



Procurement Standards and Biochemical Quality Control in the Supply Chain of Traditional Fermented Beverages in Edo North, Nigeria: A Theoretical and Conceptual Review

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Abstract

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This study develops a theoretically grounded and conceptually coherent analysis of procurement standards and biochemical quality control within the supply chain of traditional fermented beverages in Edo North, Nigeria. Departing from fragmented accounts that isolate fermentation from its structural context, the paper argues that procurement practices constitute the primary conditions under which biochemical processes emerge. Drawing on recent (2021–2026) and foundational literature, and integrating empirical illustrations from palm wine, pito, and burukutu production in Edo North, the study demonstrates that variability in microbial composition and physicochemical stability is not incidental but structurally produced through informal procurement systems and decentralised distribution networks. The paper advances an integrative conceptual framework in which procurement, fermentation, and supply chain mediation are analytically inseparable. It concludes that effective quality control requires upstream standardisation, adaptive monitoring, and context-sensitive governance mechanisms. The study contributes to scholarship on informal production systems by offering a coherent, contextually grounded model for understanding and improving quality outcomes in traditional beverage supply chains.

Keywords: Procurement standards, Biochemical quality control, Traditional fermentation, Informal supply chains, Edo North, Nigeria, Conceptual review.

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Introduction

Traditional fermented beverages are an integral component of Nigeria's informal food manufacturing landscape, serving both nutritional and socio-cultural functions. In Edo

North, beverages such as *palm wine*, *pito*, and *burukutu* are not merely sources of sustenance but also vehicles of economic empowerment, particularly for rural households. These beverages sustain micro-enterprises, contribute to local livelihoods, and facilitate cultural rituals



and social interactions. Despite their ubiquity and importance, they are produced within largely informal systems characterised by decentralised operations, limited regulatory oversight, and heterogeneous production practices (Ukwuru & Muritala, 2023).

While the cultural and economic significance of these beverages is widely acknowledged, their biochemical quality and safety remain highly variable. Empirical studies highlight the complex microbial ecology inherent in traditional fermentation, including the presence of both beneficial lactic acid bacteria and potentially pathogenic organisms (Zakari et al., 2024). This duality presents a paradox for producers and consumers alike: fermented beverages provide health benefits while simultaneously carrying contamination risks. However, much of the literature focuses narrowly on microbial composition or processing techniques, often neglecting the broader socio-technical and supply chain factors that condition these outcomes.

A critical yet underexplored factor influencing quality variability is procurement. In Edo North, the sourcing of raw materials such as palm sap, grains, water, and fermentation containers is highly informal and context-dependent. For instance, palm wine tappers in Etsako communities frequently harvest sap using locally available containers, including repurposed plastics, which are rarely cleaned or sterilised before use. Similarly, grains for *pito* and *burukutu* in Auchi and Jattu are often purchased from open-air markets where environmental exposure to dust and microorganisms is high. Such practices, while rational within socio-economic constraints, directly influence the initial microbial load and physicochemical conditions of the raw materials, effectively preconfiguring fermentation outcomes (Mohammed et al., 2025).

The structural and systemic implications of procurement practices suggest that quality variability in traditional fermented beverages is not incidental but emergent from supply chain configurations. Decentralised production, fragmented distribution, and diffused accountability exacerbate variability introduced upstream, amplifying it across transport, storage,

and retail stages. Moreover, the lack of context-sensitive monitoring and quality control mechanisms limits the ability of producers to manage these dynamics effectively. By situating procurement at the intersection of social, economic, and biochemical processes, this study foregrounds it as a primary determinant of quality, challenging conventional frameworks that isolate fermentation as the principal locus of variability.

In response to these observations, this paper adopts a theoretical and conceptual review approach to examine procurement standards and biochemical quality control in the supply chain of traditional fermented beverages in Edo North. By integrating Nigerian case illustrations with recent (2021–2026) and foundational literature, it develops a coherent conceptual framework linking procurement, microbial dynamics, and supply chain mediation. This approach emphasises the emergent nature of quality, arguing for adaptive, context-sensitive governance strategies that align indigenous production knowledge with simplified scientific controls. Through this lens, the paper contributes to broader debates on informal manufacturing systems, offering a system-wide perspective that is analytically rigorous and practically relevant for improving safety, consistency, and sustainability in traditional beverage production.

A significant limitation in the scholarship on traditional fermented beverages in Nigeria is the analytical fragmentation of production processes. Most studies isolate fermentation, distribution, or storage as separate phenomena, often neglecting how procurement and supply chain structures interact to shape biochemical outcomes. In Edo North, the production of beverages such as *kunu*, *zobo*, and *nono* occurs within informal, decentralised networks, where each stage from sourcing raw grains, hibiscus calyces, or cow's milk, to fermenting, packaging, and retail is influenced by socio-economic and environmental factors. This fragmentation is reflected in variable microbial composition, physicochemical properties, and ultimately, consumer perception of quality. To understand quality outcomes holistically, it is therefore necessary to integrate procurement,

fermentation, and distribution within a unified analytical framework.

Supply Chain Quality Management (SCQM) provides a useful starting point for this integration, as it emphasises coordination, standardisation, and continuous monitoring across all stages of production. However, conventional SCQM frameworks assume formalised, resource-rich environments that allow for strict adherence to specifications and traceability. In the context of locally fermented beverages in Edo North, SCQM principles must be adapted to account for informal procurement practices, resource constraints, and the relational logics underpinning production. For example, *kunu* producers in Auchu and Jattu often rely on personal networks to obtain millet or sorghum, selecting grains based on prior experience or visual inspection rather than formal quality certification. Similarly, *zobo* producers source hibiscus calyces directly from local farms, sometimes without washing or sanitising, reflecting a pragmatic adaptation to available resources. Conceptually, these practices demonstrate that procurement in informal beverage systems is not a peripheral administrative stage but a structural determinant of biochemical quality.

Complementing SCQM, Food Safety Systems Theory provides a lens to examine how risk emerges and can be mitigated in dynamic production environments. Frameworks such as Hazard Analysis and Critical Control Points (HACCP) emphasise the identification of critical points where contamination is most likely to occur and where intervention can be most effective. In formal industrial settings, these critical control points are often located within centralised processing or packaging stages. In contrast, for beverages like *nono* or *zobo*, the critical control point often resides upstream, at the point of procurement. For instance, the microbiological quality of cow's milk used for *nono* in rural Etsako communities is largely determined by handling, storage, and hygiene practices prior to fermentation, while water used for hibiscus extraction in *zobo* directly influences pH and microbial stability. Adaptive application of food safety principles is therefore essential, translating formal standards into

feasible interventions that account for socio-economic and infrastructural realities.

