



RESEARCH ARTICLE

Chemical and physical properties of cow milk and plant-based milk – A comparative study

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Abstract

Plant-based milk alternatives are becoming increasingly popular because they are lactose-free, gluten-free and suitable for people with food allergies or special dietary needs. Common plant-based milks include soy, almond and rice-based beverages. Most research has focused on mature grains or legumes, while milk made from immature rice-harvested during the milky stage-has been less studied, even though it may have higher protein and other beneficial nutrients. The present study compared the chemical and physical properties of cow's milk (raw and pasteurised) with selected plant-based milk alternatives, including immature rice milk, almond milk and soy milk. Key parameters, including titratable acidity, pH, electrical conductivity, viscosity and density, were measured using standardised methods, while protein, fat, solids-not-fat (SNF) and lactose were analysed using a milk analyser. Results showed that almond and soy milk contained lower protein (0.09 ± 0.02 % and 1.79 ± 0.03 %, respectively), fat (0.66 ± 0.02 % and 1.46 ± 0.01 %, respectively) and SNF (0.27 ± 0.03 % and 5.14 ± 0.04 %, respectively) compared to cow's milk (protein: raw 2.94 ± 0.07 %, pasteurised 3.18 ± 0.05 %; fat: raw 5.61 ± 0.08 %, pasteurised 3.43 ± 0.07 %; SNF: raw 7.86 ± 0.19 %, pasteurised 8.82 ± 0.31 %). Lactose was present in cow's and soy milk, but negligible in almond and immature rice milk. Immature rice milk showed a high protein content (10.0 ± 1.09 %) with low fat (0.40 ± 0.08 %). Cow's milk exhibited higher acidity and electrical conductivity than plant-based milks, while viscosity was highest in almond milk, followed by soy milk, cow's milk and immature rice milk. Density values were similar across all samples (1.01 – 1.09 g/cm³). These findings highlight the distinct compositional differences between animal and plant-based milks. Immature rice milk, with its combination of high protein and low fat, may serve as a functional plant-based alternative suitable for dietary applications where protein enrichment is desired without increasing fat intake. Understanding these differences can help consumers and food producers choose the right milk for nutrition and functional uses.

Keywords: almond milk; cow milk; immature rice milk; skimmed milk; soy milk

Introduction

Milk is one of the most widely consumed dietary fluids due to its important role in providing essential nutrients and maintaining hydration. The chemical composition of bovine milk has been extensively studied, with numerous analyses detailing its proteins, lipids, carbohydrates, vitamins and minerals (1). At the macronutrient level, bovine milk consists primarily of water (85–87 %), lipids (3.8–5.5 %), carbohydrates (approximately 5 %) and proteins (2.9–3.5 %). The carbohydrate fraction is largely composed of lactose, a disaccharide made up of glucose and galactose. Milk proteins are divided into caseins (~80 %) and whey proteins (~20 %), both of which contribute significantly to its nutritional and functional

properties. At the micronutrient level, bovine milk contains a wide range of bioactive compounds, including fat and water-soluble vitamins, essential minerals, organic acids, biogenic amines, oligosaccharides, nucleotides and immunoglobulins (2). Together, these components support diverse biological functions, including immune defence, growth and metabolic regulation.

Functional beverages are increasingly recognised for their potential health benefits, which has driven the rapid expansion of alternatives to bovine milk-based products. These alternatives are predominantly derived from plant sources, including soy, almond, coconut, rice and various nuts (3). The growing consumer demand for plant-based milk (PBM) alternatives is largely influenced by

health considerations and lifestyle choices such as flexitarianism, vegetarianism and veganism, contributing to significant growth in the PBM market segment (4).

In contrast, traditional dairy products such as buttermilk and yoghurt are derived exclusively from animal milk. Consequently, plant-based beverages are subject to regulatory restrictions regarding the use of dairy-associated terminology in India. For example, soy-based beverages are labelled as “soy milk” under specified exceptions, despite not being of animal origin. Such regulatory distinctions are defined within the list of permitted exceptions under applicable food labelling regulations (5). PBMs are entirely free from animal-derived components and do not contain certain biomolecules characteristic of mammalian milk, including cholesterol, lactose, saturated fatty acids and immunogenic dairy proteins. At the same time, PBMs provide hypoallergenic plant proteins, essential minerals and polyunsaturated fatty acids, making them suitable alternatives to conventional dairy products (6). PBMs are typically produced by aqueous extraction of plant materials such as legumes, nuts, or cereals, followed by grinding, filtration and homogenisation. This process results in dispersed particle sizes generally ranging from 5 to 20 μm , which contributes to colloidal stability and acceptable mouthfeel in the final beverage (7).

