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SCD Probiotics mitigate cafeteria diet-induced liver damage in Wistar rats during development

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Abstract

Background and Aim: The liver plays a critical role in metabolic homeostasis, and its health is often compromised by poor dietary habits. This study aimed to investigate the therapeutic potential of SCD Probiotics in mitigating adverse liver effects induced by a cafeteria diet in male Wistar rats during their developmental period.
Methods: Four groups of seven male Wistar rats each were subjected to different dietary regimens from day 21 (weaning) to day 56. The groups were as follows: a control group on normal feed; a probiotic-supplemented group on normal feed; a group on a cafeteria diet mixed with normal feed; and a group on a cafeteria diet mixed with normal feed, supplemented with SCD Probiotics. Liver health was assessed using Fourier transform infrared spectroscopy and histopathological evaluations.
Results: Rats on the cafeteria diet exhibited significant disruptions in lipid, protein, cholesterol, triglyceride levels, and glycogen/phosphate content. Histopathological abnormalities such as lymphocytic infiltration, steatosis, and necrosis were also observed. However, SCD Probiotics supplementation led to notable improvements in the liver's biomolecular composition and mitigated histopathological abnormalities. Serum liver enzyme levels (AST, ALT, ALP, and LDH) also showed beneficial effects, while serum albumin levels remained stable.
Conclusions: SCD Probiotics demonstrated a promising potential to counteract the adverse liver effects induced by a cafeteria diet in male Wistar rats. The study revealed significant improvements in biomolecular composition, histopathology, and serum enzyme levels. However, these findings are preliminary and necessitate further in vivo studies and clinical trials for validation.

Introduction

A cafeteria diet, high in processed, energy-dense foods, is a recognized experimental model for studying diet-induced health effects.[1] These vulnerable developmental stages, have documented long-term health consequences.[2] Diet can negatively affect organs such as the liver, which are crucial for metabolism and detoxification.[3] Cafeteria diets, characterized by their variety and palatability, have been found to rapidly induce obesity in Wistar rats during developmental stages, outpacing high-fat diets. Consuming these diets leads to consistent overconsumption of energy-rich foods, which in turn disrupts the body's energy balance, largely because of the diet's high caloric content and lack of essential nutrients. Not only do these diets promote significant weight gain but they also elevate metabolic markers, indicating potential health risks. One of the notable effects of a cafeteria diet is the pronounced surge in leptin levels, indicating a potential onset of leptin resistance, accompanied by detrimental changes in lipid profiles, such as increased cholesterol levels. While the cafeteria diet effectively mimics the appeal of a Westernized diet, it faces criticism for its inconsistent and non-standardized food components.[4] It may also pose lasting liver health risks, potentially leading to metabolic diseases in later life.[5] Investigating these links provides important insights into the diet, metabolism, and health outcomes. This knowledge can aid in identifying new treatment targets and devising strategies to counter the negative effects of a cafeteria diet on liver health and metabolic homeostasis.[6] Moreover, diet can also disturb the gut microbiota, potentially amplifying inflammation and promoting liver damage.[7]

The gut microbiome significantly affects digestion and metabolic processes, influencing the liver and other organs.[8–11] It is implicated in various liver diseases, including oxidative liver injury, chronic hepatitis B, steatosis, non-alcoholic steatohepatitis (NASH), cirrhosis, and hepatocellular carcinoma.[12] Probiotics, which are beneficial microorganisms, can potentially improve these outcomes by modulating gut microbiota, reducing inflammation, and enhancing gut barrier function, positively impacting liver

health and metabolic stability.[13,14] Utilizing probiotics in development may counter the harmful effects of a cafeteria diet on the liver and metabolism. Future animal studies can offer critical insights into potential therapeutic targets.[15]

Infrared (IR) spectroscopy, particularly in its application to biological analyses, has emerged as a revolutionary tool, harnessing its ability to collect detailed data swiftly and without invasive procedures. This method leverages the vibrational characteristics of molecules, resulting in distinctive spectral bands, especially within the mid-infrared region.[16,17] The potency of IR spectroscopy amplifies when combined with computational tools like machine learning and other statistical data analysis techniques, making it a promising instrument for diagnosing a variety of diseases.[18,19] Among the different forms of IR, attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopic scanning stands out. Its rising prominence is attributed to the advantages it offers in the early detection, classification, and monitoring of numerous liver diseases.[20] The rationale behind its application lies in its