Integrating these theoretical perspectives leads to a systemic view of quality in locally fermented beverages, where procurement, fermentation, and distribution are analytically inseparable. Procurement decisions establish the microbial and physicochemical baseline; fermentation processes amplify or modulate these conditions, resulting in dynamic biochemical transformations; and the supply chain characterised by informal transport, storage, and retail mediates and often amplifies variability. In this integrated model, quality emerges as an outcome of interdependent socio-technical processes, rather than as an attribute produced in isolation during fermentation. This conceptualisation challenges traditional narratives that locate quality solely within artisanal skill or fermentation techniques, redirecting attention to upstream structural determinants and systemic interactions.

By reframing the analysis in terms of systemic integration, this study provides a foundation for both scholarly inquiry and practical intervention. For scholars, it highlights the need to examine locally fermented beverages through multi-level frameworks that account for social, economic, and biochemical factors. For practitioners and regulators, it emphasises the importance of context-sensitive procurement standards, simplified monitoring tools, and cooperative supply chain structures that can enhance consistency and safety without undermining local production practices. In doing so, it establishes a theoretical platform for subsequent analysis of procurement practices, biochemical quality control, and supply chain mediation in Edo North's traditional beverage systems.

Procurement as a Structural Determinant of Quality

Procurement in traditional beverage production is frequently underestimated, often treated as a preliminary, transactional stage rather than a process that fundamentally shapes biochemical outcomes. In Edo North, the production of beverages such as *kunu*, *zobo*, and *nono* illustrates how procurement decisions are

structurally constitutive of quality. The selection, handling, and preparation of raw materials grains, hibiscus calyces, cow's milk, and water introduces microbial populations and chemical properties that serve as the initial conditions for fermentation. Consequently, the variability observed in fermented beverages is less a product of artisanal skill alone and more an emergent property of the inputs secured at the procurement stage.

In the case of *kunu*, millet or sorghum is often sourced from local markets where storage practices vary widely. Grains may be exposed to dust, pests, and moisture fluctuations, introducing diverse microbial communities before fermentation even begins. Producers rely heavily on visual assessment, tactile inspection, and prior experience to select grains deemed "good quality," reflecting a pragmatic adaptation to the informal market environment. However, this informal procurement logic produces structural variability: the microbial composition of grains differs between batches, creating differences in fermentation kinetics, taste, acidity, and shelf life (Mohammed et al., 2025).

Similarly, the production of *zobo* in Edo North demonstrates the direct impact of procurement on biochemical outcomes. Hibiscus calyces are typically harvested from local farms or open markets, sometimes without washing or sanitisation. Water used for extraction may be drawn from wells or streams with variable microbiological quality. Each of these inputs introduces potential vectors of contamination, but they also contribute to desirable microbial activity when appropriately handled. Therefore, procurement acts as a critical control point, determining the baseline conditions under which fermentation occurs. In other words, quality is structurally anchored in procurement rather than merely shaped during processing.

The production of *nono*, a fermented milk beverage, further exemplifies procurement's determinative role. Milk sourced from local Fulani herders or smallholder farmers is frequently unpasteurised and transported under ambient conditions. Temperature fluctuations, handling practices, and storage duration influence the proliferation of lactic acid bacteria and the risk of contamination by pathogenic

organisms such as *Escherichia coli* or *Listeria monocytogenes*. These microbial dynamics, established at the point of procurement, directly affect acidity, viscosity, and safety, illustrating that structural quality determinants operate upstream of the fermentation process itself (Adesulu-Dahunsi et al., 2025).

From a theoretical perspective, recognising procurement as a structural determinant of quality challenges the prevailing assumption that fermentation alone dictates the biochemical properties of traditional beverages. Instead, it situates quality within a socio-technical system where informal market conditions, social relations, and environmental exposure intersect to shape microbial ecology. In Edo North, this implies that interventions to improve the quality and safety of *kunu*, *zobo*, and *nono* cannot be limited to processing techniques or storage practices; they must begin with upstream procurement. Strategies such as promoting clean water usage, providing guidance on grain and hibiscus selection, and encouraging hygienic milk handling practices could reduce initial variability, thereby creating conditions that support more predictable and safe fermentation outcomes.

Adaptive Food Safety and Contextual Rationality

Traditional models of food safety, such as Hazard Analysis and Critical Control Points (HACCP), assume formalised production environments with standardised processes, continuous monitoring, and regulatory enforcement. While these frameworks have proven effective in industrial settings, their direct application to locally fermented beverages in Edo North is constrained by the informal nature of production, limited infrastructure, and socio-economic realities of small-scale producers. For example, *kunu* producers in Auchi and Jattu rarely have access to laboratory testing, temperature-controlled storage, or sterilised processing equipment, yet they consistently produce beverages that are culturally and commercially accepted. This illustrates a critical insight: traditional production systems rely on contextually rational adaptations rather than formalised protocols (Mohammed et al., 2025).

Contextual rationality refers to the way producers make quality and safety decisions within the constraints of their environment. In Edo North, procurement, handling, and fermentation practices are guided by experiential knowledge, social networks, and immediate resource availability. For instance, *zobo producers* often select hibiscus calyces based on visual inspection and freshness rather than laboratory microbiology, while *nono producers* rely on the perceived hygiene of milk sources and handling practices. These practices are not arbitrary; they represent rational adaptations to local realities where formal regulatory oversight is weak, and economic pressures demand low-cost solutions. Conceptually, this situates food safety as emergent from local decision-making systems, rather than imposed externally.

Adaptive food safety approaches emphasise feasibility, incremental intervention, and risk prioritisation within informal systems. For locally fermented beverages, this means focusing on critical points where interventions are most effective and realistic, particularly at procurement. For *kunu*, ensuring grains are sourced from dry, pest-free environments and washed before fermentation can reduce initial microbial variability. For *nono*, sourcing milk from herders with basic hygiene practices, and cooling or fermenting promptly, helps minimise pathogenic growth. *Zobo* production benefits from washing and briefly boiling hibiscus calyces and using treated water for extraction. These adaptive strategies align with HACCP principles but are calibrated to local contexts, balancing safety, cost, and cultural practice (Adesulu-Dahunsi et al., 2025).

This adaptive framework also acknowledges the dual role of microorganisms in locally fermented beverages. Beneficial microbes, such as lactic acid bacteria in *nono* or wild yeasts in *kunu*, are essential for fermentation, flavour development, and potential probiotic benefits. At the same time, pathogens and spoilage organisms introduced during procurement or handling pose risks to consumers. Adaptive food safety recognises that interventions must preserve beneficial microbial activity while limiting harmful contamination, a balance achievable

only by considering the socio-technical realities of production systems in Edo North.

Finally, contextual rationality emphasises that food safety is socially and economically embedded. Producers often balance microbial safety against market demands, taste preferences, and resource availability. For example, delaying fermentation to suit market timing may increase microbial variability, yet ensures economic viability. This underscores a critical theoretical insight: in informal beverage production, quality and safety emerge from interdependent socio-technical processes, in which procurement, microbial ecology, and adaptive practices are inseparable. Conceptually, adaptive food safety transforms the understanding of risk from a rigid, compliance-oriented framework to a dynamic, context-sensitive system that respects both local knowledge and scientific principles.