Plant-based milks can be taxonomically classified into five principal categories based on their botanical origin: cereal-based milks, including rice, oat, corn and spelt; pseudo-cereal-based milks, such as quinoa, amaranth and teff; nut-based milks, including almond, coconut, hazelnut, pistachio and walnut; legume-based milks, including soy, peanut, lupin and cowpea; and seed-based milks, such as sesame, sunflower, flax and hemp milks (8–9).

Soy milk and almond milk are notable for their opaque, creamy white appearance and rheological properties that closely resemble those of bovine milk, which has contributed to their widespread consumer acceptance (10). Soy milk is considered a nutritionally dense beverage, characterised by relatively high levels of high-quality plant protein, bioavailable iron, unsaturated fatty acids and niacin, while containing lower amounts of total lipids, carbohydrates and calcium compared with cow's milk. In addition, soy milk is a significant source of phosphatidylcholine, fat-soluble vitamins and isoflavones-phytoestrogenic compounds known for their antioxidant activity and potential health-modulating effects (11).

Rice is predominantly consumed as milled grain, produced either by removing only the outer husk to yield brown rice or by further removal of the germ and bran layers to obtain white rice. From a nutritional standpoint, mature rice grains consist primarily of starch (approximately 80 %), followed by water (12 %), protein (7.5 %) and ash (0.5 %). In several regions, particularly in sub-Saharan Africa, rice contributes up to 43 % of dietary protein intake and 46 % of total caloric consumption (12). Essential nutrients such as iron, zinc, dietary fibre, B-complex vitamins (including thiamine, riboflavin and niacin) and vitamin E are concentrated mainly in the bran and germ fractions (11–12). However, the widespread consumption of polished white rice has been associated with micronutrient deficiencies, as milling removes the nutrient-rich husk, germ and bran layers (12).

Rice products derived from immature grains, particularly those harvested at the dough stage (e.g., green rice flakes) and milky stage (e.g., rice milk), are traditionally consumed as nutritious foods

in several Asian countries, including Thailand. Studies have reported that immature rice grains contain higher levels of bioactive compounds such as sterols, γ -oryzanol, tocopherols, tocotrienols, ferulic acid and *p*-coumaric acid compared with fully mature rice grains (13–14). These bioactive constituents contribute to the functional and antioxidant potential of immature rice-based products.

In contrast, almond milk is recognised as a rich source of micronutrients, particularly vitamin E (α -tocopherol), a lipid-soluble antioxidant that must be obtained through dietary intake (15). Almond milk offers a nutrient-dense yet low-calorie alternative to soy milk and bovine milk and has been associated with beneficial effects on cardiovascular health and the improvement of mineral status, especially with respect to iron and zinc availability (16).

Most of the existing research on plant-based milk alternatives has focused on soy, almond, oat and beverages derived from mature cereal grains, including conventional rice milk, whereas milk produced from immature rice grains remains largely unexplored (17, 18). Immature rice is harvested at an earlier developmental stage, during which its metabolic and biochemical profiles differ markedly from those of mature rice, resulting in distinct starch composition and structure, including a higher proportion of short-chain amylopectin and lower crystallinity (19–20). These characteristics, together with the reportedly higher levels of bioactive compounds such as phenolics, antioxidants and certain micronutrients that tend to decline during grain maturation, suggest that immature rice milk may exhibit unique nutritional and functional properties that cannot be extrapolated from studies on mature rice milk (20, 21). Furthermore, the physicochemical properties of immature rice starch, including its hydration capacity, gelatinisation behaviour and viscosity, may influence beverage stability, mouthfeel and sensory quality, potentially reducing the need for additives or extensive processing (19–22). From a consumer perspective, rice-based beverages are widely regarded as hypoallergenic, gluten-free and lactose-free, making them suitable for individuals with food allergies or dietary restrictions (17, 18). The inclusion of immature rice milk alongside well-studied alternatives such as soy and almond milk, therefore, provides a broader comparative framework to elucidate the influence of grain maturity on nutritional composition and functionality, strengthening the scientific relevance of the present study and supporting the development of novel plant-based milk formulations (18, 22).

