



Effects of Alum and Lime Coagulants on Physicochemical Properties, Microstructure, Elemental Composition, Nutritional Quality, Microbial Stability, and Sensory Attributes of Soymilk-based Wara: A Nigerian Soft Cheese Obtained from Ilorin, Kwara State, Nigeria

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ABSTRACT: Soybean (*Glycine max* (L.) Merrill) is an important plant protein source widely used in traditional foods such as wara; a soft, unripened cheese commonly consumed in West Africa. The quality of wara is strongly influenced by the type of coagulant used during production. Consequently, the objective of this paper was to evaluate the effects of alum and lime as coagulants on the physicochemical properties, microstructure, elemental composition, nutritional quality, microbial stability, and sensory attributes of soymilk-based wara-Nigerian soft cheese obtained from a local market in Ilorin, Kwara State, North-Central Nigeria using appropriate standard method. Physicochemical evaluation showed that alum-coagulated wara exhibited significantly higher water absorption capacity (105.7%) and bulk density (0.86 g/mL) than lime-coagulated samples (47.7% and 0.78 g/mL, respectively; $p < 0.05$), indicating enhanced water retention and structural compactness. Scanning electron microscopy revealed a dense and compact protein matrix in alum-coagulated wara, whereas lime-coagulated wara displayed a more porous and loosely arranged microstructure. Energy-dispersive X-ray spectroscopy showed that both samples were predominantly composed of carbon and oxygen, with higher calcium content in lime-coagulated wara and detectable aluminum in alum-coagulated samples. Proximate analysis indicated comparable protein contents (~21.5%) in both samples, while ash content was significantly higher in alum-coagulated wara. Microbiological assessment over five days of refrigerated storage revealed low total viable counts and absence of coliforms, indicating satisfactory microbial quality. Sensory evaluation demonstrated significantly higher preference scores for lime-coagulated wara in texture, taste, aroma, and overall acceptability. Overall, while alum enhanced structural and water-holding properties, lime produced wara with superior sensory quality and comparable nutritional and microbial stability, supporting its use as a preferred natural coagulant for household and small-scale wara production.

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Soybean (*Glycine max* (L.) Merrill) is among the most important legume crops worldwide, valued for its high protein and oil contents, averaging approximately 40% and 20%, respectively. Owing to its rich nutritional composition and functional versatility, soybean is widely used as a raw material for numerous plant-based foods, including both fermented and non-fermented traditional products (Usman *et al.*, 2025). The increasing interest in soy-based cheese analogues reflects global shifts toward plant-based milk alternatives driven by health considerations, dietary preferences, and sustainability concerns (Ironi *et al.*, 2025; Leal *et al.*, 2025). One such product is *wara*, a soft, unripened cheese traditionally produced from soymilk and widely consumed in West Africa, particularly Nigeria. As demand grows for affordable and sustainable plant-derived protein sources, soybean-based *wara* has gained recognition as a viable alternative to conventional dairy cheese (Awoyale *et al.*, 2025). Nutritionally, *wara* is a valuable source of high-quality protein, essential amino acids, lipids, and minerals. It also contributes non-heme iron, which is essential for hemoglobin synthesis and oxygen transport, with enhanced bioavailability when consumed alongside vitamin C-rich foods (daSilver *et al.*, 2023). Previous studies have further highlighted its contribution to dietary minerals and proximate nutrients, reinforcing its importance as an affordable protein source in developing regions (Adeyeye *et al.*, 2021). Beyond its nutritional significance, *wara* also holds cultural and economic relevance, serving as a common street food and household protein source. Coagulation is a key step in cheese production, involving protein destabilization and aggregation to form a curd matrix. In soy-based cheese production, the choice of coagulant strongly influences curd yield, moisture retention, textural properties, nutritional composition, microbial stability, and sensory quality (James *et al.*, 2017). Coagulants used in *wara* production are broadly classified into acid-based (e.g., lime juice, lemon juice, vinegar, and lactic acid), salt-based (such as alum and magnesium salts), and enzymatic coagulants (Oyinlola *et al.*, 2024; Liu *et al.*, 2024). Several studies have demonstrated that coagulant type significantly affects the textural, compositional, and microbial characteristics of soy-based *wara* (Akinyele *et al.*, 2019; Adebayo *et al.*, 2020). Among commonly used coagulants, alum (potassium aluminum sulfate) and lime (citric acid-rich juice) are widely adopted in traditional production due to their low cost and accessibility. Alum is known to improve curd firmness, moisture retention, and shelf stability; however, concerns have been raised regarding potential aluminum residues and consumer