Procurement Practices and the Configuration of Fermentation Conditions

1. Socially Embedded Procurement and Informal Logic

In Edo North, procurement for locally fermented beverages is embedded within social, economic, and environmental realities that prioritise accessibility and cost-effectiveness over formalized standardization. Producers of *kunu*, *zobo*, and *nono* operate in contexts where formal supply chains are limited or absent, and procurement decisions are guided by experience, community networks, and immediate availability. For example, a *kunu* producer in Auchu may source millet from a trusted local vendor based on prior knowledge of storage conditions rather than laboratory verification. Similarly, *zobo* producers may select hibiscus calyces directly from farms or open-air markets, prioritising freshness and price over controlled microbial quality. *Nono* producers rely on the trustworthiness of milk suppliers, often balancing hygiene considerations against availability and cost. These procurement practices, while locally rational, introduce variability in raw materials that fundamentally shapes fermentation outcomes.

The informal nature of procurement in Edo North has structural consequences. Variability in microbial load, moisture content, and physicochemical properties is introduced before fermentation even begins. For instance, grains for *kunu* sourced from high-humidity markets may already harbour mould spores, while unwashed hibiscus calyces for *zobo* carry environmental yeasts and bacteria. Milk for *nono*, if not cooled promptly, may contain a heterogeneous mixture of lactic acid bacteria and potential pathogens. Conceptually, this demonstrates that procurement does not merely precede fermentation it configures the initial biochemical landscape, establishing the conditions under which microbial communities will interact and fermentation will proceed.

2. Biochemical Implications of Raw Material Variability

The impact of procurement decisions on biochemical quality is particularly evident in the fermentation dynamics of locally produced beverages. In *kunu*, the composition of millet or sorghum determines the spectrum and activity of fermentative microbes, influencing pH decline, alcohol content, and viscosity. Variations in grain moisture, starch composition, or microbial load at the point of procurement can lead to noticeable differences in taste, consistency, and shelf life between batches. For *zobo*, water quality and the microbial status of hibiscus calyces dictate the rate of fermentation, acidity development, and stability of anthocyanin pigments that influence colour and flavour. *Nono* production illustrates an even more direct microbial linkage: lactic acid bacteria in milk proliferate under conditions set by procurement, such as ambient temperature during transport, initial microbial diversity, and handling hygiene. In all cases, procurement acts as a primary determinant of fermentation kinetics and functional properties, with downstream processing only amplifying or modulating these effects (Adesulu-Dahunsi et al., 2025).

3. Temporal and Environmental Dynamics

Beyond the inherent variability of raw materials, environmental exposure during transport and

storage further shapes biochemical outcomes. In Edo North, beverages are often transported in non-standardized containers over uneven terrain, exposing them to fluctuating temperatures and additional microbial inoculation. *Kunu* transported from rural production sites to urban markets may undergo partial fermentation en route, altering acidity and viscosity before reaching consumers. *Zobo* prepared in open-air processing spaces is subject to airborne microbial seeding, which may accelerate fermentation or, conversely, introduce spoilage organisms. *Nono*, sensitive to temperature changes, may experience rapid lactic acid accumulation or unwanted microbial growth if milk is not handled appropriately. These temporal and environmental factors illustrate that fermentation conditions are continuously configured by upstream procurement and subsequent handling, making quality control a dynamic, system-wide challenge.

4. Implications for Quality Governance

Understanding procurement as a configurative stage of fermentation has important implications for quality management in locally fermented beverages. Rather than focusing exclusively on processing techniques or storage, interventions must address upstream input quality and handling practices. Simple measures such as ensuring grains are stored dry, washing hibiscus calyces, or providing milk cooling options can significantly reduce variability and improve both safety and consistency. Furthermore, cooperative procurement strategies, where groups of producers collectively source inputs according to agreed standards, may enhance uniformity while remaining feasible within informal systems. This approach aligns with adaptive food safety principles, emphasizing interventions that are practical, context-sensitive, and embedded within local socio-economic realities (Mohammed et al., 2025).

5. Conceptual Synthesis

From a theoretical perspective, procurement practices in Edo North illustrate a systemic view of quality formation: inputs, environmental exposure, and social logic co-produce the

conditions under which fermentation unfolds. In this framework, biochemical variability is not merely a consequence of artisanal skill or spontaneous fermentation but emerges from the structured interplay of procurement, microbial ecology, and supply chain dynamics. Recognizing this interdependence allows for a more precise conceptualization of quality control, where interventions target the entire production ecosystem rather than isolated processing stages. For *kunu*, *zobo*, and *nono*, this integrated perspective provides a foundation for both scholarly analysis and the design of locally relevant, scientifically informed governance strategies.

6. Informality, Experience, and the Logic of Practice

The production of locally fermented beverages in Edo North operates within highly informal socio-economic and infrastructural contexts. Unlike industrial food systems, where procurement, processing, and quality control are formalised and codified, producers of *kunu*, *zobo*, and *nono* rely on practical knowledge, experiential judgement, and social networks to navigate constraints. This informal logic of practice shapes procurement choices, fermentation methods, and handling strategies in ways that are locally rational but often invisible to conventional regulatory frameworks (Ukwuru & Muritala, 2023).

Experience is central to this logic. Producers assess the quality of millet, sorghum, hibiscus calyces, or cow's milk based on sensory cues appearance, texture, aroma, and prior outcomes rather than laboratory testing. For instance, a *kunu* producer may select millet that appears clean, dry, and free of pests, relying on accumulated knowledge of how grains from particular markets ferment over time. Similarly, *zobo* producers often judge the freshness of hibiscus by colour intensity and dryness, while *nono* producers evaluate milk based on consistency and smell. These tacit assessments are learned over repeated practice and constitute a knowledge system that governs quality in the absence of formal standards.

Informality also extends to the tools, containers, and environments used in production. *Kunu* is frequently fermented in clay pots or reused plastic containers; *zobo* is extracted and cooled in open vessels; *nono* is produced using milk churned and fermented in ambient conditions. While these practices introduce variability in microbial composition and physicochemical properties, they are adapted to the realities of resource constraints, climate, and market logistics. The informality of these arrangements does not imply negligence but reflects a contextual rationality whereby producers optimise outcomes within available means (Mohammed et al., 2025).

The logic of practice highlights the interdependence between procurement and fermentation. Informal sourcing decisions such as purchasing millet from a particular trader or collecting milk from a familiar herder directly influence microbial communities and biochemical trajectories. For *zobo*, variations in water source and hibiscus handling produce consistent differences in acidity and anthocyanin stability, demonstrating that upstream choices shape downstream outcomes. In effect, quality is co-produced through a combination of environmental exposure, material properties, and the practical reasoning of producers. This aligns with contemporary theorisation in socio-technical studies, which emphasises that material and human factors are mutually constitutive in shaping outcomes (Adesulu-Dahunsi et al., 2025).