Materials and Methods

Plant-based milks were prepared from almond, soybean and immature rice using standardised aqueous extraction procedures with controlled processing conditions. Raw plant materials (100 g of each) were first cleaned thoroughly to remove dust, broken kernels and foreign matter and all samples were processed from the same batch to minimise variability. Almond milk was prepared by soaking raw almonds in distilled water at a ratio of 1:5 (w/v) for 10–12 hr at room temperature ($25 \pm 2^\circ\text{C}$) to soften the kernels. After soaking, the almond skins were manually removed and the kernels were ground with distilled water using a high-speed blender at approximately 12000 rpm for 3–4 min, maintaining a kernel-to-water ratio of 1:6 (w/v). The resulting slurry was filtered through a double-layered muslin cloth to obtain almond milk, which was stored at 4°C and analysed within 24 hr.

Soy milk was prepared using a conventional wet extraction method. Cleaned soybeans were soaked in distilled water at a ratio of 1:3 (w/v) for 8–10 hr at room temperature. The soaked beans were then blanched at 90–95 °C for 5 min to inactivate lipoxygenase enzymes and reduce undesirable beany flavour. Blanched soybeans were ground with hot distilled water (approximately 80 °C) in a 1:8 (w/v) ratio for 4–5 min and the resulting slurry was filtered through muslin cloth. The filtrate was subsequently heated at 95 °C for 10 min to ensure microbial safety, cooled and stored at 4 °C until analysis. Late milky stage immature rice grains (var. *Neelam*) were harvested from the RPCAU, Pusa farm. Immature rice milk was extracted from these rice grains, typically occurring 10–15 days after flowering, during which the endosperm remains soft and exudes a milky fluid upon pressing. Freshly harvested immature rice panicles were manually de-husked and washed with distilled water. Due to the naturally high moisture content and soft texture of the grains, no soaking step was applied. The de-husked grains were immediately ground with chilled distilled water at a ratio of 1:5 (w/v) using a laboratory blender at approximately 10000 rpm for 3 min, with grinding performed under cold conditions (≤ 15 °C) to minimise enzymatic degradation of proteins. The homogenate was filtered through fine muslin cloth to obtain immature rice milk, which was stored at 4 °C until analysis.

These samples, namely almond milk and soy milk, were subsequently adjusted to a final volume of 250 mL with distilled water for their analysis. Raw bovine milk was collected directly from the dairy farm of RPCAU, Pusa. Bovine milk samples were analysed in both raw and pasteurised forms. Pasteurisation was carried out using the low-temperature long-time (LTLT) method by heating the raw milk at 60 °C for 30 min, a conventional thermal treatment widely employed to ensure microbial safety while retaining most of the nutritional and physicochemical properties of milk (23, 24). Although LTLT pasteurisation is generally considered milder than high-temperature short-time (HTST) processing, it may still induce limited changes in heat-sensitive components such as certain vitamins, enzymes and bioactive proteins; therefore, potential compositional alterations cannot be completely excluded and should be interpreted with caution (25).

Chemical characterisation

Quantitative analysis of milk constituents, including total protein, fat, solids-not-fat (SNF) and lactose, was performed using an automated milk analyser. The analyser is conventionally calibrated for bovine milk matrices; therefore, its application to PBM samples was employed primarily for comparative and screening purposes rather than for absolute quantification (17, 22). Differences in macromolecular composition, carbohydrate profile and the absence of true lactose in PBMs may influence the accuracy of lactose, SNF and protein readings and the resulting values should be interpreted with caution (17). Accordingly, the data obtained from PBM samples were used to assess relative trends among samples under identical analytical conditions rather than to claim direct equivalence with bovine milk (18).

Titrate acidity was determined using the Soxhlet–Henkel method, which involves the titration of milk with standardised 0.25 N sodium hydroxide (NaOH) using 2 % phenolphthalein as the endpoint indicator. The endpoint was identified by the appearance of a faint pink colouration persisting for approximately 30 s. Acidity was expressed in Soxhlet–Henkel degrees (°SH), where one SH

corresponds to 0.0225 % lactic acid in the sample. Although originally developed for dairy milk, the Soxhlet–Henkel method has been widely applied for comparative acidity assessment of plant-based milk analogues due to its simplicity and reproducibility, with the limitation that organic acid profiles may differ from those of bovine milk (26, 25).