safety (Shi *et al.*, 2024). In contrast, lime is a natural, plant-derived coagulant that is generally perceived as safer and more acceptable, although it may produce softer curds with reduced structural compactness (Oyinlola *et al.*, 2024). Despite its widespread consumption and cultural relevance, *wara* production remains largely artisanal and non-standardized. Variations in coagulant type, concentration, and processing conditions often result in inconsistent quality, short shelf life typically 2–3 days under ambient conditions and increased risk of microbial contamination (Oladipo *et al.*, 2012; Iwe *et al.*, 2013). Although previous studies have explored the influence of different coagulants on *wara* quality (Leal *et al.*, 2025), there remains limited information from integrated assessments that simultaneously examine physicochemical properties, microstructural features, nutritional composition, microbial stability during storage, and sensory acceptability within a single experimental framework.

Therefore, the objective of this paper was to evaluate the effects of alum and lime as coagulants on the physicochemical properties, microstructure, elemental composition, nutritional quality, microbial stability, and sensory attributes of soymilk-based *wara*-Nigerian soft cheese obtained from a local market in Ilorin, Kwara State, North-Central Nigeria

MATERIALS AND METHOD

Source of Materials: Soybeans (*Glycine max*) and coagulants (alum and fresh lime fruits) were obtained from a local market in Ilorin, Kwara State, North-Central Nigeria. All reagents used were of analytical grade. Laboratory analyses were carried out at the Department of Microbiology Laboratory, University of Ilorin, Nigeria.

Preparation of Soymilk: Soymilk was prepared according to the method described by Raji *et al.* (2023), with slight modifications. Five kilograms (5 kg) of soybeans were manually sorted to remove stones, damaged seeds, and other extraneous materials, then thoroughly washed. The cleaned beans were soaked in potable water at a ratio of 1:1 (w/v) for 2 h at room temperature (35–37 °C). After soaking, the beans were manually dehulled and repeatedly rinsed to remove the hulls. The dehulled beans were wet-milled into a fine paste using a grinding machine. The resulting slurry was mixed with sterile water at a ratio of 1:5 (w/v) and filtered through a sterile muslin cloth to obtain raw soymilk, which was collected in sterile containers for further processing.

Production of Wara: The extracted soymilk was heated to boiling (~100 °C) and maintained for 15 min with continuous stirring to ensure enzyme inactivation and microbial reduction. The boiled soymilk was then cooled to approximately 80 °C and divided equally into two portions. Coagulation was induced by adding 2% (w/v) alum solution (potassium aluminum sulfate) to one portion and 2% (v/v) freshly extracted lime juice to the other, based on preliminary trials and literature recommendations (Ndife *et al.*, 2021). Each mixture was gently stirred until visible curd formation occurred and allowed to stand for 10 min to complete coagulation. The curds were separated from the whey using sterile muslin cloth, gently pressed to remove excess moisture, and cut into uniform cubes measuring approximately 4 × 4 × 4 cm. The samples were wrapped in aluminum foil and stored at 4 ± 1 °C prior to analysis.

Determination of Physicochemical Properties

Water Absorption Capacity (WAC): Water absorption capacity was determined using the centrifugation method described by Ndife *et al.* (2021). Briefly, 0.5 g of each *wara* sample was mixed with 10 mL of distilled water in a centrifuge tube and vortexed for 30 s. The mixture was allowed to stand at room temperature for 30 min and subsequently centrifuged at 3,000 rpm for 25 min. The supernatant was decanted and measured. WAC was expressed as milliliters of water absorbed per gram of sample.