From a conceptual standpoint, acknowledging the logic of practice provides a bridge between formal food safety frameworks and local production realities. Adaptive interventions must respect the informal knowledge systems that govern production while introducing manageable enhancements to reduce risk. For example, promoting simple hygiene practices, advocating for safer water sources, or introducing low-cost monitoring tools can improve the consistency and safety of *kunu*, *zobo*, and *nono* without disrupting the socio-cultural logic that sustains local production networks. Recognising the interplay of informality, experience, and practical reasoning thus reframes biochemical variability as a

structurally emergent property of localised production systems, rather than a failure of artisanal competence.

Nigerian Case Illustrations: Tracing Variability Upstream

The variability observed in locally fermented beverages in Edo North can often be traced to procurement and handling practices at the very start of the production process. For example, in *kunu* production, millet or sorghum sourced from open-air markets in Auchi and Jattu exhibits significant differences in moisture content, pest infestation levels, and microbial load. Producers report that batches of millet from the same vendor may ferment differently, resulting in inconsistent viscosity, acidity, and taste. These variations are not merely incidental but emerge from the interaction of environmental exposure, storage practices, and informal sourcing networks that constitute the upstream procurement system (Mohammed et al., 2025).

Similarly, *zobo* production illustrates the impact of upstream variability on final product quality. Hibiscus calyces, harvested from different farms or purchased from local markets, show marked differences in microbial content and pigment stability. Water used for extraction ranging from well water to municipal supply further contributes to microbial and physicochemical variation. Producers in Edo North often report that the same process, when applied to calyces from different sources, yields *zobo* with contrasting acidity, colour intensity, and shelf life. This demonstrates that biochemical outcomes are pre-configured at the procurement stage, with subsequent fermentation and storage largely modulating, rather than fully determining, final quality (Zakari et al., 2024).

The production of *nono*, a fermented milk beverage, provides a complementary case. Milk collected from smallholder Fulani herders or local farmers arrives at production sites with highly variable microbial compositions due to differences in animal health, milking hygiene, and transport conditions. Producers indicate that milk collected in the early morning often ferments differently than milk obtained later in the day, even when the same fermentation

technique is applied. Temperature fluctuations during transport and handling exacerbate these differences, affecting lactic acid production, viscosity, and safety. This underscores a central insight: procurement practices establish the baseline biochemical landscape upon which fermentation dynamics operate (Adesulu-Dahunsi et al., 2025).

These Nigerian case illustrations collectively highlight the structural nature of variability in traditional beverage systems. They demonstrate that differences in taste, acidity, microbial composition, and shelf life are often traceable to upstream decisions, such as the selection of raw grains, water source, or milk handling methods. While artisanal skill and fermentation technique contribute to quality, the primary determinants are the conditions introduced at procurement. This aligns with theoretical perspectives on socio-technical systems, which argue that outcomes emerge from the interaction of human decisions, material properties, and environmental contexts.

Finally, tracing variability upstream has practical implications for quality governance. By identifying procurement as a critical control point, interventions can be designed to target the earliest stage of the production system, where improvements can have disproportionate effects on downstream fermentation outcomes. Simple, context-sensitive measures such as sourcing grains from dry, well-stored environments, washing hibiscus calyces, or adopting basic hygienic practices in milk collection can reduce microbial heterogeneity and enhance both safety and consistency. Nigerian case studies thus reinforce the conceptual argument that quality is structurally and systemically produced, not merely a consequence of artisanal fermentation or downstream processing.

Biochemical Quality Control as an Emergent Process

Biochemical quality control in locally fermented beverages such as *kunu*, *zobo*, and *nono* cannot be understood as a discrete intervention applied after production; rather, it emerges dynamically from the interplay of procurement practices, microbial ecology, and supply chain conditions.

The concept of emergent quality recognises that physicochemical properties such as acidity, viscosity, alcohol content, and colour stability are not solely products of artisanal skill but are co-constituted by the conditions introduced at each stage of the production system. In Edo North, variability in raw materials, handling, and environmental exposure collectively shapes the trajectory of fermentation and, by extension, final product quality (Adesulu-Dahunsi et al., 2025).

In *kunu*, for example, the biochemical composition of millet or sorghum including starch content, moisture level, and naturally occurring microbial communities sets the initial parameters for fermentation. Microbial activity during fermentation is influenced by these parameters, leading to differences in pH decline, viscosity, and flavour development between batches. Similarly, *zobo*, produced from hibiscus calyces, is sensitive to the microbial load of the calyces and the water used for extraction. The interaction between endogenous yeasts and bacteria, environmental microorganisms, and extraction conditions generates a dynamic system in which acidity, pigment stability, and flavour compounds evolve continuously over time.

Nono, a fermented milk beverage, further exemplifies the emergent nature of biochemical quality. Lactic acid bacteria introduced via procurement through milk collection, handling, and storage undergo rapid proliferation under ambient conditions. The interplay of temperature, microbial competition, and substrate availability determines the rate of acidification, texture development, and microbial safety. In this context, quality is not static; it evolves temporally, with fermentation conditions interacting with microbial dynamics to produce outcomes that are context-specific, batch-dependent, and sensitive to upstream procurement and handling decisions (Mohammed et al., 2025).

Emergent biochemical quality also highlights the importance of supply chain mediation. Transport, storage, and retail conditions further influence microbial and physicochemical stability. For instance, *kunu* transported in non-standardised containers over long distances may

undergo partial fermentation en route, altering acidity and flavour. *Zobo* sold in roadside markets may experience pigment degradation or microbial seeding from ambient air, while *nono* kept at ambient temperatures can undergo excessive acidification or spoilage. These downstream dynamics underscore that biochemical quality control is distributed across the entire system, rather than confined to processing or storage stages.

Conceptually, recognising biochemical quality as emergent aligns with a socio-technical systems perspective. It foregrounds procurement, experiential knowledge, environmental exposure, and supply chain practices as co-determinants of product outcomes. Interventions aimed at improving safety and consistency in *kunu*, *zobo*, and *nono* should therefore target the system as a whole, beginning with upstream procurement, reinforcing adaptive handling practices, and incorporating context-sensitive monitoring. By viewing biochemical quality as emergent, this framework integrates scientific principles with local production realities, providing a coherent foundation for both theoretical analysis and practical governance in Edo North's informal beverage sector.

Microbial Ecology and Conditional Outcomes

The biochemical characteristics of locally fermented beverages in Edo North are inextricably linked to their microbial ecology, which is both complex and highly sensitive to upstream procurement and handling practices. Beverages such as *kunu*, *zobo*, and *nono* host diverse microbial communities including lactic acid bacteria, wild yeasts, and occasionally pathogenic organisms whose interactions determine acidity, flavour, viscosity, and safety. Importantly, these microbial populations are conditioned by the initial quality of raw materials, environmental exposure, and socio-technical handling practices, making quality an emergent and context-dependent phenomenon (Zakari et al., 2024).

