	3.78 ± 3.54	5.54 ± 4.95
PS 0.5	3.41 ± 5.66	3.64 ± 7.78	3.95 ± 26.87	3.88 ± 5.66
PS 1.0	3.86 ± 21.21	4.06 ± 14.85	4.19 ± 31.11	4.28 ± 6.36
PS 1.5	4.38 ± 19.80	3.91 ± 5.66	4.10 10.61	4.18 ± 3.54

3.2.2 Yeast and Molds

Although yeast are essential in typical cheese characteristic, as it impart in cheese ripening process (by consuming lactate, producing alkaline metabolites, fermenting lactose, breaking down fat and proteins and interacting with other microbes in the cheese microbiome, both positively and negatively), yeast thus promote potential spoilage via cheese decomposition (through the production of off flavours, changes in texture, an increase in acidity, surface discolorations, and excessive gas development) by various factors of spoilage (change of weather, poor sanitary in cheese making, temporary contaminant during cheese ripening) and potential health risk [21-23]. Likewise, molds contribute to characteristic appearance, consistency, flavor and shelf-life extension can unintendedly produce mycotoxins and potential health risks due to cheese contamination [20].

Table 10 shows the yeast and mold counts (log_{10} CFU/mL) for different cheese samples. By day 7, yeast and mold counts rise across all samples, but control and XPS groups deteriorate by day 28. After day 14, the control and PS 0.5 had less yeast and mold, hence PS 0.5 was less damaged on day 28. Figures 1(c) and 1(d) show the comparison of yeast and mold count with samples with and without potassium sorbate. It shows that the samples without potassium sorbate shows an increase gradually in trend compared to samples with potassium sorbate, with PS 0.5 shows a lower rate of yeast and mold count. Potassium sorbate inhibited yeast and mold growth in cheese for 28 days [24]. GDL concentration seems to affect early microbial counts, however, some studies suggest that it offers an acidic state that extends cheese shelf life. Cheese samples with potassium sorbate may have increased bacteria counts before the preservatives take effect due to pH changes. Due to the progressive acidification process, this may encourage microbial development [13]. Different interactions between GDL and potassium sorbate can affect cheese's microbiological ecology. GDL may soften and weaken cheese, influencing its interaction with microbial preservatives such as potassium sorbate. Additionally, handling, contamination, and cheese matrix differences may increase the early microbial load. Potassium sorbate reduces microbiological deterioration and extends cheese shelf life. Potassium sorbate acts as a preservative by inhibiting yeast and mold growth, which are primary spoilage organisms. The efficacy of potassium sorbate increases as the pH value decreases, and less preservatives are needed at lower pH levels. It works optimally below a pH of 6.5, making it suitable to be used for a variety of foods including dairy products, such as cheese, and has the ability to extend cheese shelf-life while preserving sensory qualities; taste, color and texture [24]. Potassium sorbate functions by impacting microbial spores or cells, especially by inhibiting or delaying their growth and obstructing the activity of the dehydrogenase enzyme, essential for the metabolic activities of yeast and mold [25].

Table 10 Yeast and mold counts, log_{10} CFU/mL over 28 days of storage.

Variables	Samples	Storage Time (day)			
		0	7	14	28
Yeast & Molds, log CFU/mL	CXPS	3.51 ± 8.49	4.51 ± 38.18	6.35 ± 14.85	*Spoiled
	XPS 0.5	3.89 ± 10.61	5.41 ± 31.11	5.47 ± 9.90	*Spoiled
	XPS 1.0	3.57 ± 5.66	4.41± 28.99	5.36 ± 41.72	*Spoiled
	XPS 1.5	3.15 ± 14.14	4.55 ± 12.02	5.35 ± 43.84	*Spoiled

	CPS	2.48 ± 1.41	2.60 ± 1.41	3.92 ± 5.66	5.46 ± 4.24
	PS 0.5	2.54 ± 0.71	2.74 ± 0.71	3.89 ±10.61	4.22 ± 16.26
	PS 1.0	3.89 ± 12.02	4.60 ± 17.68	5.45 ± 17.68	4.37 ± 22.63
	PS 1.5	4.01 ± 7.07	3.99 ± 4.24	5.37 ± 13.44	5.50 ± 6.36

*CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbate

The microbial testing of the cheese samples was conducted over a 28-day period. However, certain samples were labelled as spoiled before reaching the expected duration. Organoleptic indicators, which is noticeable changes in appearance and smell were observed to assess sensory degradation. Microbial threshold were established where to define spoilage as microbial loads exceeding 20,000 CFU/mL (equivalent to 4.3 log10 CFU/mL) for TPC and 1,000 CFU/mL (equivalent to 3 log10 CFU/mL) for yeast and mold count [26].