Physicochemical analysis

The pH and electrical conductivity of the milk samples were measured using a calibrated conductivity meter. Dynamic viscosity measurements were performed at 20 °C using an Ostwald capillary viscometer. The efflux time (t , s) required for the milk sample to flow through the capillary was recorded and the dynamic viscosity (η) was calculated using the viscometer constant (K), specific to the instrument geometry, according to the relationship:

$$\eta = K \times t \quad (\text{Eqn. 1})$$

Where η is expressed in mPa·s, K is the viscometer constant (mPa·s⁻¹) and t is the flow time (s). Viscosity values were reported in millipascal-seconds (mPa·s), which is the appropriate unit range for milk and milk-like beverages, including plant-based milk alternatives (17, 18, 22).

Sample density was determined at 20 °C using a calibrated lactodensimeter. All measurements were carried out in triplicate to ensure analytical precision and reproducibility and results are expressed as mean $\pm$ standard deviation (SD).

It is noted that viscosity in milk and plant-based milk systems is influenced by multiple factors, including total solids content, starch characteristics, protein concentration, fat globule size and the presence of soluble polysaccharides, rather than by fat or protein content alone (18, 27). Therefore, any observed differences in viscosity among samples were interpreted considering the combined effects of compositional and structural attributes, rather than attributing changes solely to reductions in fat or protein levels.

Data collection and statistical analysis

All experimental data obtained from milk extracts were subjected to statistical analysis using IBM SPSS Statistics software (Version 27.0). Each analytical parameter for each sample was measured in triplicate and results are expressed as mean $\pm$ standard deviation (SD). Comparisons between two related groups, specifically raw bovine milk and pasteurised bovine milk, were performed using the Student's t -test, as these samples originated from the same milk source and differed only by thermal treatment. Comparisons among multiple independent milk types (almond milk, soy milk, immature rice milk and bovine milk) were carried out using one-way analysis of variance (ANOVA), as the treatments represented distinct sample groups prepared independently. When significant differences were detected by ANOVA, mean separation was performed using an appropriate post-hoc test (e.g., Tukey's HSD) at a significance level of $p < 0.05$.

Although the experimental work followed a controlled laboratory setup with uniform processing and analytical conditions, the data structure did not involve blocking factors; therefore, statistical interpretation was primarily based on one-way ANOVA and t -test and the term completely randomised design (CRD) is more appropriate than a completely randomised block design (CRBD). All samples were randomly analysed to minimise experimental bias.

Results

Comparative assessment with selected physicochemical parameters such as proteins, fats, SNF, lactose and lactic acid w.r.t. its percentage availability in PBMs and bovine milk was evaluated. Almond milk, soy milk and immature rice milk were selected as representative PBMs due to their growing relevance in consumer markets, while bovine milk was assessed in both raw and pasteurised forms. Pasteurisation is widely reported to cause minimal alterations in protein and lactose content, while moderately reducing fat and total solids due to thermal and physical effects on milk fat globules (23). In agreement with this, the present study observed no statistically significant differences between raw and pasteurised cow's milk for most parameters, except for a clear reduction in fat content following pasteurisation. As per the earlier study and the present study, among the PBMs, soy milk exhibited comparatively higher protein and SNF contents than almond milk, consistent with its legume origin and previously reported compositional profiles (22). As expected, bovine milk demonstrated overall higher levels of protein, fat, SNF and lactose compared with PBMs, reflecting its naturally balanced macronutrient composition and superior nutritional density (28).

Immature rice milk exhibited a comparatively higher apparent protein content (10.00 ± 1.09 %) than the other plant-based milks and bovine milk evaluated in this study. This observation may be partially attributable to the use of immature rice grains harvested at the milky stage, a developmental phase characterised by relatively higher protein accumulation before extensive starch deposition (29, 30). Previous studies have reported protein contents of approximately 12–15 % (dry weight basis) in immature rice grains, compared to lower values in fully matured rice (30). Fat content followed the expected trend, with bovine milk exhibiting significantly higher values than PBMs, while immature rice milk contained minimal fat. Solid-not-fat values were highest in bovine milk and comparatively lower in PBMs, reflecting differences in total solids and macromolecular composition. Lactose was detected exclusively in bovine milk, whereas PBMs, including immature rice milk, were lactose-free, supporting their suitability for lactose-intolerant consumers (31).