In *kunu*, lactic acid bacteria such as *Lactobacillus plantarum* and *Leuconostoc spp.* drive fermentation, producing organic acids that

contribute to acidity, preservation, and flavour. The prevalence and activity of these microorganisms are contingent upon the moisture content, cleanliness, and storage conditions of millet or sorghum, as well as water used in processing. Variations in procurement practices such as sourcing grains from humid versus dry markets or using unwashed water containers directly shape microbial composition, resulting in differences in fermentation kinetics and taste profiles across batches. Thus, microbial ecology functions as a mediating mechanism, translating material and environmental inputs into conditional biochemical outcomes.

Zobo illustrates the same principle within a plant-based fermentation context. The extraction of hibiscus calyces introduces endogenous microbial populations, including yeasts and acid-tolerant bacteria, while water quality contributes additional microbial and chemical variability. Environmental factors such as ambient temperature, exposure to airborne microorganisms, and handling hygiene further modulate fermentation trajectories. The resultant acidity, pigment stability, and flavour profile are therefore conditional on a network of microbial interactions that are directly linked to upstream sourcing and handling practices (Mohammed et al., 2025).

For *nono*, the microbial ecology is primarily shaped by lactic acid bacteria derived from milk and ambient environmental sources. The rate of acidification, texture development, and microbial safety are contingent upon milk collection practices, transport conditions, and fermentation containers. Milk procured from different herders or farms can carry divergent microbial communities, which in turn influence the speed and quality of fermentation. This demonstrates that microbial dynamics and their associated biochemical outcomes are highly contingent upon both human decisions and environmental conditions, rather than solely intrinsic to the fermentation process.

Understanding microbial ecology as a conditional system provides critical insight for quality governance. Interventions in locally fermented beverages should not attempt to eliminate variability entirely but instead manage microbial interactions to optimise beneficial

outcomes while mitigating risk. For instance, simple upstream measures such as selecting dry, pest-free grains for *kunu*, washing hibiscus calyces for *zobo*, or sourcing milk from hygienically managed herds can steer microbial communities toward desired functional outcomes. By recognising that microbial ecology mediates the relationship between procurement, handling, and biochemical quality, this framework situates emergent variability as a structural property of the production system, providing both theoretical clarity and practical pathways for enhancing the safety, consistency, and sustainability of *kunu*, *zobo*, and *nono* in Edo North.

Physicochemical Variability and Process Sensitivity

The quality of locally fermented beverages such as *kunu*, *zobo*, and *nono* is not solely determined by microbial activity; it is also shaped by physicochemical properties that emerge dynamically during fermentation. Parameters such as pH, acidity, viscosity, temperature, moisture content, and pigment stability interact with microbial communities to define the sensory, nutritional, and safety attributes of these beverages. Crucially, these physicochemical variables are highly sensitive to procurement decisions, environmental conditions, and handling practices, highlighting the systemic and emergent nature of quality in informal production systems (Adesulu-Dahunsi et al., 2025).

In *kunu*, variations in grain type, moisture content, and particle size create differential substrate availability for fermentative microbes, influencing the rate of acidification and the final viscosity of the beverage. Grains with higher moisture content, for instance, support faster microbial metabolism, resulting in quicker pH decline and more pronounced sourness. Conversely, drier grains may ferment more slowly, producing milder flavours but extending fermentation time. These differences underscore the sensitivity of fermentation processes to upstream procurement and handling practices, revealing that physicochemical variability is pre-configured before active fermentation begins.

Zobo, a hibiscus-based beverage, demonstrates similar sensitivities. The anthocyanin content of hibiscus calyces, water mineral composition, and temperature during extraction collectively influence colour intensity, acidity, and flavour development. Slight variations in water quality such as pH or mineral content can accelerate or inhibit pigment stability and microbial activity, altering both aesthetic and sensory quality. The physicochemical environment thus mediates the translation of microbial dynamics into observable product outcomes, making process sensitivity a critical factor in predicting beverage consistency (Mohammed et al., 2025).

In *nono*, physicochemical variability is even more pronounced due to the complex interactions between milk composition, lactic acid bacteria, and fermentation conditions. Factors such as, initial fat content, protein concentration, and ambient temperature, influence curd formation, viscosity, and acidity. Milk sourced from different herders or stored under varying conditions exhibits distinct physicochemical characteristics, which in turn affect microbial growth rates and acid production. Even minor deviations in these parameters can lead to substantial differences in texture, taste, and shelf life, illustrating the high sensitivity of *nono* fermentation to both material and environmental inputs.

Understanding physicochemical variability in relation to process sensitivity provides actionable insights for quality management. By recognising that small differences in raw materials, handling, or environmental conditions can cascade into significant variations in beverage quality, producers and regulators can prioritise interventions at the most influential points. For instance, selecting dry, uniform millet for *kunu*, standardising water quality for *zobo*, and ensuring timely cooling of milk for *nono* can stabilise pH, viscosity, and flavour outcomes. Conceptually, this reinforces the emergent and systemic view of quality: physicochemical parameters act as both mediators and indicators of upstream variability, linking procurement, microbial ecology, and environmental exposure to the ultimate biochemical and sensory characteristics of locally fermented beverages.

Temporal Instability and Post-Production Dynamics

The quality of locally fermented beverages in Edo North is not static; rather, it evolves continuously after production due to temporal instability and post-production dynamics. Beverages such as *kunu*, *zobo*, and *nono* experience ongoing biochemical and microbial transformations during transport, storage, and sale. These changes are contingent on environmental conditions, container types, and handling practices, making post-production periods a critical yet often overlooked determinant of final product quality (Zakari et al., 2024).

In the case of *kunu*, partially fermented millet drinks may continue to acidify during transportation from rural production sites to urban markets. Transport conditions such as exposure to heat, vibration, and varying container hygiene accelerate microbial metabolism, potentially leading to excessive sourness or reduced shelf life. Producers often rely on empirical knowledge to predict these temporal changes, adjusting fermentation duration or selecting transport times to optimise final acidity and flavour. These practices illustrate the dynamic interplay between upstream procurement, fermentation, and post-production handling.

For *zobo*, temporal instability manifests in both colour and microbial composition. Anthocyanin pigments are sensitive to pH, temperature, and light exposure, causing colour degradation during storage or display in open-air markets. Concurrently, residual microbial populations may continue to metabolise sugars, altering acidity and taste over time. Vendors and producers in Edo North often manage these dynamics through empirical strategies such as producing smaller batches or selling the beverage quickly to maintain marketable quality, highlighting the conditional and time-sensitive nature of biochemical stability (Mohammed et al., 2025).