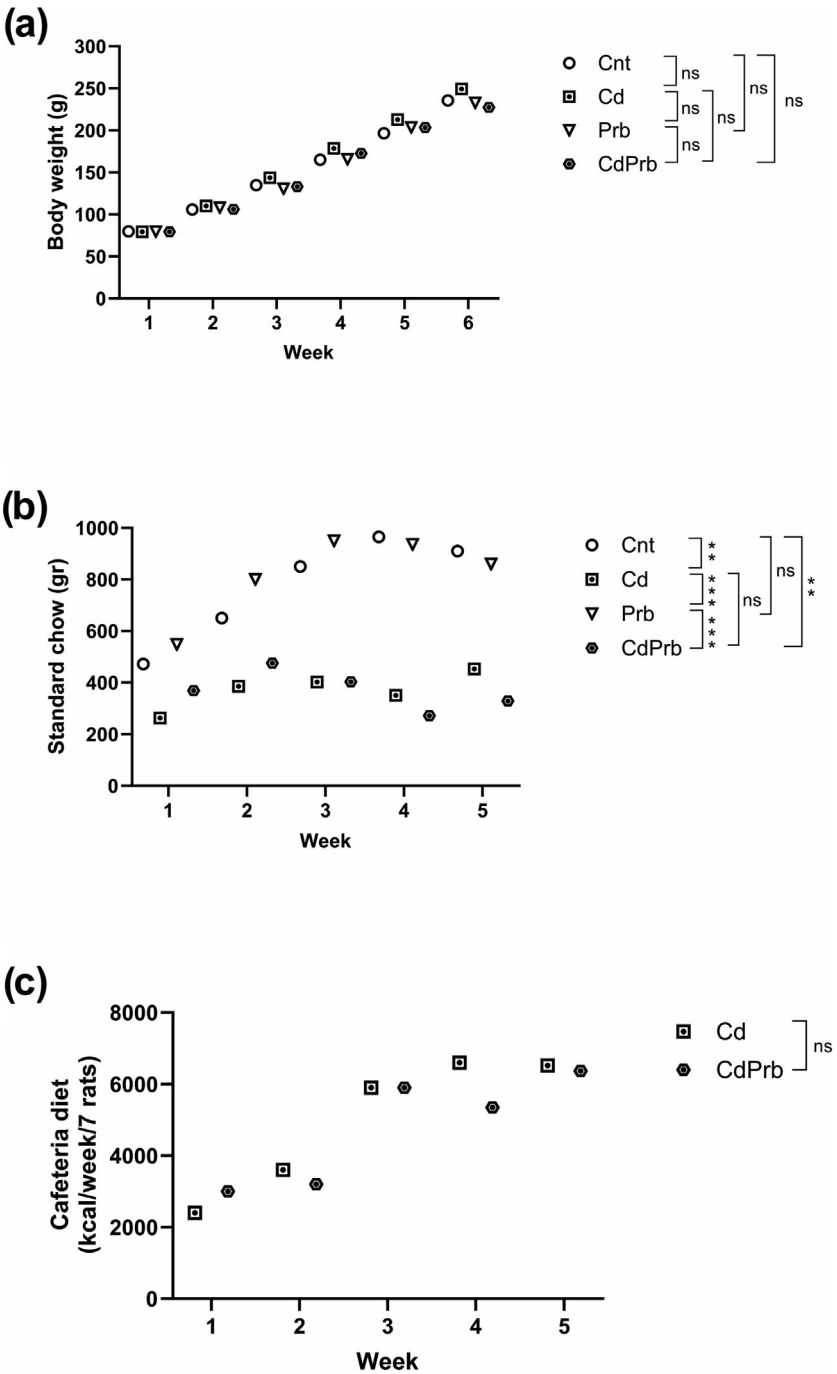

Figure 1 The effects of cafeteria diet, SCD Probiotics supplementation, and SCD Probiotics supplementation during cafeteria diet on (a) body weight, (b) standard chow, and (c) cafeteria diet consumption. The data were analyzed using one-way ANOVA (a, b) and an unpaired *t*-test (c). Values were expressed as mean ± SEM, $n = 7$ group, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$ and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet) and CdPrb (cafeteria diet with SCD Probiotics supplementation).

precision, efficiency, and the valuable insights it provides into the molecular changes associated with diseases, underscoring its significance in the current research context.[21]

Given the aforementioned background, this study seeks to investigate the detrimental effects of the cafeteria diet on the liver's biomolecular composition and histopathology in male Wistar rats during their developmental stages. Concurrently, we aim to assess the potential mitigating effects of SCD Probiotics supplementation on liver damage induced by this diet. Furthermore, through our findings, we aspire to enrich the existing body of knowledge and lay a foundation for future research into dietary interventions that target liver health against the negative impacts of certain dietary patterns.

Methods

This section was presented in Data S1.

Results

Effect of cafeteria diet and SCD Probiotics on body weight, standard chow and cafeteria diet consumption. In terms of body weight, no significant difference was identified among the groups (P = 0.9913), suggesting comparable body weights across groups (Fig. 1a). However, when exposed to the cafeteria diet regimes as detailed in Table 1, a significant difference was found in standard feed consumption (SD) among the groups ($P < 0.0001$), signifying varied rates of standard feed consumption across the study cohorts (Fig. 1b). Specifically, pairwise comparisons revealed significant differences in SD consumption between the Cnt (control) and Cd (cafeteria diet) groups (P = 0.0019), the Cnt and CdPrb (cafeteria diet with SCD Probiotics) group (P = 0.0019), the Cd and Prb (SCD Probiotics) groups (P = 0.0006), and the Prb and CdPrb groups (P = 0.0006). In contrast, there were no significant differences between the Cnt and Prb (P = 0.9438), or the Cd and CdPrb groups ($P > 0.9999$). Furthermore, no significant difference was observed in cafeteria diet consumption among the groups given the cafeteria diet (P = 0.8327), indicating similar cafeteria diet consumption across these groups (Fig. 1c).

Effect of cafeteria diet and SCD Probiotics on liver biomolecules in the band area. According to Beer's Lambert law, the intensity or area of infrared absorption bands from a molecule's functional group reflects its concentration. Thus, areas beneath these bands determined relative biomolecule concentrations. Spectrum characteristics, including band areas, band area ratios, and bandwidths, were analyzed to shed light on the chemical changes in lipids, proteins, and nucleic acids.[17] The study found that the band area at 2955 cm^{-1} (CH3 antisymmetric stretching: lipids and proteins) exhibited a significant increase in the SCD Probiotics group compared with the control group, and an even more pronounced increase in the cafeteria diet group. This band displayed a decreasing trend in the cafeteria diet group, but the addition of SCD Probiotics supplementation in the CdPrb group resulted in an increase that did not cause a significant difference (Fig. 2a). Similarly, regarding the 2922 cm^{-1} (CH2 antisymmetric stretching: lipids) value, a significant difference was observed in comparison to the cafeteria diet with SCD Probiotics supplementation, showing a substantial increase (Fig. 2b). The 1740 cm^{-1} (C=O stretching: cholesterol ester) band, which was significantly increased by the cafeteria diet, appeared to be similar to the control in the SCD Probiotics group. The CdPrb group also demonstrated the same level of significance in difference as the cafeteria diet group (Fig. 2c).