3.3 Molecular structure identification: Fourier Transformed Infrared Spectra (FT-IR) Analysis

FTIR measures specific wavelengths in the milk spectrum to predict fat, protein, and lactose components, crucial for cheese coagulation, providing detailed insights into milk molecular composition [27]. Different formulations of cheese samples are classified in Table 11 and Table 12. The control XPS shows a common chemical structure of cheese without additives, with broad O-H stretches, multiple C-H stretches, and a strong C=O stretch. When GDL is added, significant shifts in the O-H stretch and intensified C-H and C=O stretches occur, possibly due to changes in water content and esters and ketones formation. Higher GDL concentrations amplify these shifts. The enhanced %T values in C-H stretches and new peaks suggest complex interactions between proteins and lipids, leading to a firmer, more cohesive cheese structure. GDL concentrations can also lower pH during coagulation, enhancing protein-protein interactions, which are critical for forming a stable gel structure and a firmer cheese texture [28]. Strong and defined C-H, C=O, and amide peaks stretches indicate significant chemical changes, likely improving coagulation and cheese texture. The concentration of GDL in cream cheese can enhance the acidification process, causing more reactive interactions between casein proteins and forming a firmer gel structure. Acidification reduces the net negative charge on casein micelles, encouraging them to aggregate. This affects the protein network and fat globule distribution within the cheese matrix [28]. Higher concentrations of GDL lead to a denser network of interactions, resulting in a more cohesive and firm cheese. The increase in GDL concentration was observed to be reflected in the enhanced C-H, C=O, and amide peaks. Potassium sorbate, even without GDL, shows significant interactions with proteins and lipids, contributing to its antimicrobial properties and extending the cheese's shelf-life. Samples with 0.5% to 1.0% GDL and 1% potassium sorbate show a balanced effect, providing coagulation and preservation without excessive acidification, which could negatively impact flavor and texture.

4. Conclusions

This study investigated the impact of different GDL concentrations and the addition of potassium sorbate on physicochemical properties, microbial stability, texture, and structure over 28-days of storage. Cheeses with higher GDL concentrations had an increasingly acidic and softer texture. Potassium sorbate controlled microbiological development, extending cheese shelf life to day 28. In texture examination, potassium sorbate cheese had a better and more stable texture. GDL affected cheese's adhesiveness, resilience, hardness, and cohesiveness. GDL acidified the chemical structure by shifting O-H, C-H, and C=O peaks in FT-IR analysis, whereas potassium sorbate stabilized it by interacting with proteins and lipids. Combining yield percentages, moisture content, and color helps optimize cheese production.

Table 11 The FT-IR spectrum and list peaks for Control and XPS (0.5, 1.0, and 1.5) group.