Nono demonstrates perhaps the most pronounced temporal sensitivity. Fermented milk continues to acidify and thicken post-production, with lactic acid bacteria proliferating under ambient

temperatures. Small deviations in storage conditions temperature fluctuations, container cleanliness, or exposure to airborne microbes can significantly alter viscosity, taste, and microbial safety. Consequently, *nono*'s shelf life and consumer acceptability are highly contingent on immediate post-production handling. This underscores the systemic nature of quality, where procurement, fermentation, and distribution interact dynamically across time to produce variable outcomes (Adesulu-Dahunsi et al., 2025).

From a conceptual perspective, recognising temporal instability reframes quality control as a process distributed over both space and time. Rather than treating biochemical characteristics as fixed upon completion of fermentation, adaptive quality management must account for post-production transformations. Interventions might include selecting containers that minimise microbial contamination, optimising transport conditions, or coordinating production and sales to reduce time-dependent deterioration. By integrating temporal dynamics into the analytical framework, the emergent variability of *kunu*, *zobo*, and *nono* can be systematically understood, enabling evidence-based, context-sensitive strategies to enhance safety, consistency, and consumer satisfaction in informal beverage systems.

Supply Chain Mediation and the Reproduction of Variability

The production and distribution of locally fermented beverages in Edo North, including *kunu*, *zobo*, and *nono*, occur within informal, decentralised supply chains that mediate the emergence and amplification of biochemical variability. Unlike industrial food systems with controlled logistics, cold chains, and standardised quality monitoring, these informal networks rely on heterogeneous transport methods, non-standardised storage, and socio-economic relationships that shape the fate of microbial and physicochemical properties after production. Consequently, supply chains act as both conduits and modifiers of variability, reproducing differences established upstream at the procurement stage (Zakari et al., 2024).

In the case of *kunu*, transport from rural production sites to urban markets often involves non-insulated containers, exposure to fluctuating temperatures, and variable handling practices. Partially fermented *kunu* may continue to acidify en route, and microbial proliferation can be accelerated by heat or agitation. Even when upstream procurement and fermentation practices are consistent, these transport conditions introduce a secondary layer of variability, influencing taste, viscosity, and shelf life. The supply chain thus functions as a dynamic mediator, amplifying or modulating the effects of procurement-driven heterogeneity.

For *zobo*, supply chain mediation affects both microbial stability and pigment quality. Vendors often display the beverage in open containers along roadsides or markets, exposing it to dust, airborne microorganisms, and sunlight. Water quality, container hygiene, and the duration of exposure collectively influence acidity, microbial load, and anthocyanin degradation. These downstream interactions can reproduce, and sometimes exaggerate, upstream variability arising from hibiscus calyx procurement and initial extraction conditions. In this sense, the supply chain serves as a secondary quality determinant, transforming initial material properties into conditional outcomes observable at the point of consumption (Mohammed et al., 2025).

Nono illustrates the extreme sensitivity of biochemical quality to supply chain dynamics. Milk based beverages continue to ferment after production, and ambient transport conditions including temperature fluctuations, container cleanliness, and handling frequency can accelerate acidification, affect viscosity, and introduce pathogenic risks. Even minor deviations in storage and distribution practices can generate substantial batch-to-batch variability. In the informal supply networks of Edo North, producers and vendors deploy experiential knowledge to mitigate these risks, for instance by producing small batches, timing delivery to markets, or selecting familiar transport routes. These practices reflect a pragmatic adaptation to system-wide variability, highlighting the interdependence of procurement, fermentation, and distribution in

shaping quality outcomes (Adesulu-Dahunsi et al., 2025).

Conceptually, supply chain mediation underscores the systemic and emergent nature of quality in locally fermented beverages. Biochemical variability is not confined to production or fermentation stages but propagates through transport, storage, and retail, interacting with socio-economic and environmental conditions at each point. Recognising this distributed system of quality control challenges reductionist approaches that treat fermentation as the sole determinant of product safety and consistency. For policy and practice, this perspective implies that interventions must target the entire production-distribution continuum, including upstream procurement, adaptive fermentation strategies, and context-sensitive transport and handling practices, to reduce variability and enhance consumer safety and satisfaction.

Decentralisation and Cumulative Effects

The production and distribution of locally fermented beverages in Edo North are characterised by highly decentralised systems, in which multiple actors across different locations participate in procurement, processing, transport, and retail. Unlike centralised industrial production, where standardisation and monitoring are maintained through formal protocols, these decentralised networks rely on informal practices and experiential knowledge to coordinate activities. Decentralisation amplifies the cumulative effects of upstream and midstream variability, as minor differences in procurement, fermentation, and handling propagate through the network, shaping the biochemical, sensory, and microbial properties of *kunu*, *zobo*, and *nono* (Adesulu-Dahunsi et al., 2025).

In *kunu* production, for example, millet or sorghum may be sourced from multiple vendors, processed in small household units, and transported via a variety of informal routes to markets. Each stage introduces variability in moisture content, microbial load, and fermentation kinetics. These incremental differences accumulate across batches and

locations, producing final beverages that may vary in acidity, texture, and taste even when produced using similar artisanal techniques. The decentralised nature of the system therefore transforms local procurement and handling decisions into systemic determinants of cumulative quality variability.

Zobo production similarly illustrates cumulative effects. Hibiscus calyces sourced from different farms, combined with variations in water quality, extraction technique, and market handling, lead to incremental differences in pH, pigment stability, and microbial composition. Open-air display in local markets further exposes the beverage to airborne microorganisms and fluctuating temperatures, reinforcing and sometimes amplifying variability established at earlier stages. Here, decentralisation interacts with environmental heterogeneity to produce complex, time-dependent patterns of quality variation (Mohammed et al., 2025).

In *nono*, cumulative effects are particularly pronounced due to the dynamic nature of milk fermentation. Milk collected from multiple herders, transported under ambient conditions, and fermented in different containers exhibits diverse microbial trajectories. Small differences in handling, temperature exposure, and container hygiene combine over time to influence viscosity, acidity, and microbial safety. Decentralised production and distribution therefore create a network of interacting variabilities, where each incremental difference contributes to emergent biochemical outcomes.

The cumulative effects observed in these decentralised systems underscore the importance of system-level thinking in quality governance. Rather than addressing variability solely at the point of production or fermentation, interventions must consider the entire network, from procurement to retail. Strategies may include cooperative sourcing to harmonise raw material quality, sharing best practices for handling and transport, and context-sensitive monitoring to detect cumulative deviations before they impact consumer safety and satisfaction. By recognizing decentralisation and cumulative effects as structural determinants of variability, this perspective situates quality as an emergent property of socio-technical networks,

offering a robust framework for both scholarly analysis and practical intervention in Edo North’s informal beverage systems.