Foaming Capacity: Foaming capacity was evaluated following the method of James *et al.* (2019). A 1% (w/v) suspension of each *wara* sample was prepared in distilled water and adjusted to pH 7.4 using 1.0 N NaOH or HCl. A 100 mL aliquot was blended at high speed for 3 min and immediately transferred into a graduated cylinder. The volume of foam produced was recorded, and foaming capacity was expressed as the percentage increase in volume.

Bulk Density: Bulk density was determined according to the method described by Jacob *et al.* (2024). A known weight of *wara* sample was gently filled into a 5 mL graduated cylinder and tapped until a constant volume was attained. Bulk density was calculated as the ratio of sample weight to volume and expressed as g/mL.

Microstructural and Elemental Analysis: The microstructural characteristics and elemental composition of the *wara* samples were examined using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS) (Hitachi SU3500, Bruker QUANTAX 200). Samples were dried, mounted on aluminum stubs, and gold-

coated prior to imaging. SEM micrographs were captured at magnifications of 290×, 500×, and 1000×. Elemental analysis was conducted using ZAF correction, and results were expressed as both atomic and weight percentages, excluding contributions from the sample holder and coating materials.

Proximate Composition Analysis: Proximate composition, including moisture, ash, crude protein, crude fat, crude fiber, and carbohydrate contents, was determined using standard AOAC methods (2019). Crude protein content was estimated using the Kjeldahl method ($N \times 6.25$), while carbohydrate content was calculated by difference.

Microbiological Analysis and Shelf-Life Study: Microbial quality was assessed during refrigerated storage at 4 ± 1 °C over a five-day period. Ten grams (10 g) of each *wara* sample were aseptically homogenized in 90 mL of sterile Maximum Recovery Diluent to obtain a 10⁻¹ dilution. Serial dilutions were prepared, and aliquots were plated using the pour plate technique. Total viable bacterial counts were determined on Nutrient Agar, coliform counts on MacConkey Agar, and fungal counts on Potato Dextrose Agar. Bacterial plates were incubated at 37 °C for 24–48 h, while fungal plates were incubated at 28 °C for 72 h. Microbial counts were expressed as colony-forming units per gram (CFU/g) of sample.

Sensory Evaluation: Sensory evaluation was conducted using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely), following the method of Ajibola *et al.* (2021). A panel of 50 semi-trained assessors, who were regular consumers of *wara*, evaluated the samples for appearance, texture, taste, color, aroma, and overall acceptability. Samples were coded and presented in random order to minimize bias.

Statistical Analysis: All analyses were performed in triplicate, and results were expressed as mean ± standard deviation. Data were analyzed using SPSS software (version 25.0). Differences between alum- and lime-coagulated *wara* samples were assessed using an independent samples *t*-test, with statistical significance set at $p < 0.05$.

RESULTS AND DISCUSSION

Effect of Coagulants on Physicochemical Properties of Wara: The effects of alum and lime coagulants on the physicochemical properties of *wara* are presented in Fig. 1–3. Water absorption capacity (WAC) differed significantly ($p < 0.05$) between the samples. Alum-coagulated *wara* exhibited a markedly higher WAC (105.7%) compared to lime-coagulated *wara* (47.7%) (Fig.1). Foaming capacity values were