Effect of cafeteria diet and SCD Probiotics on liver biomolecules in the band area ratio. The glucose/protein ratio ($A_{1030}/A_{1644\ +\ 1536}$) significantly decreased in the cafeteria diet group compared with the control group, while no substantial differences were observed in other groups (Fig. 3a). The glycogen/phosphate content (A_{1047}/A_{1083}) was significantly increased in the cafeteria diet group compared with the control and CdPrb groups (Fig. 3b). Saturated lipid content ($A_{2853}/A_{2927\ +\ 2853}$) displayed a

Table 1 The ingredients of the cafeteria diet

Energy and food ingredients (100)	Total (kcal)	Total fat (g)	Total carbohydrate (g)	Protein (g)	Sugar (g)
Control diet					
SC 7001 (Harley)	382	4	54	25	0
CAF diet					
Crackers					
Çay Keyfi (Eti)	462	20.4	67.8	5.8	28.5
Cookies					
Hoşbeş (Eti)	493	24.5	63.9	7.6	28.5
Hanımeller (Ülker)	427	18.1	62.1	3.9	25.0
Nestlé Crunch	500	26	67	5	55
Cereals					
Nesquik mısır gevreği (Nestle)	372	4.1	76.1	7.6	30.7
Chips					
Lays Wavy (Frito-Lay)	536	36	54	7	0
Lays Klasik (Frito-Lay)	529	33	51	7.0	0
Doritos (Frito-Lay)	491	24.5	60.5	7.2	2.3

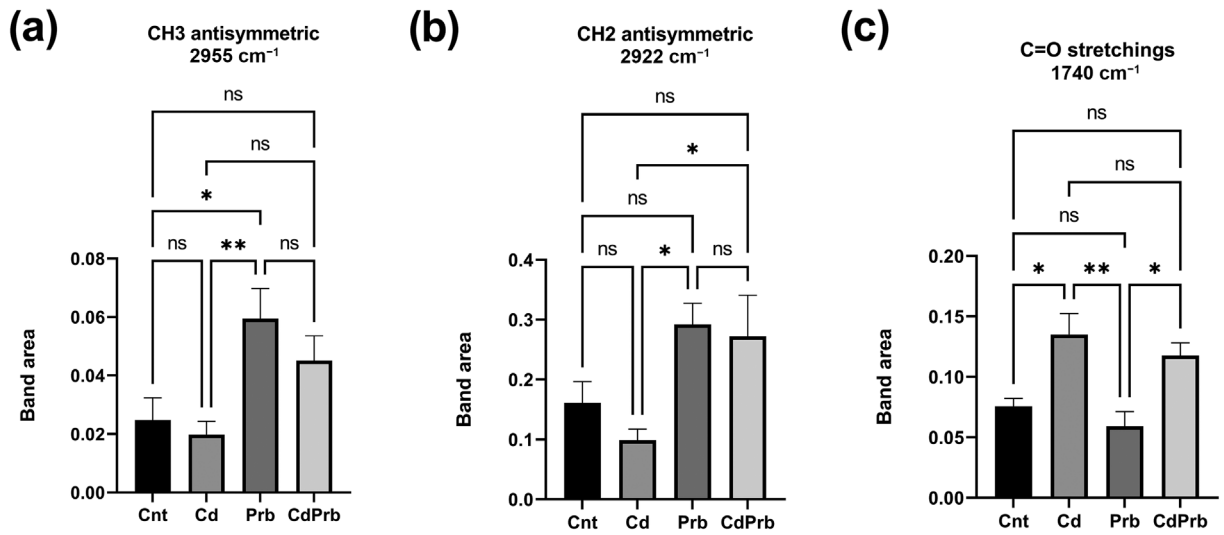

Figure 2 The quantitative changes in liver-associated spectrochemical parameters. The band areas for (a) CH_3 antisymmetric (2955 cm^{-1}), (b) CH_2 antisymmetric (2922 cm^{-1}), (c) lipid carbonyl (C=O stretchings, 1740 cm^{-1}). The data were analyzed using one-way ANOVA. Values were expressed as mean ± SEM, $n = 7$ group, $*P \leq 0.05$, $**P \leq 0.01$ and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet) and CdPrb (cafeteria diet with SCD Probiotics supplementation).

decreasing trend in the cafeteria diet group but increased significantly in the SCD Probiotics group. It appears that SCD Probiotics also contributed to this increase in the CdPrb group (Fig. 3c). The triglyceride content ($A_{1737}/A_{2922+2853}$) value demonstrated a significant increase in the cafeteria diet group compared with all other groups, while SCD Probiotics caused a decrease in the CdPrb group by preventing this increase (Fig. 3d). The nucleic acid/protein content ($A_{1242+1083}/A_{1644+1536}$), which significantly increased with SCD Probiotics, tended to decrease in the cafeteria diet group. SCD Probiotics also appeared to increase this value in the CdPrb group (Fig. 3e). It was observed that SCD Probiotics significantly increased protein phosphorylation (A_{1080}/A_{1545}) and contributed to an increase in this value in the CdPrb group (Fig. 3f). Protein phosphorylation (A_{1239}/A_{2958}) decreased in all groups, with a significant decrease in SCD Probiotics and CdPrb groups (Fig. 3g). Protein carbonylation (A_{1740}/A_{1545}) and protein carbonylation (A_{1743}/A_{1536}) bands increased with cafeteria diet, and it was found that SCD Probiotics prevented this increase in the CdPrb group by causing a decrease in this value (Fig. 3h,i).