Diagrammatic Conceptual Framework

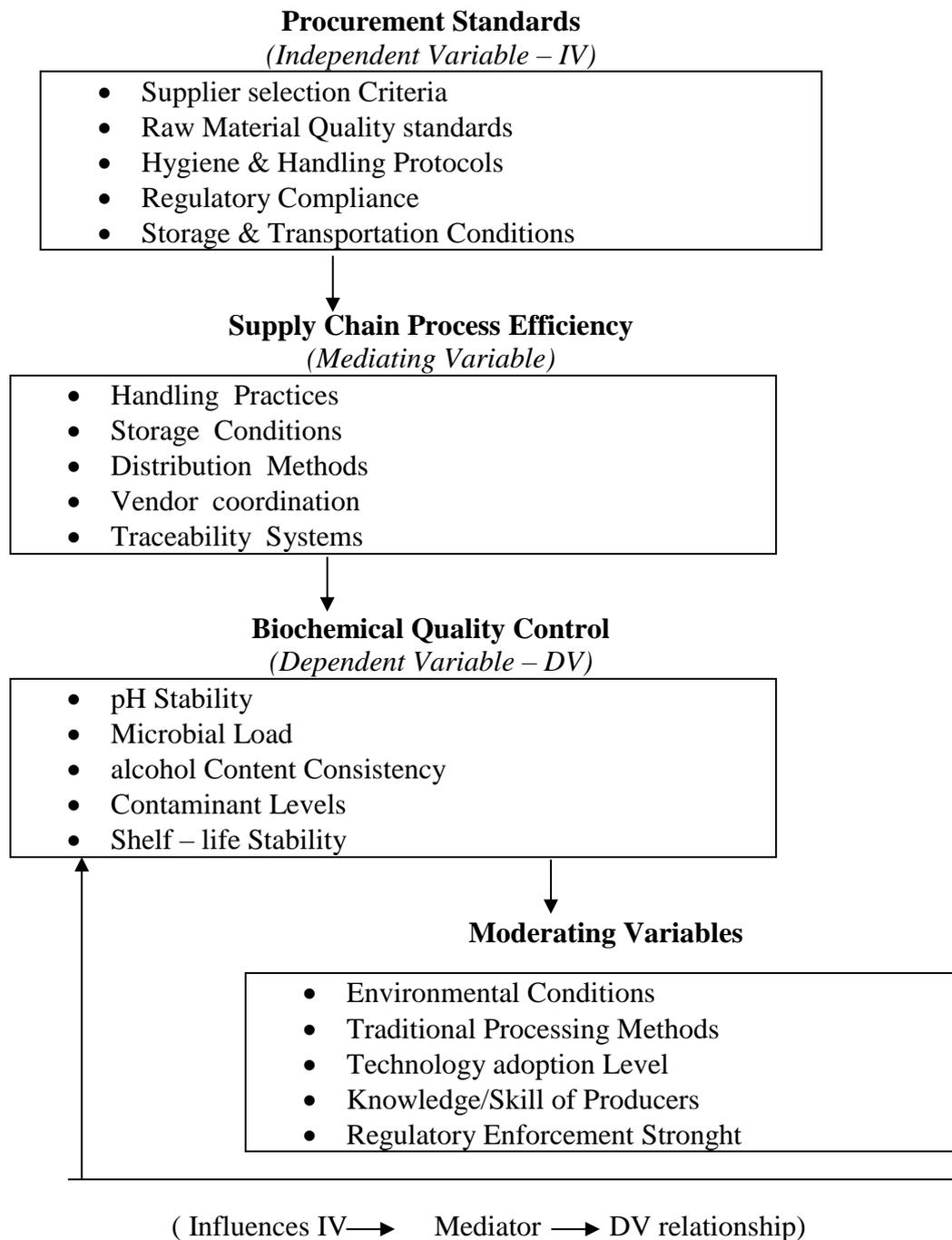


Figure 1: *Conceptual Framework on Procurement Standards and Biochemical Quality Control in the Supply Chain of Traditional Fermented Beverages in Edo North Nigeria.*

Source: *Conceptualized by Christopher Ikhianosime Oboh (2026).*

Conceptual Logic of the Framework

1. Procurement standards (IV)

This represents the foundation of quality control in traditional fermented beverage production in Edo North. Poor Sourcing practices directly introduce variability and contamination risks.

- Emphasizes input quality and compliance
- Sets the initial biochemical baseline

2. Supply Chain Process Efficiency (Mediator)

This explains how procurement standards translate into biochemical outcomes.

- Even high-quality raw materials can degrade through:
 - a. Poor storage
 - b. Contamination during transport
- Acts as the mechanism linking inputs to outcomes

3. Biochemical Quality Control (DV)

This is your core outcome variable, measured scientifically:

- pH → fermentation stability
- Microbial load → safety
- Alcohol content → consistency
- Contaminates → health risk
- Shelf-Life → Market viability

4. Moderating Variables

These variables explain why the relationship may strengthen or weaken in Edo North's Local Context:

- Traditional Processing Variability (non-standardized methods)
- Environmental exposure (Temperature, humidity)
- Skill level differences among producers
- Weak or inconsistent regulatory enforcement

Theoretical Flow

Procurement Standards influence biochemical quality control outcomes both

directly and indirectly through supply chain efficiency, while environmental, technological and socio-cultural factors moderate these relationships.

Conceptual Synthesis: Towards an Integrated Model

The analysis of procurement, fermentation, microbial ecology, physicochemical variability, and supply chain dynamics in Edo North demonstrates that the quality of locally fermented beverages such as *kunu*, *zobo*, and *nono* is fundamentally systemic and emergent. Across the production-distribution continuum, quality is not a static attribute nor the exclusive result of artisanal skill; rather, it arises from the interaction of socio-technical, material, and environmental factors that cumulatively shape biochemical outcomes. Upstream procurement establishes baseline microbial and physicochemical conditions, which are modulated by fermentation dynamics and amplified or attenuated through informal, decentralised supply chains. This integrated perspective reconciles the apparent tension between artisanal variability and the need for safety and consistency (Adesulu-Dahunsi et al., 2025).

Procurement emerges as a structural determinant of quality, as decisions about grain, hibiscus, or milk sourcing directly influence microbial diversity, substrate availability, and fermentation kinetics. The logic of practice, grounded in experience and local knowledge, mediates the translation of material properties into predictable biochemical trajectories. Informal sourcing networks and contextually rational handling strategies serve as adaptive mechanisms that navigate resource constraints and environmental uncertainties, yet they also introduce upstream variability that propagates through the system (Mohammed et al., 2025).

The emergent nature of biochemical quality is further shaped by microbial ecology, physicochemical properties, and temporal dynamics. Lactic acid bacteria in *nono*, wild yeasts in *kunu*, and acid-tolerant microbes in *zobo* interact with pH, moisture, temperature,

and substrate composition to produce outcomes that are contingent on both prior conditions and ongoing environmental exposure. Temporal instability manifested during transport, storage, and market display modulates these interactions, creating variability that is distributed across space and time. Such dynamics illustrate that quality is co-produced by microbial, material, and socio-technical processes rather than reducible to discrete production steps (Zakari et al., 2024).