generally low for both samples (Fig. 2). Lime-coagulated *wara* showed a slightly higher foaming capacity (0.2%) than alum-coagulated *wara* (0.1%); however, this difference was not statistically significant ($p > 0.05$). Bulk density was significantly influenced by the type of coagulant used ($p < 0.05$) (Fig. 3). Alum-coagulated *wara* recorded a higher bulk density (0.86 g/mL), whereas lime-coagulated *wara* exhibited a lower value (0.78 g/mL). The significant differences observed in water absorption capacity and bulk density between alum- and lime-coagulated *wara* highlight the strong influence of coagulant type on protein–water interactions and curd architecture. The higher water absorption capacity of alum-coagulated *wara* indicates enhanced water retention within the protein matrix, likely resulting from ionic interactions between aluminum ions and soy proteins that promote tighter aggregation and reduced syneresis (Akinyele *et al.*, 2019). Salt-based coagulants are known to facilitate protein cross-linking, leading to denser curd structures with improved water-holding capacity (Fagbemi *et al.*, 2020). In contrast, the lower water absorption capacity and bulk density observed in lime-coagulated *wara* suggest the formation of a looser protein network with reduced water retention. Acid-induced coagulation primarily occurs through pH reduction toward the isoelectric point of soy proteins, resulting in protein denaturation and aggregation without extensive ionic bonding (Akinyele *et al.*, 2019; Liu *et al.*, 2024). Similar trends have been reported for acid-coagulated soy cheeses, which generally exhibit softer textures and lower density than salt-coagulated counterparts (Shi *et al.*, 2024).

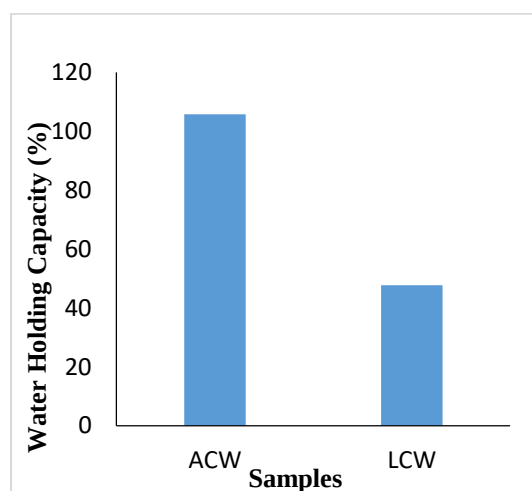


Fig. 1: Water holding capacity of *wara* produced using alum (ACW) and lime (LCW) as coagulants.

Alum-coagulated *wara* exhibited significantly higher water holding capacity (105.7%) compared to lime-coagulated *wara* (47.7%), suggesting differences in

protein network structure and water-binding ability influenced by the type of coagulant used (Fig 1). Lime-coagulated *wara* exhibited a higher foaming capacity (0.2) compared to alum-coagulated *wara* (0.1), suggesting differences in protein functionality and air incorporation ability. (Fig 2).

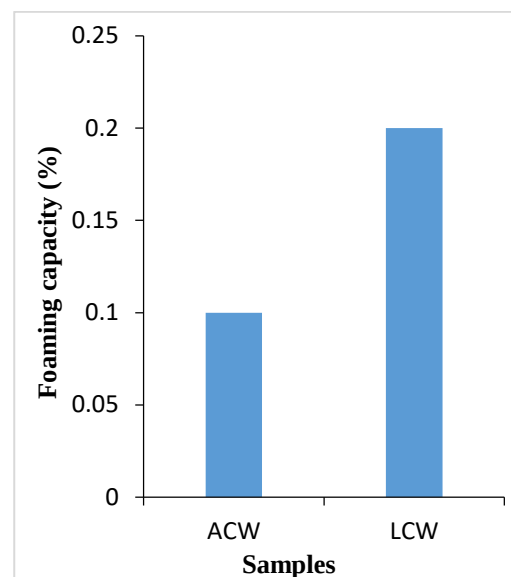


Fig. 2: Foaming capacity of *wara* produced using alum (ACW) and lime (LCW) as coagulants.

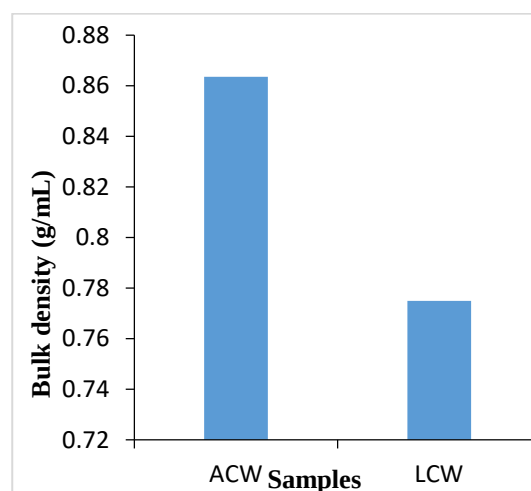


Fig. 3: Bulk density of *wara* produced using alum (ACW) and lime (LCW) as coagulants.