	XPS			XPS 0.5			XPS 1.0			XPS 1.5		
Peak No.	X cm^{-1}	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group
1	3277.66	3	O-H stretch (alcohols, phenols, water) - Broad and strong peak indicating the presence of hydroxyl groups.	3352.62	3	O-H stretch, typical for alcohols, phenols, water	3279.91	3	O-H stretch (alcohols, phenols, water) – has a strong absorption indicating hydroxyl group	3279.62	3	O-H stretch (alcohols, phenols, water)
2	2959.94	35.34	C-H stretch (alkanes) - Characteristic of C-H stretching vibrations in alkanes.	2924.42	40.9	C-H stretch vibrations and characteristics of alkanes	2964.37	40.58	C-H stretch (alkanes)	2924.92	37.95	C-H stretch (alkanes)
3	2924.82	27.73	C-H stretch (alkanes) - Another peak for C-H stretching vibrations in alkanes.	2854.69	60.73	C-H stretch, another peak showing C-H stretching vibrations in alkanes	2926.46	38.22	C-H stretch (alkanes)	2854.62	58.18	C-H stretch (alkanes)
4	2854.58	47.55	C-H stretch (alkanes) - Another peak for C-H stretching vibrations in alkanes.	2380.75	95.57	CO2 overtone or C≡N stretch (nitriles)	2855.56	59.32	C-H stretch (alkanes)	2109.58	87.8	C≡C stretch (alkynes) or C≡N stretch (nitriles)
5	2110.23	84.03	C≡C stretch (alkynes) or C≡N stretch (nitriles) - Indicates presence of alkynes or nitriles	2112.68	88.16	C≡C stretch (alkynes) or C≡N stretch (nitriles)	2113.68	88.6	C≡C stretch (alkynes) or C≡N stretch (nitriles)	1742.95	47	C=O stretch (esters, aldehydes, ketones)
6	1743.22	44.73	C=O stretch (esters, aldehydes, ketones) - Strong carbonyl stretch, indicating esters, aldehydes, or ketones. carboxylic acid	1743.23	41.26	C=O stretch, typical esters, aldehydes, ketones	1742.93	62.18	C=O stretch (esters, aldehydes, ketones) – strong carbonyl stretch	1631.19	7.95	C=C stretch (alkenes) / N-H bend (amines)-amide I
7	1633.92	3.14	C=C stretch (alkenes) or N-H bend (amines) - Could be alkenes or primary/secondary amines	1639.74	14.78	C=C stretch (alkenes) or N-H bend (amines)	1636.13	3.75	C=C stretch (alkenes) or N-H bend (amines)	1545.55	26.9	N-O asymmetric stretch (nitro compounds)
8	1544.34	10.83	N-O asymmetric stretch (nitro compounds) - Indicates presence of nitro groups	1554.47	47.44	N-O asymmetric stretch, presence of nitro compounds	1545.29	12.35	N-O asymmetric stretch (nitro compounds)	1455.51	49.27	C-O-H bend (protein & collagen)
9	1452.77	33.12	C-O-H bend (alkanes) - Bending vibration of C-H in alkanes.	1459.51	60.72	C-O-H bending in alkanes	1452.75	39.47	C-O-H bend (alkanes) – bending vibration in alkanes	1376.32	60.94	C-H bend (alkenes)
10	1402.15	44.08	C-O-O stretch, characteristics of carboxylates	1374.69	71.07	C-O-H bend (alkanes), another peak	1401.95	49.61	COO- symmetric stretch (carboxylate groups of fatty acids and amino acids)	1232.99	60.96	C-Nor Amide III (proteins)
11	1235.59	48.47	C-N stretch (amide/protein) – commonly found in amides/protein.	1232.12	71.46	C-N stretch, common in amides or protein	1317.88	67.51	CH2 wagging, twisting (lipids, proteins)	1163.11	63.67	C-O stretch (protein, carbs)
12	1163.71	58.9	C-O stretch (protein) - Another C-O stretching vibration, common in alcohols and ethers.	1160.4	58.69	C-O stretching in proteins	1238.93	61.23	C-N (protein/amide III)	1093.32	76.91	C-O stretch (alcohols, carboxylic acids)
13	1085.42	58.18	C-O stretch (alcohols, carboxylic acids) - Further evidence of C-O stretching in alcohols and carboxylic acids.	1106.83	75.66	C-O stretch, typical for secondary alcohols and hydroxy compounds	1158.11	74.35	C-O stretch (protein & carbs)	621.76	30.14	C-Cl stretch (alkyl halides) or CH_3S (thioethers)
14	594.19	23.95	C-I stretch (aliphatic iodol compounds)	625.71	31.59	C-Cl stretch (alkyl halides) or CH_3S (thioethers)	1089.55	62.29	C-O stretch (alcohols, carboxylic acids)	-	-	-
15	-	-	-	-	-	-	997.79	84.48	C-O-C stretch (ethers) or N-H deformation (amines)	-	-	-
16	-	-	-	-	-	-	587.24	27.26	C-I stretch (thioethers)	-	-	-

Table 12 The FT-IR spectrum and list peaks for Control and PS (0.5, 1.0, and 1.5) group.