Acidity and pH measurements further distinguished bovine milk from PBMs. Higher titratable acidity and lower pH in cow's milk are consistent with the presence of lactose and naturally occurring lactic acid, even in non-fermented dairy systems (31). In contrast, PBMs exhibited lower acidity and relatively higher pH values, which are primarily governed by native organic acids and buffering components of plant matrices rather than microbial fermentation. Electrical conductivity was also higher in bovine milk, attributable to

its greater mineral and ionic content, whereas lower conductivity in PBMs reflects reduced ionic strength and the absence of casein-associated mineral equilibria (32).

Overall, these findings highlight fundamental compositional and functional differences between bovine milk and PBMs. While immature rice milk demonstrated a comparatively high apparent protein value, this result should be interpreted conservatively and considered preliminary until supported by additional analytical validation. Rather than serving as a direct nutritional equivalent to bovine milk, PBMs-including immature rice milk-should be viewed as compositionally distinct beverages with specific functional and dietary applications. As the summary of assessment with respect to proteins, fats, SNF, lactose and lactic acid is tabulated at Table 1 and graphical plotting of comparative assessment is shown in Fig. 1. Also, Table 2 shows the comparison of acidity, pH, conductivity, density and viscosity in cow milk, almond milk, soya milk and immature rice milk, which are graphically reflected in Fig. 2.

Discussions

Comparative analysis of milk acidity, expressed in Soxhlet-Henkel degrees ($^{\circ}\text{SH}$) and lactic acid percentage, showed significantly higher acidity in bovine milk than in plant-based milks (PBMs). This observation is consistent with the intrinsic composition of cow's milk, in which lactose serves as a fermentable carbohydrate and lactic acid may be present at low levels even in fresh milk due to inherent microbial activity or post-milking biochemical changes (33, 34). In contrast, PBMs do not naturally contain lactose and therefore their titratable acidity primarily reflects the presence of organic acids originating from raw materials or processing rather than microbial fermentation. As no fermentation step or microbial assessment was included in the present study, acidity observed in immature rice milk and other PBMs should be attributed to native organic acids and buffering components rather than lactic acid production by lactic acid bacteria.

Correspondingly, lower pH values observed in bovine milk samples reflect their higher titratable acidity. In dairy systems, the accumulation of lactic acid increases hydrogen ion concentration, resulting in a measurable decline in pH, which is widely used as an indicator of milk freshness and biochemical stability (33, 34). In PBMs, pH is influenced mainly by the botanical source, processing conditions and the presence of weak organic acids rather than lactose metabolism, explaining their comparatively higher pH values.

Table 1 Comparison of percentage availability of proteins, fats, SNF, lactose and lactic acid in cow milk, almond milk, soya milk and immature rice milk.

Parameters	Proteins (%)	Fats (%)	SNF (%)	Lactose (%)	Lactic acid (%)
Raw milk (cow)	2.94 ± 0.07	5.61 ± 0.08	7.86 ± 0.17	4.34 ± 0.09	0.17 ± 0.01
Pasteurized milk (cow)	3.18 ± 0.05	3.43 ± 0.07	8.82 ± 0.31	4.75 ± 0.15	0.18 ± 0.01
Almond milk	0.09 ± 0.02	0.66 ± 0.02	0.27 ± 0.03	0.19 ± 0.03	0.07 ± 0.01
Soy milk	1.79 ± 0.03	1.46 ± 0.01	5.14 ± 0.04	2.78 ± 0.03	0.06 ± 0.01
Immature rice milk	10 ± 1.09	0.4 ± 0.08	7.1 ± 0.19	0.00	0.04 ± 0.01
S.E(m)	0.015	0.003	0.015	0.003	0.0017
S.E(d)	0.021	0.004	0.021	0.004	0.0025
CD (5 %)	0.044	0.009	0.044	0.008	0.005
CV	2.20	0.76	1.35	0.64	8.84

Values represent mean values $\pm$ standard deviation (SD) of three independent parallel experiments ($p < 0.05$).