Alum-coagulated *wara* exhibited a higher bulk density (0.8636 g/mL) than lime-coagulated *wara* (0.775 g/mL), which may be attributed to the formation of a more compact protein network structure. (Fig 3).

Microstructural Characteristics: Scanning electron micrographs of alum- and lime-coagulated *wara* obtained at magnifications of 290×, 500×, and 1000×

are shown in Fig. 4 and 5. Alum-coagulated *wara* exhibited densely packed protein aggregates with narrow microfissures, characteristic of salt-induced coagulation where multivalent ions enhance protein aggregation and network compactness (Lu *et al.*, 2011). Such microstructural features are associated with increased mechanical strength, improved water retention, and firmer texture in soy-based curd products (Fagbemi *et al.*, 2020). In contrast, lime-coagulated *wara* exhibited a more open and porous microstructure, with larger voids and thinner protein strands, indicating weaker protein aggregation. The porous and discontinuous protein matrix observed in lime-coagulated *wara* is typical of acid-coagulated soy curds, where protein aggregation is driven primarily by pH-induced denaturation rather than ionic cross-linking (Liu *et al.*, 2024; Akinyele *et al.*, 2019). Larger pore sizes and thinner protein strands promote whey expulsion and reduced water-holding capacity, consistent with the lower WAC and bulk density recorded in this study (Shi *et al.*, 2024). These findings underscore the role of coagulation mechanism in defining the internal structure and functional behavior of soymilk-based *wara*.

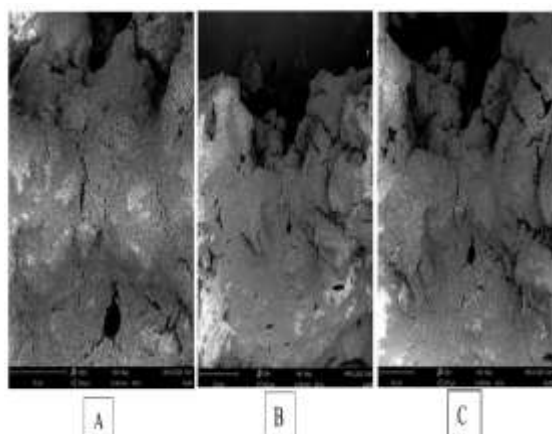


Fig. 4: Scanning electron micrographs (SEM) of alum-coagulated *wara* showing microstructural features at different magnifications.

The images (Fig 4) reveal a relatively dense and compact protein matrix with closely packed aggregates, narrow fissures, and limited pore spaces, indicative of strong protein–protein interactions induced by alum coagulation. Micrographs are presented at magnifications of (A) 1000×, (B) 290×, and (C) 500×.

The micrographs in figure 5 display a comparatively loose and porous network with larger voids, thinner protein strands, and less compact aggregation,

suggesting weaker protein cross-linking associated with lime coagulation. Micrographs are shown at magnifications of (A) 1000×, (B) 290×, and (C) 500×.

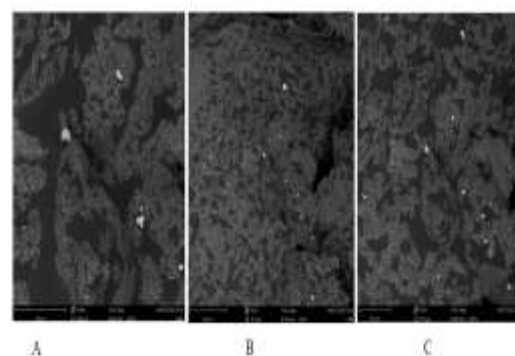


Fig. 5: Scanning electron micrographs (SEM) of lime-coagulated *wara* illustrating microstructural characteristics at different magnifications.