	PS			PS 0.5			PS 1.0			PS 1.5		
Peak No.	X cm^{-1}	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group	X (cm^{-1})	Y (%T)	Functional Group
1	3356.48	3	O-H stretch (alcohols, phenols, water)	3351.45	3	O-H stretch (alcohols, phenols, water)	3369.23	3	O-H stretch (alcohols, phenols, water)	3359.29	3	O-H stretch (alcohols, phenols, water)
2	2922.99	29.67	C-H stretch (alkanes)	2923.66	33.63	C-H stretch (alkanes)	2921.68	13.27	C-H stretch (alkanes)	2922.48	21.85	C-H stretch (alkanes)
3	2853.67	48.41	C-H2 stretch (alkanes) - lipids	2854.06	52.33	C-H stretch (alkanes)	2853.12	28.47	C-H stretch (alkanes)	2853.55	40.01	C-H stretch (alkanes)
4	2344.96	93.51	NH components (amino related components Very strong absorption, possibly an artifact or CO_2	2381.12	94.25	CO2 overtone or C≡N stretch (nitriles)	2166.87	88.13	C≡C stretch (alkynes) or C≡N stretch	2381.18	94.3	CO2 overtone or C≡N stretch (nitriles)
5	2109.54	88.58	C≡C terminal alkyne Very strong absorption, possibly C≡N stretch (nitriles) or CO_2	2345.4	93.14	NH components (amino related components Very strong absorption, possibly an artifact or CO_2	2106.64	87.18	C≡C stretch (alkynes) or C≡N stretch (nitriles)	2345.19	94.58	NH components (amino related components Very strong absorption, possibly an artifact or CO_2
6	1742.98	33.08	C=O stretch (esters, ketones, aldehydes)	2165.83	86.97	C≡C stretch (alkynes) or C≡N stretch/	1742.88	15.1	C=O stretch (esters, aldehydes, ketones)	2166.06	88.4	C≡C stretch (alkynes) or C≡N stretch
7	1636.71	15.48	C=O stretch (carbonyl compounds) strong absorption (amide I)	2108.55	86.03	C≡C stretch (alkynes) or C≡N stretch/	1638.1	15.39	C=C stretch (alkenes) or N-H bend (amines)	2112.14	87.63	C≡C stretch (alkynes) or C≡N stretch
8	1460.53	57.5	C-H bend (methyl groups)	1743.02	38.00	C=O stretch (esters, aldehydes, ketones)/	1461.34	45.03	C-O-H bend (alkanes)	1983.36	94.49	C=O stretch (anhydrides)
9	1376.72	73.13	C-H bend (methyl groups, CH_3)	1635.78	14.24	C=C stretch (alkenes) or N-H bend (amines)/	1376.91	66.47	C-O-H bend (alkanes)	1742.88	21.82	C=O stretch (esters, aldehydes, ketones)
10	1236.86	69.57	C-N (Amide III) stretch (alcohols, esters)	1460.12	56.84	C-O-H bend (alkanes)	1238.82	55.07	C-N stretch (amide/ protein)	1636.7	14.67	C=C stretch (alkenes) or N-H bend (amines)
11	1160.32	48.18	C-O stretch (alcohols, ethers)/protein and carbs	1376.96	69.68	C-O-H bend (alkanes)	1161.34	27.12	C-O stretch (protein)	1460.68	50.14	C-H bend (alkanes)
12	1110.23	70.14	C-O stretch (alcohols, ethers, esters)	1236.31	68.65	C-N stretch (amide/protein)	1104.6	49.81	C-O stretch (secondary alcohols, hydroxy compounds)	1375.66	63.38	COO- symmetric stretch (carboxylate groups of fatty acids and amino acids)
13	653.41	37.28	C-S stretch (alkyl chlorides) - thiols	1160.62	52.01	C-O stretch (protein)	964.73	93.31	C-H out-of-plane bending vibrations (alkenes, aromatics)	1233	59.44	C-O stretch (alcohols, carboxylic acids, esters)
14	-	-	-	1113.33	71.48	C-O stretch (alcohols, ethers, esters)	718.98	34.19	C-H out-of-plane bending vibrations (alkenes, aromatics)	1161.26	37.92	C-O stretch (alcohols, ethers)
15	-	-	-	609.57	37.49	C=C stretch (most likely alkene)	3369.23	3	O-H stretch (alcohols, phenols, water)	1106.51	60.95	C-O stretch (alcohols, ethers, esters)

Liu 2021[29]; Nandiyanto et. al. [30] *CXPS: Control with no GDL concentration and no potassium sorbate; XPS 0.5: 0.5% GDL concentrations with no potassium sorbate; XPS 1.0: 1.0% GDL concentrations with no potassium sorbate; XPS 1.5: 1.5% GDL concentrations with no potassium sorbate; CPS: Control with no GDL concentration, with 1% potassium sorbate; PS 0.5: 0.5% GDL concentrations with 1% potassium sorbate; PS 1.0: 1.0% GDL concentrations with 1% potassium sorbate; PS 1.5: 1.5% GDL concentrations with 1% potassium sorbate

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