Effect of cafeteria diet and SCD Probiotics on liver biomolecules in the bandwidth. The bandwidths at 1653 cm^{-1} (Amide I: α-helical structure of proteins) significantly decreased in the cafeteria diet group. SCD Probiotics, which had a value similar to the control group, prevented this value from decreasing significantly in the CdPrb group (Fig. 4a). The 2922 cm^{-1} (CH2 antisymmetric stretching: lipids) band, which showed a decreasing trend in the cafeteria diet group, experienced a significant increase in the SCD Probiotics group compared with the cafeteria diet group. Moreover, it was observed that SCD Probiotics contributed to decreasing this value in the CdPrb group (Fig. 4b). No significant differences were found in terms of membrane dynamics ($A_{2922}/A_{2955\ cm\text{-}1}$) (Fig. 4c).

Cafeteria diet induced hepatosteatosis and inflammation during development period. At the end of the experiment, the histopathological parameters for all investigated abnormalities (lymphocytic infiltration, steatosis, and necrosis) were significantly higher in cafeteria diet induced group rats compared with the control, and CdPrb treatment groups (Fig. 5a). We next investigated the inflammatory status of the hepatic tissue. The liver sections of the cafeteria diet induced rats showed increased lymphocytic infiltration consistent with an inflammatory process (Fig. 5b). The density of the lymphocytic infiltration was significantly decreased in SCD Probiotics given cafeteria diet induced rats compared with the cafeteria diet group (Fig. 5b).

Hematoxylin and eosin (H&E) staining of liver sections demonstrated normal liver histological structure with no macro/microvesicular fat accumulation in Cnt group rats. Cafeteria diet-fed rat livers displayed minor to major microvesicular steatosis, respectively (Fig. 5a). In addition, the percentage increase in the area fraction (%) of steatosis and lipid droplets perimeter (mm) in the cafeteria diet group was significantly higher than in the control group (Fig. 5c,d). Steatosis associated with cafeteria diet group was mixed macro and microvesicular, localized to the periportal to midzonal regions and distinctly absent in the pericentral regions where normal tissue architecture was conserved. So that, the cafeteria diet invoked hepatosteatosis that encompassed the entire liver lobule and was micro/macrovesicular in nature (Fig. 5a). H&E-stained liver sections revealed that lipid accumulation and lipid droplets perimeter (mm) decreased effectively in CdPrb group compared with cafeteria diet group (Fig. 5c,d). So SCD Probiotics treatment decreased liver triglyceride levels in the CdPrb group.

Regulation of hepatic fibrosis by SCD Probiotics treatment in cafeteria diet fed rats. Masson's trichrome (MT) staining was used to quantify collagen levels in the rat liver sections. MT