Elemental Composition by Energy-Dispersive X-ray Spectroscopy (EDS): Energy-dispersive X-ray spectroscopy (EDS) analysis revealed that both alum- and lime-coagulated *wara* samples were predominantly composed of organic elements, mainly carbon and oxygen (Table 1). In lime-coagulated *wara*, carbon accounted for 76.60% (atomic) and 63.56% (weight), while oxygen contributed 10.10% (atomic) and 11.16% (weight). Alum-coagulated *wara* exhibited higher carbon concentrations, with atomic and weight percentages of 81.55% and 71.88%, respectively, and oxygen contents of 8.64% (atomic) and 10.14% (weight). Nitrogen was detected in both samples, with slightly higher atomic concentration in lime-coagulated *wara* (5.87%) compared to alum-coagulated *wara* (4.94%). Calcium was more abundant in lime-coagulated *wara* (2.30% atomic; 6.36% weight), whereas alum-coagulated *wara* showed lower calcium levels (0.97% atomic; 2.86% weight). Aluminum was present at higher concentrations in alum-coagulated *wara* (1.06% atomic; 2.09% weight) compared to lime-coagulated *wara* (0.85% atomic; 1.58% weight). Iron was detected only in the lime-coagulated sample (0.22% atomic; 0.85% weight), while magnesium was observed exclusively in the alum-coagulated *wara* (0.28% atomic; 0.49% weight). Other elements, including phosphorus, sulphur, potassium, zirconium, and silicon, were present in both samples at varying concentrations. EDS analysis revealed that both alum- and lime-coagulated *wara* samples were dominated by carbon and oxygen, reflecting the organic matrix primarily composed of proteins, lipids, and carbohydrates. Similar elemental dominance has been reported in EDS analyses of dairy and protein-rich food matrices (Walstra *et al.*,

2006; McSweeney *et al.*, 2000). The relatively higher carbon content in alum-coagulated *wara* suggests greater retention of organic matter within the compact protein matrix. Nitrogen detected in both samples is attributable to protein content, as nitrogen is a fundamental component of amino acids and peptides. Comparable nitrogen presence has been reported in EDS studies of cheese and traditional coagulated milk products (Lucey *et al.*, 2011; Oyeyiola *et al.*, 2013). The higher calcium and phosphorus contents observed in lime-coagulated *wara* reflect the contribution of lime-based coagulants and the close association of these minerals within protein–mineral complexes (Walstra *et al.*, 2006; Fox *et al.*, 2017). Aluminium was more prominent in alum-coagulated *wara*, directly reflecting the use of aluminum salts during coagulation. Similar findings have been documented in foods processed with alum-based additives (Oyeyiola *et al.*, 2013). The selective presence of magnesium and iron in different samples suggests minor variations in trace element incorporation, possibly influenced by coagulant composition, processing equipment, or raw material characteristics (Walstra *et al.*, 2006). Overall, these results demonstrate that coagulant type significantly influences the mineral profile of *wara*.

Proximate Composition of Wara: The proximate composition of alum- and lime-coagulated *wara* samples is presented in Table 2. Moisture content was slightly higher in lime-coagulated *wara* (30.20%) compared to alum-coagulated *wara* (28.68%), with the difference being statistically significant ($p < 0.05$). Ash content was significantly higher ($p < 0.05$) in alum-coagulated *wara* (4.93%) than in lime-coagulated *wara* (3.91%). Crude protein content did not differ significantly ($p > 0.05$) between alum-coagulated (21.66%) and lime-coagulated (21.53%) *wara*. In contrast, fat, crude fiber, and carbohydrate contents showed significant differences ($p < 0.05$) between the two samples. The comparable protein contents observed in alum- and lime-coagulated *wara* indicate that coagulant type did not significantly affect protein retention, suggesting that both coagulation methods effectively preserve soy protein. Similar observations have been reported for soy-based cheese analogues, where protein recovery remained largely independent of coagulant type (Liu *et al.*, 2024). The higher ash content in alum-coagulated *wara* reflects increased mineral contribution from salt-based coagulants, consistent with earlier reports (Adeyeye *et al.*, 2021). While enhanced mineral content may offer nutritional benefits, it may also influence sensory perception and raise concerns regarding excessive mineral intake.