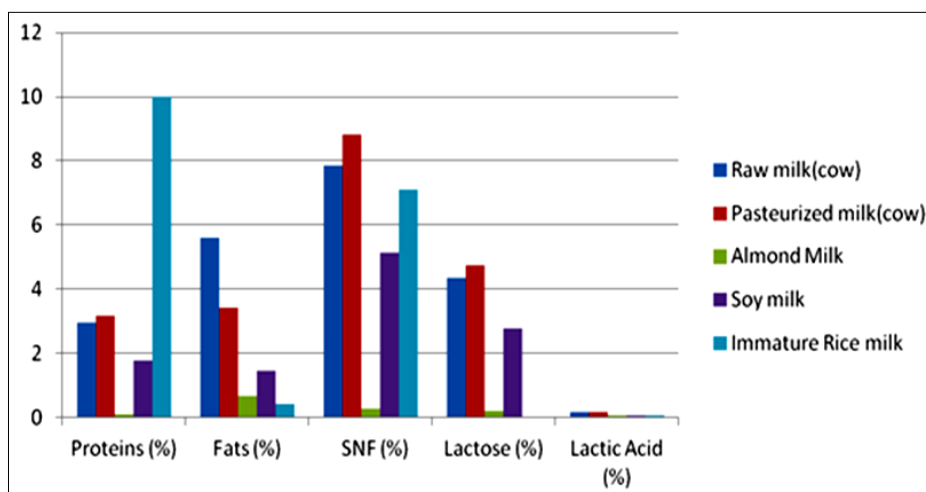


Fig. 1. Graph showing comparative study for available percentage of proteins, fats, SNF, lactose and lactic acid found in cow's milk, almond, soya milk and immature rice milk.

Table 2. Comparison of acidity, pH, conductivity, density and viscosity in cow milk, almond milk, soya milk and immature rice milk.

Parameters	Acidity (°SH)	pH	Conductivity (ms)	Density (g/cm ³)	Viscosity (Pa s) at 25 °C
Raw milk (cow)	7.35 ± 0.17	6.0 ± 0.05	3.41 ± 0.05	1.01 ± 0.01	1.81 ± 0.03
Pasteurized milk (cow)	8.72 ± 0.16	6.72 ± 0.04	3.43 ± 0.08	1.09 ± 0.022	1.74 ± 0.031
Almond milk	0.55 ± 0.07	8.25 ± 0.05	1.28 ± 0.04	1.01 ± 0.01	4.21 ± 0.03
Soy milk	2.40 ± 0.19	8.29 ± 0.05	1.99 ± 0.06	1.09 ± 0.012	2.00 ± 0.034
Immature rice milk	0.76 ± 0.06	6.5 ± 0.07	1.53 ± 0.01	1.07 ± 0.014	1.07 ± 0.01
S.E(m)	0.003	0.009	0.0034	0.0038	0.009
S.E(d)	0.004	0.127	0.004	0.005	0.012
CD (5 %)	0.009	0.026	0.009	0.01	0.026
CV	0.425	0.650	0.75	1.85	2.186

Values represent mean values ± standard deviation (SD) of three independent parallel experiments ($p < 0.05$).

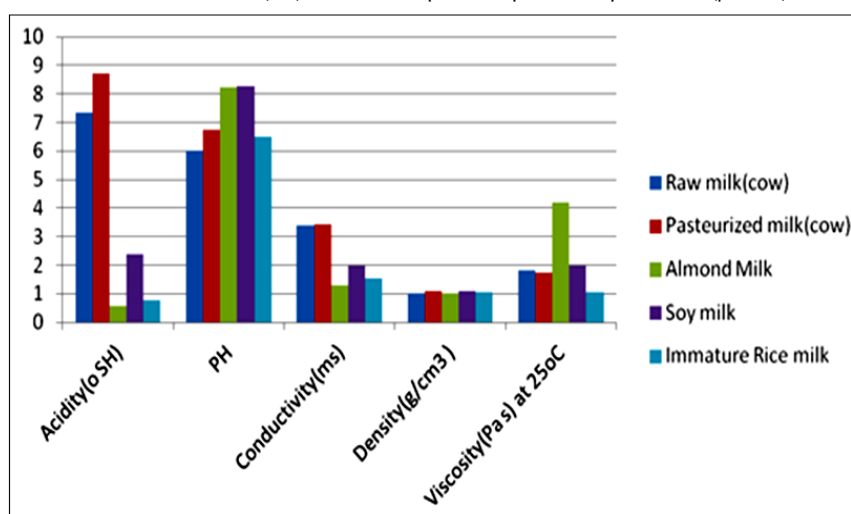


Fig. 2. Graph showing comparative study for the presence of Acidity, pH, conductivity, density and Viscosity w.r.t. cow's milk, almond milk, soya milk and immature rice milk.