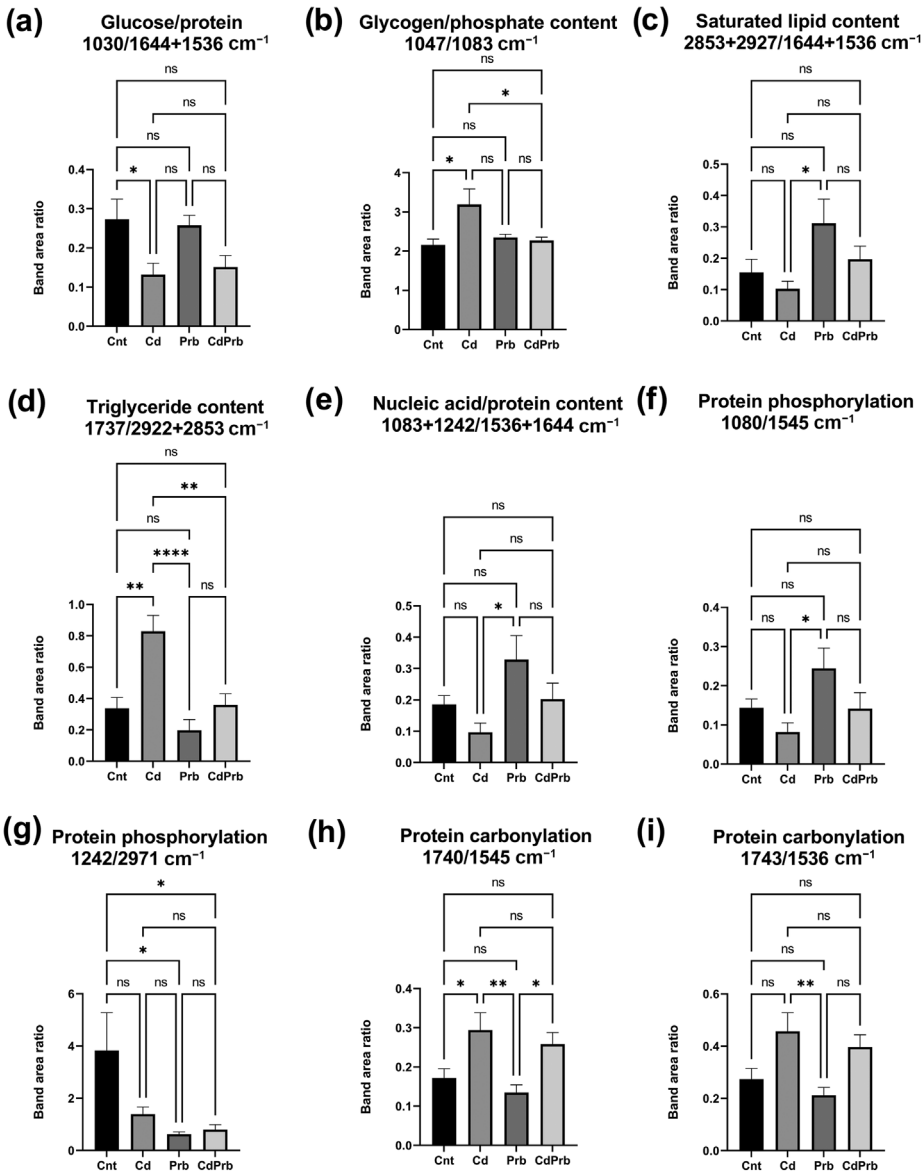

Figure 3 The quantitative changes in liver-associated spectrochemical parameters. The band area ratios for (a) Glucose/protein ($A_{1030}/A_{1644\,+\,1536}$), (b) Glycogen/phosphate content (A_{1047}/A_{1083}), (c) Saturated lipid content ($A_{2853}/A_{2927\,+\,2853}$), (d) Triglyceride content ($A_{1737}/A_{2922\,+\,2853}$), (e) Nucleic acid/protein content ($A_{1242\,+\,1083}/A_{1644\,+\,1536}$), (f) Protein phosphorylation (A_{1080}/A_{1545}), (g) Protein phosphorylation (A_{1242}/A_{2971}), (h) Protein carbonylation (A_{1740}/A_{1545}), and i) Protein carbonylation (A_{1743}/A_{1536}). The data were expressed as mean ± SEM, $n = 7$ group, $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{****}P \leq 0.0001$, and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

staining examination of hepatic tissues on cafeteria diet group showed focal areas of degeneration, hepatic fibrosis and marked collagen fiber deposition around the central vein and portal tracts compared with normal patterns in the Cnt group (Fig. 6). Hepatic collagen levels significantly increased in cafeteria diet group compared with Cnt and CdPrb groups in the central vein and the portal tracts. In contrast, SCD Probiotics treatment decreased collagen levels in the livers of CdPrb group rats. SCD probiotics supplementation in CdPrb group showed nearly normal hepatic architecture (Fig. 6). So SCD probiotics supplementation for 5 weeks with cafeteria diet fed rats resulted in ameliorative process of hepatic cells morphologies in the form of marked reduction of the amount of collagen fibers accumulation (Fig. 6).

Effects of SCD Probiotics on serum liver enzymes in cafeteria diet fed rats. Results of the liver function tests (AST, ALT, ALP, LDH, and albumin) are shown in Figure 7. The findings showed that serum AST and ALT levels significantly decreased in the cafeteria diet group compared with control group and CdPrb treatment groups (Fig. 7a,b), while ALP levels showed significantly increased in the Cd group compared with Cnt, Prb, and

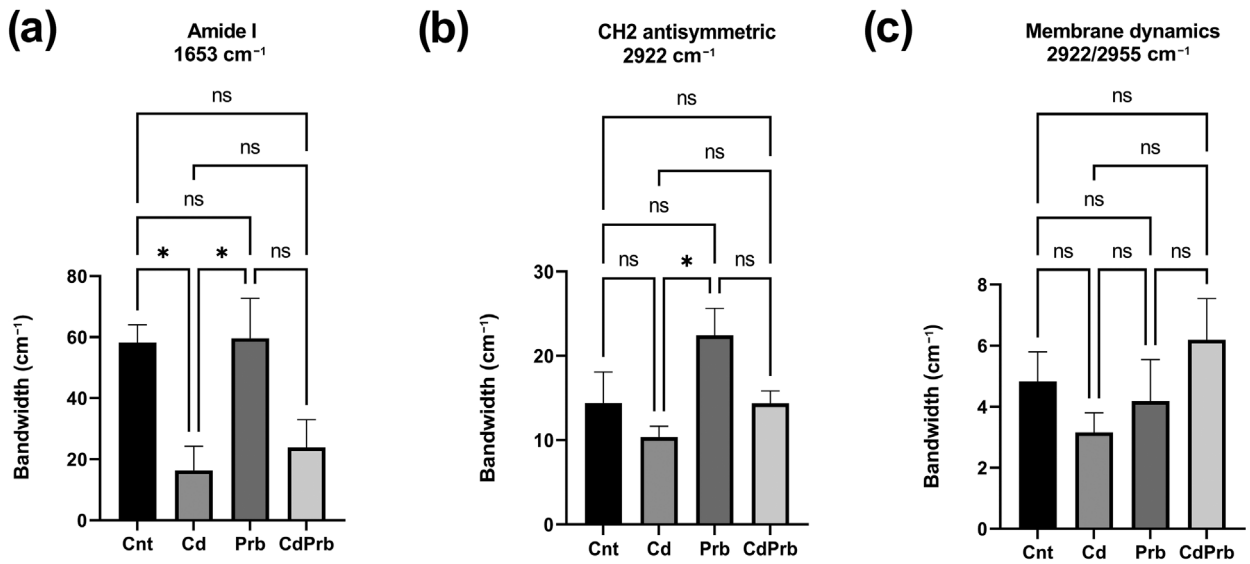

Figure 4 The quantitative changes in liver-associated spectrochemical parameters. The bandwidths for (a) Amide I (1653 cm^{-1}), (b) CH_2 antisymmetric (2922 cm^{-1}), and (c) membrane dynamics (A_{2922}/A_{2955}). The data were analyzed using one-way ANOVA. Values were expressed as mean ± SEM, $n = 7$ group, $^*P \leq 0.05$ and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

CdPrb treatment groups (Fig. 7c). AST and ALT levels significantly increased in the CdPrb treatment group compared with cafeteria diet group (Fig. 7a,b). However, ALP levels significantly decreased in the CdPrb group compared with cafeteria diet group (Fig. 7c). LDH levels, an essential enzyme found primarily in liver, significantly decreased serum levels in the cafeteria diet group compared with the control and other groups (Fig. 7d). Whereas LDH levels significantly increased in CdPrb treatment group compared with cafeteria diet group (Fig. 7d). There were no significant differences between control group and the other groups (Cd, Prb, and CdPrb) for albumin levels (Fig. 7e). The cafeteria diet did not induce changes in serum albumin levels in all groups.