Table 1: Comparative Elemental Composition of Lime- and Alum-Coagulated Wara Samples

Element Name	Symbol	Element No.	LWA Atomic Conc. (%)	LWA Weight Conc. (%)	ACW Atomic Conc. (%)	ACW Weight Conc. (%)
Carbon	C	6	76.6	63.56	81.55	71.88
Oxygen	O	8	10.1	11.16	8.64	10.14
Nitrogen	N	7	5.87	5.68	4.94	5.08
Calcium	Ca	20	2.3	6.36	0.97	2.86
Phosphorus	P	15	1.38	2.95	0.57	1.29
Sulphur	S	16	1.19	2.63	0.99	2.34
Zirconium	Zr	40	0.39	2.43	0.26	1.77
Potassium	K	19	0.83	2.24	0.64	1.84
Aluminum	Al	13	0.85	1.58	1.06	2.09
Iron	Fe	26	0.22	0.85	–	–
Silicon	Si	14	0.29	0.56	0.1	0.21
Magnesium	Mg	12	–	–	0.28	0.49

Table 2: Proximate composition of alum- and lime-coagulated wara

Samples	Moisture %	Ash%	Fibre%	Lipid%	Protein%	CHO%
ACW	28.68 ± 0.01 ^a	4.93 ± 0.01 ^e	2.28 ± 0.02 ^f	20.50 ± 0.02 ^d	21.66 ± 0.02 ^b	21.11 ± 0.015 ^c
LCW	30.20 ± 0.012 ^a	3.91 ± 0.015 ^e	1.54 ± 0.02 ^f	20.94 ± 0.015 ^d	21.53 ± 0.02 ^b	22.15 ± 0.04 ^c

Values are expressed as mean ± standard deviation ($n = 3$). Mean values within the same row bearing different superscript letters are significantly different ($p < 0.05$).

Microbiological Quality during Refrigerated Storage: Microbial counts of *wara* samples during refrigerated storage (4 ± 1 °C) over five days are presented in Table 3. Total viable bacterial counts increased slightly with storage time in both samples but remained relatively low throughout the storage period. By day 5, total bacterial counts of 1.50×10^3

CFU/g and 1.55×10^3 CFU/g were recorded for alum- and lime-coagulated *wara*, respectively. Coliform bacteria were not detected in either sample throughout the storage period. Fungal growth was absent during the initial storage days but showed a slight increase from day 3 onward in both samples. Microbiological evaluation revealed low total viable

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counts and absence of coliforms throughout refrigerated storage, indicating satisfactory hygienic quality and effective thermal processing. These findings align with previous studies on freshly prepared *wara* stored under refrigerated conditions (Chen *et al.*, 2019), suggesting that coagulant type had minimal impact on microbial stability under controlled storage conditions.

Sensory Evaluation: Mean sensory scores for alum- and lime-coagulated *wara* are presented in Table 4. Lime-coagulated *wara* received significantly higher ($p < 0.05$) scores for texture, taste, aroma, and overall acceptability compared to alum-coagulated *wara*. No significant differences ($p > 0.05$) were observed between the samples with respect to color and appearance.

Despite the firmer structure and higher water retention of alum-coagulated *wara*, sensory evaluation revealed significantly higher preference scores for lime-coagulated samples, particularly for texture, taste, aroma, and overall acceptability. Acid-coagulated soy products are generally perceived as having a milder flavor and softer mouthfeel, which aligns with consumer expectations for traditional *wara* (Liu *et al.*, 2024; Akinyele *et al.*, 2019). The lower acceptability of alum-coagulated *wara* may be linked to subtle metallic or astringent aftertastes

associated with aluminum salts, as well as excessive firmness that may reduce palatability (Lu *et al.*, 2011). Similar reductions in consumer preference for salt-based coagulants at higher concentrations have been reported previously (Oyinlola *et al.*, 2024). These findings emphasize the need to balance structural integrity with sensory quality in *wara* production. The contrasting effects of alum and lime observed in this study underscore the importance of informed coagulant selection in *wara* production. Alum offers advantages in curd firmness, water retention, and structural stability, which may be beneficial for handling and short-term storage (Lu *et al.*, 2011; Fagbemi *et al.*, 2020).