Electrical conductivity was higher in cow's milk than in PBMs, which can be mechanistically linked to its greater ionic strength. Cow's milk contains higher concentrations of mineral salts such as calcium, potassium, sodium, phosphate and chloride ions, which contribute to electrical conductivity through partially dissociated ionic species in the aqueous phase (35). A significant proportion of these minerals exists in dynamic equilibrium between free ionic forms and those associated with casein micelles and serum proteins. Changes in pH and temperature can shift this equilibrium, thereby influencing conductivity. In PBMs, lower mineral content and the absence of casein micelles result in reduced ionic mobility and consequently lower conductivity values.

The lower density values observed in PBMs compared to cow's milk are attributable to their lower concentrations of fat, protein and SNF, leading to a higher proportion of free water in the system. Density in liquid foods is strongly governed by total solids and molecular packing efficiency; thus, dilution effects and reduced macromolecular content in PBMs result in lower measured densities. Although immature rice milk showed a higher apparent protein value, this should not be interpreted as a proportional increase in true solids content, as previously discussed, due to methodological limitations associated with protein estimation in plant-based matrices.

Viscosity measurements indicated that PBMs generally exhibited higher viscosity than cow's milk, reflecting differences in colloidal structure and macromolecular composition. In PBMs, viscosity is influenced by suspended plant particles, starch granules, soluble polysaccharides and protein–carbohydrate interactions, all of which can increase resistance to flow. Almond milk exhibited the highest viscosity among the samples, which may be attributed to the presence of finely dispersed insoluble particles and soluble polysaccharides that enhance structural entanglement and internal friction within the fluid matrix. Importantly, viscosity in such systems cannot be attributed solely to fat, protein, or SNF levels; rather, it arises from the combined effects of particle size distribution, hydration behaviour and intermolecular interactions within the continuous aqueous phase (11–14).

Conclusion

The present findings indicate that bovine milk, in both raw and pasteurised forms, generally exhibits higher concentrations of protein, fat, SNF and lactose when compared with commonly consumed plant-based milks such as almond and soy milk. An important exception was observed for immature rice milk, which demonstrated comparatively higher protein content while maintaining a lower fat level than bovine milk, almond milk and soy milk. Thermal processing primarily influenced the fat fraction of bovine milk, with pasteurisation resulting in a noticeable reduction, while other compositional parameters were comparatively less affected. Among the plant-based alternatives evaluated, soy milk showed higher protein, fat and SNF contents than almond milk, indicating its relatively superior nutritional density within this category. In contrast to bovine milk, plant-based milks were characterised by higher pH and viscosity but lower titratable acidity, electrical conductivity and overall nutrient density. Despite these compositional differences, plant-based milks may serve as suitable alternatives to bovine milk for specific population groups, particularly individuals with bovine milk protein allergy, lactose malabsorption, or dietary requirements involving reduced caloric intake, lipid modulation, or glycemic control. Furthermore, the absence of cholesterol and lactose, along with distinct macronutrient profiles, makes plant-based milks advantageous in dietary regimens associated with fasting or metabolic health considerations. Overall, while bovine milk remains nutritionally dense, selected plant-based milks—especially immature rice milk—demonstrate promising potential as functional alternatives under targeted nutritional and clinical contexts.

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Authors' contributions

K drafted the manuscript, participated in the design of the methodology and assisted in compiling the data. PK drafted the manuscript, performed the statistical analysis and assisted in compiling the data. GK and KS participated in the design of the methodology. MK participated in the design of the methodology, performed the statistical analysis and assisted in compiling the data. S participated in the design of the methodology. SK and AK edited the first draft of the manuscript. AJ edited the first draft of the manuscript and assisted in compiling the data. SP and N performed the statistical analysis. All authors reviewed and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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