Discussion

The present study provides an insightful examination into the detrimental effects of a cafeteria diet on liver health during a crucial developmental phase in rats. Importantly, it sheds light on the therapeutic potential of SCD Probiotics supplementation to counteract these adverse outcomes. Given the ubiquity of fast-food-like cafeteria diets and the rising prevalence of liver diseases globally, these findings hold significant implications for both prevention and intervention strategies. Spectroscopic analyses highlighted a notable rise in cholesterol esters following the cafeteria diet, a consequence of cholesterol's esterification with fatty acids.[22] Interestingly, this uptrend was attenuated upon introducing SCD Probiotics. Specific strains within SCD Probiotics, such as *Bifidobacterium ssp*, *Lactobacillus acidophilus*, and *Lactobacillus plantarum*, have metabolic functions known to decrease blood cholesterol levels. Aligning with existing literature, these strains emphasize the probiotics' potential in cardiovascular health protection.[23]

A cafeteria diet is known to induce hypertriglyceridemia, a condition characterized by elevated triglyceride levels. Animal studies have demonstrated that rats fed a cafeteria diet developed significantly increased triglyceride levels.[24] The administration of SCD Probiotics has been found to attenuate these increases in triglyceride levels. Certain strains of probiotics, including those in the Lactobacillus and Bifidobacterium genera, have shown promise in reducing hypertriglyceridemia. For instance, a study found that supplementation with *Lactobacillus curvatus* HY7601 and *L. plantarum* KY1032 in diet-induced obese mice led to a significant decrease in triglyceride levels.[25] Cafeteria diet led to metabolic disturbances including changes in glycogen storage. It was reported that probiotic administration mitigated liver damage in obese mice, improving glycogen storage in the liver. For example, *Lactobacillus fermentum* from the species found in SCD Probiotics reported that helped regulate glycogen metabolism in mice.[26]

SCD Probiotics appear to beneficially influence protein phosphorylation and the structure of proteins, along with impacting nucleic acid content. As protein phosphorylation, regulated by protein kinases, is key to cellular rejuvenation,[27] its modification by SCD Probiotics might signal a positive cellular response. However, changes in phosphorylation markers aren't straightforward and depend on the specific proteins and the context. The observed fluctuations, accompanied by shifts in nucleic acid content, could imply a restorative effect of these probiotics. Still, this interpretation requires further rigorous examination to validate these preliminary findings and understand the full scope of SCD Probiotics' impact.

An additional critical spectrochemical observation made in this study was that SCD Probiotics administration effectively hindered the elevation in protein carbonylation witnessed in the group of rats subjected to a cafeteria diet. Protein carbonylation, an unalterable oxidative alteration of proteins, is a pivotal spectrochemical