However, concerns regarding aluminum intake and reduced sensory acceptance necessitate careful control of its application (Adeyeye *et al.*, 2021). Lime, as a natural and readily available coagulant, produced *wara* with superior sensory acceptability and aligns with consumer preferences for minimally processed foods (Ironi *et al.*, 2025; Leal *et al.*, 2025). Although lime-coagulated *wara* exhibited a less compact structure, optimization of processing conditions could enhance functional properties without compromising acceptability. Overall, these findings provide a scientific basis for improving the quality, safety, and consumer appeal of soymilk-based *wara*.

Table 3: Microbial counts (CFU/g) of alum- and lime-coagulated *wara* during refrigerated storage

Days	Alum-Coagulated Wara (ACW)			Lime-Coagulated Wara (LCW)		
	TBC (10 ⁻³ CFU/mL)	TCC (10 ⁻³ CFU/mL)	TFC (10 ⁻³ SFU/mL)	TBC (10 ⁻³ CFU/mL)	TCC (10 ⁻³ CFU/mL)	TFC (10 ⁻³ SFU/mL)
1	1.00	NG	NG	1.20	NG	NG
2	1.10	NG	NG	1.25	NG	NG
3	1.30	NG	2.0	1.30	NG	NG
4	1.45	NG	2.3	1.40	NG	1.8
5	1.50	NG	2.6	1.55	NG	2.0

Values are expressed as colony-forming units per gram (CFU/g). NG = no growth detected. TBC = total bacterial count; TCC = total coliform count; TFC = total fungal count. Refrigerated storage was maintained throughout the study period.

Table 4: Sensory attributes of alum- and lime-coagulated *wara* samples

Samples	Appearance	Texture	Taste	Colour	Aroma	Overall Acceptability
ACW	7.06 ± 0.26 ^a	6.02 ± 0.28 ^a	6.26 ± 0.18 ^a	6.06 ± 0.24 ^a	6.28 ± 0.20 ^a	7.30 ± 0.21 ^a
LCW	7.04 ± 0.23 ^a	6.48 ± 0.24 ^b	6.62 ± 0.23 ^b	6.06 ± 0.24 ^a	6.44 ± 0.23 ^b	7.45 ± 0.21 ^a

Values are expressed as mean ± standard deviation. Sensory evaluation was conducted using a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely. Different superscript letters within the same column indicate statistically significant differences between samples at $p < 0.05$. ACW = alum-coagulated *wara*; LCW = lime-coagulated *wara*.

Conclusion: This study demonstrates that coagulant type plays a critical role in determining the physicochemical, structural, nutritional, microbial, and sensory qualities of soymilk-based *wara*. Both alum and lime were effective under controlled processing conditions, yielding nutritionally valuable products with satisfactory microbiological quality during refrigerated storage. However, differences in

coagulation mechanisms resulted in distinct structural and sensory outcomes, highlighting the importance of coagulant selection in product optimization. The findings offer practical guidance for improving *wara* production by balancing functional performance with consumer preference and contribute to the broader understanding of coagulation mechanisms in soy-based cheese analogues.

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DECLARATION

Ethical Approval: This study involved human participants and therefore ethical approval was obtained from the Faculty of Life Sciences Ethical Review Committee, University of Ilorin. All procedures involving data handling and analysis were conducted responsibly and in accordance with standard academic and institutional guidelines.

Disclaimer (Artificial Intelligence): Author(s) hereby declare that no generative *Artificial Intelligence* (AI) technologies such as Large Language Models (ChatGPT, COPILOT, XLNet, Emie 3.0 Titan etc) and text-to-image generators have been used during writing or editing of this manuscript.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that have influence the work reported in this paper

Declaration of Data Availability: Data are available upon request from the corresponding author.

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