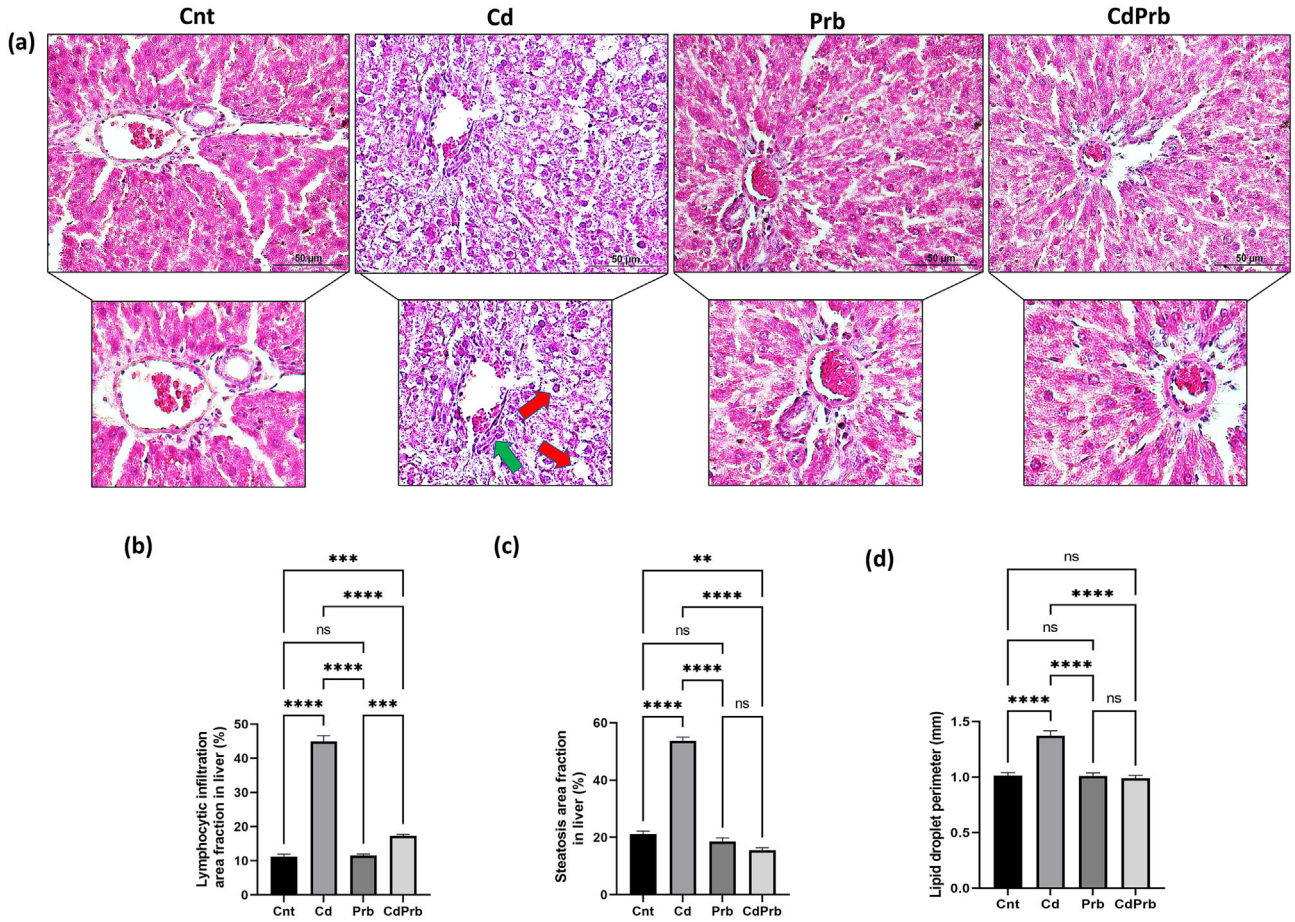

Figure 5 In rats fed a cafeteria diet, livers displayed increased steatosis and lymphocytic infiltration. However, SCD Probiotics and combination treatments mitigated these histopathological changes. Hematoxylin and eosin staining showed alterations in lymphocytic infiltration and hepatic steatosis area fractions, evident from representative images (a, b, c). Lymphocytic infiltration and bile micro/macrovesicular steatosis were indicated by green and red arrows, respectively (d). Magnified images of areas in hematoxylin and eosin stained microphotographs highlighted these areas of interest. Scale bar = 50 µm. The data were analyzed using one-way ANOVA. Values were expressed as mean ± SEM, n = 7 group, $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$, $^{****}P \leq 0.0001$, and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

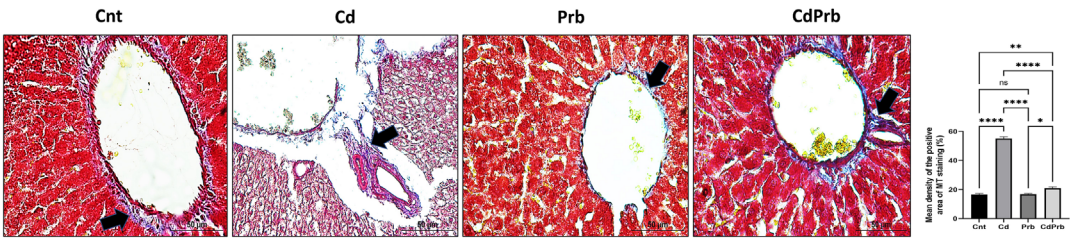

Figure 6 Representative images of Masson's trichrome staining showing collagen deposition in control, Cd, SCD Probiotics, and combination treatment (CdPrb) groups liver tissue with quantification of collagen density area fraction (%) in all groups. Scale bar = 50 µm. The data were analyzed using one-way ANOVA. Values were expressed as mean ± SEM, n = 7 group, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$, $^{****}P \leq 0.0001$, and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

marker indicative of oxidative stress-associated disorders.[28] Oxidative stress is a state characterized by an imbalance between the generation of reactive oxygen species and the organism's capacity to counteract their detrimental effects and mend the consequential damage. This phenomenon is implicated in the etiology and progression of numerous chronic pathologies, encompassing

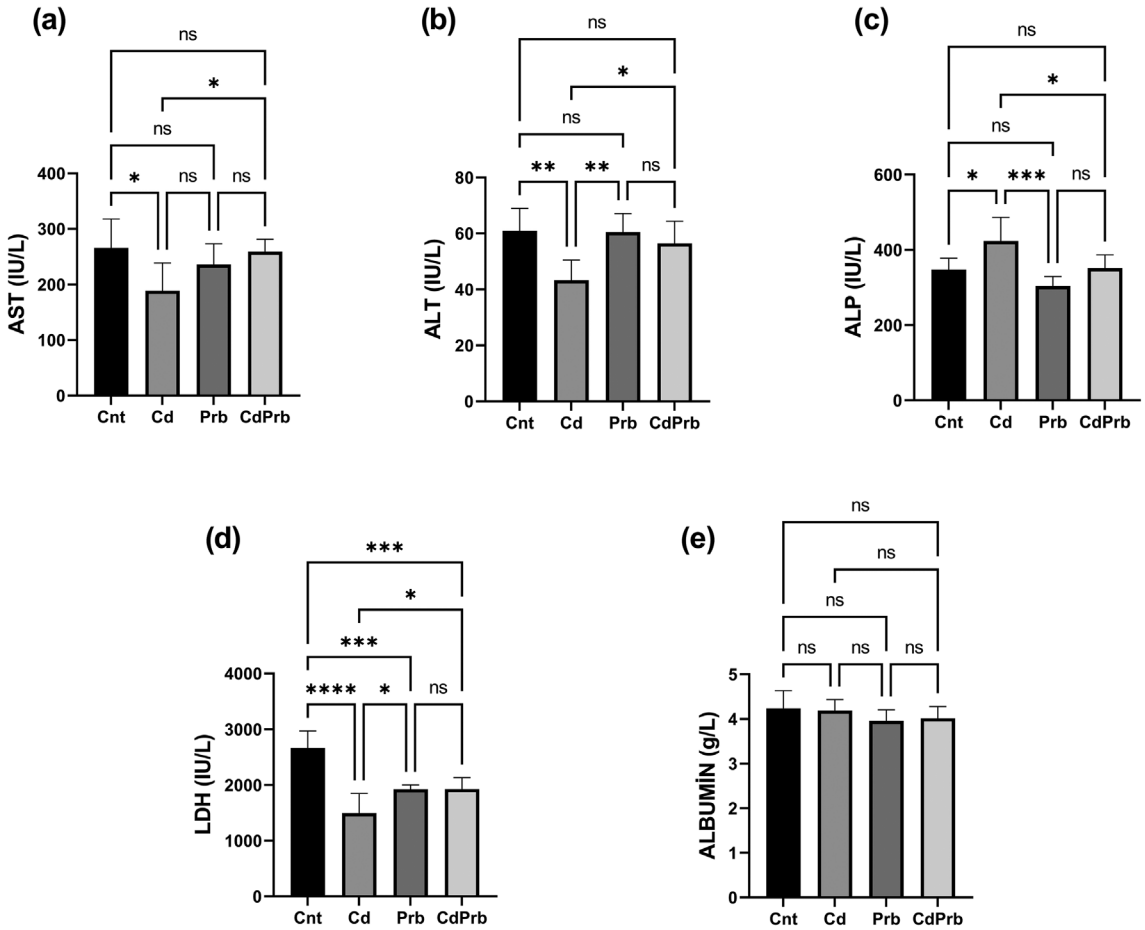

Figure 7 Effects of all treatment groups (Cd, Prb, and Cd Prb groups) on the serum levels of (a) AST, (b) ALT, (c) ALP, (d) LDH, and (d) Albumin. The data were analyzed using one-way ANOVA. Values were expressed as mean ± SEM, $n = 7$ group, $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$, $^{****}P \leq 0.0001$, and ns (non-significant). Cnt (control) and Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

cardiovascular diseases, cancer, and neurodegenerative conditions. Specific probiotic bacteria species contained in SCD Probiotics, such as *Bifidobacterium bifidum*, *Lactococcus lactis*, and *Lactobacillus plantarum*, are known to play a contributory role in curbing oxidative stress.[29]

The cafeteria diet administered during the developmental phase led to augmented adiposity, a surge in hepatic glycogen/phosphate concentrations, and hepatic steatosis in rats, consistent with prior findings using the same experimental obesity model.[30–33] The evident increase in lipid and glycogen content in liver tissues, coupled with the pronounced steatosis density observed histologically, denotes adaptive metabolic shifts in response to the nutritional changes introduced by the cafeteria diet. This heightened glycogen and lipid presence might account for the diminished cellular and vascular spaces observed in the livers of the cafeteria group, subsequently limiting oxygen consumption. Supporting this, prior research has suggested an uptick in glycerol gluconeogenesis in the livers of rats on a cafeteria diet.[31,34] This aligns with the rise in triglyceride levels we detected biochemically in the liver tissues of the cafeteria diet group, mirroring our histological observations. In essence, select substrates and gluconeogenic regulators appear to amplify gluconeogenesis in the livers of rats exposed to the cafeteria diet.

The cafeteria diet results in dyslipidemia, characterized primarily by an upsurge of triglycerides in hepatocytes, triggering lipid buildup.[35,36] This accumulation precipitates structural changes in hepatocytes, leading to fibrosis development in periportal and sinusoidal areas. An MT staining analysis showcased fibrosis in the liver, marked by elevated collagen fiber density and structural disarray in cellular organization within the cafeteria diet group. However, our findings suggest that SCD Probiotics administration notably mitigates this collagen fiber density increase in rats subjected to the cafeteria diet during their developmental stage. The probiotic dose utilized in this study appeared to foster structural revitalization of liver tissue architecture by curbing hepatocyte damage and inflammation. This protective action is likely attributed to the antioxidant and anti-inflammatory attributes of probiotics. These properties hinder lipid oxidation and fibrosis, both intricately linked to hepatometabolic complications and the exacerbation of inflammation.[37,38]

In our research, we investigated the protective role of SCD Probiotics against liver enzyme disturbances in rats subjected to

a cafeteria diet. The cafeteria diet group exhibited decreased levels of AST, ALT, and LDH, but an elevation in ALP levels. This increase in ALP is likely a reflection of liver injury due to the diet, which results in the enzyme's discharge into the circulation, hinting at compromised liver integrity and cell death. Interestingly, a downward trend in these enzyme levels was apparent in both the SCD Probiotics and CdPrb cohorts, suggesting a potential hepatoprotective role. These findings are in consonance with earlier literatures,[39,40] underscoring the positive influence of probiotics on liver health and the well-being of epithelial cells.

LDH, an enzyme participating in anaerobic glycolysis, helps interconvert lactate and pyruvate.[41] Its activity can vary with metabolic shifts due to liver dysfunction. Reduced gluconeogenesis in cafeteria diet-affected livers, as shown in previous research, may explain the lowered LDH levels observed in the cafeteria diet group. However, the increased liver steatosis indicates a rise in glycerol substrates. Despite lower gluconeogenic ratios than lactate + pyruvate, the presence of the fatty acid stearate amplifies stimulation in cafeteria diet-fed livers, signifying complex metabolic responses.[42,43] The alterations in hepatic glucose production result from intricate interactions between hormonal systems and hepatic metabolism pathways, particularly those involving gluconeogenic substrates and effectors. These findings demonstrate that liver histopathologies in cafeteria diet-treated rats can lead to functional losses due to metabolic changes.

Conclusion

In our investigation, SCD Probiotics supplementation demonstrated a protective role against the detrimental effects on the liver elicited by a cafeteria diet during the developmental period in male Wistar rats. We observed notable improvements in the liver's biomolecular composition, histopathological features, and serum liver enzyme profiles. Notably, disturbances like lymphocytic infiltration, steatosis, and necrosis induced by the cafeteria diet were notably mitigated by the SCD Probiotics' intervention. However, it is crucial to interpret these findings with caution. While the results are indicative of the potential therapeutic benefits of SCD Probiotics in a controlled experimental setting, it remains essential to further substantiate these findings through comprehensive in vivo studies and human clinical trials before making broader recommendations or generalizations about the efficacy of SCD Probiotics in countering diet-induced hepatic ailments.

Data availability statement. All data generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Supporting Information.