Supply chain structures in Edo North, characterised by decentralisation and informal mediation, act as amplifiers of variability, translating small upstream differences into larger divergences in taste, texture, acidity, and microbial safety. Cumulative effects of procurement heterogeneity, environmental exposure, and handling practices highlight the systemic nature of quality, necessitating interventions that address the entire socio-technical network. This includes cooperative sourcing, context-sensitive hygiene protocols, adaptive transport strategies, and targeted monitoring all of which operate synergistically to stabilise quality without undermining local production practices (Adesulu-Dahunsi et al., 2025).

Synthesising these insights, an integrated model of locally fermented beverage quality in Edo North positions procurement, fermentation, microbial ecology, physicochemical dynamics, and supply chain mediation as interconnected nodes within a complex system. In this framework, interventions aimed at improving safety, consistency, and consumer acceptability are most effective when they account for upstream determinants, leverage experiential knowledge, and manage cumulative variability across decentralised networks. Conceptually, this model shifts the discourse from linear, reductionist approaches to a holistic, system-oriented understanding of biochemical quality, offering both theoretical clarity and practical guidance for scholars, regulators, and producers in Nigeria's informal beverage sector.

Implications for Quality Governance and Practice

The systemic and emergent nature of quality in locally fermented beverages in Edo North carries profound implications for both governance and practical intervention. Traditional approaches to food quality, often modelled on industrial or formalised food systems, are insufficient in informal contexts where procurement, microbial ecology, and decentralised supply chains collectively shape biochemical outcomes. For *kunu*, *zobo*, and *nono*, effective quality governance must be adaptive, context-sensitive, and distributed, recognising that interventions upstream at the point of procurement and early handling have cascading effects on fermentation dynamics, physicochemical stability, and microbial safety (Adesulu-Dahunsi et al., 2025).

At the procurement level, governance strategies should focus on standardising key inputs without undermining local practice. This may involve promoting basic hygiene and storage protocols for millet and sorghum used in *kunu*, recommending clean water use and calyx washing for *zobo*, and encouraging hygienic milk collection for *nono*. Interventions should leverage existing social networks and trusted supplier relationships, rather than imposing rigid top-down standards, to ensure feasibility and adoption. Such upstream interventions function as primary quality control points, shaping microbial and physicochemical conditions that determine the trajectory of fermentation.

Within production, the findings underscore the value of experience-driven, contextually rational practices as a form of adaptive quality management. Artisanal knowledge, accumulated through repeated engagement with local raw materials and environmental conditions, serves as a critical mediator of quality. Policymakers and extension agents can engage producers through participatory training and collaborative monitoring, introducing simple techniques such as monitoring pH, maintaining clean fermentation containers, or adjusting fermentation time that enhance safety and consistency without disrupting cultural and economic logics.

Decentralised supply chains further necessitate distributed approaches to quality governance. Transportation, storage, and market display significantly influence post-production dynamics, often amplifying upstream variability. Interventions might include low-cost transport containers, scheduling production to reduce time-to-market, and establishing cooperative networks for coordinated batch handling. These measures acknowledge the cumulative and systemic nature of variability, addressing quality not as an isolated attribute but as a property of the entire production-distribution ecosystem (Mohammed et al., 2025).

Finally, the emergent and contextual nature of biochemical quality highlights the importance of adaptive regulatory frameworks. Standardised industrial protocols, if applied rigidly, may be impractical in informal beverage systems and risk alienating producers. Instead, regulatory attention should emphasise risk-informed guidance, scalable monitoring, and participatory engagement, aligning scientific principles with local production realities. By integrating upstream procurement, experiential knowledge, and supply chain mediation, governance interventions can stabilise biochemical quality, reduce public health risks, and enhance consumer confidence, while respecting the socio-cultural and economic realities of Edo North's informal beverage sector.

Recommendations

Building on the analysis of procurement, fermentation dynamics, microbial ecology, physicochemical variability, and supply chain mediation, several actionable recommendations emerge to enhance quality governance, safety, and consistency of locally fermented beverages in Edo North. These recommendations integrate scientific insights with local socio-cultural and economic realities, ensuring feasibility and sustainability.

1. Strengthen Upstream Procurement Practices:

- Promote the sourcing of millet, sorghum, and hibiscus calyces from dry, pest-free

storage environments to reduce initial microbial and physicochemical variability.

- Encourage hygienic milk collection for *nono*, including basic cooling, clean containers, and avoidance of prolonged ambient exposure.
- Facilitate cooperative procurement networks among producers to harmonise raw material quality and leverage economies of scale without undermining informal market structures.

2. Enhance Adaptive Fermentation Practices:

- Introduce context-sensitive interventions, such as monitoring fermentation duration and temperature, using clean fermentation containers, and periodic sensory checks to maintain consistent acidity, flavour, and viscosity.
- Promote knowledge-sharing workshops where experienced producers demonstrate best practices in managing microbial activity while preserving traditional taste profiles.
- Encourage the documentation of empirical techniques that have proven effective locally, bridging tacit knowledge with formal food safety principles.

3. Implement Distributed Quality Monitoring:

- Employ low-cost, scalable tools for pH measurement, microbial assessment, and temperature monitoring that are suitable for informal production contexts.
- Encourage the use of mobile or community-based monitoring systems to track product safety and stability along the supply chain, particularly during transport and storage.
- Develop simple record-keeping protocols to capture batch-specific conditions,

enabling producers to learn from outcomes and reduce variability over time.

4. Strengthen Supply Chain Resilience:

- Advocate for transport and storage solutions that minimise temperature fluctuations, contamination, and excessive handling, such as insulated containers or clean batching stations.
- Promote scheduling and batch management strategies to reduce time-to-market, ensuring beverages reach consumers at optimal biochemical and sensory quality.
- Foster cooperative marketing platforms where producers can coordinate distribution, enhancing quality consistency across decentralised networks.

5. Develop Adaptive Regulatory and Extension Frameworks:

- Design regulatory guidelines that are flexible, risk-informed, and participatory, aligning scientific food safety principles with the realities of informal production.
- Collaborate with local extension agencies to provide training, advisory support, and technical assistance tailored to the socio-technical context of Edo North.
- Encourage research-practice partnerships that integrate microbiological, physicochemical, and socio-economic data to inform continuous improvement in quality governance.

6. Leverage Local Knowledge and Social Networks:

- Recognise and integrate the experiential knowledge of producers into quality management strategies, ensuring that interventions respect traditional taste

profiles, cultural practices, and economic constraints.

- Support peer-learning initiatives where producers exchange insights about procurement, fermentation, and handling practices, reinforcing adaptive and contextually rational behaviours.

These recommendations collectively advance a systemic approach to quality governance, targeting upstream procurement, fermentation processes, supply chain mediation, and adaptive monitoring. By balancing scientific principles with local knowledge and socio-economic constraints, Edo North producers can stabilise biochemical quality, reduce health risks, and enhance consumer trust while sustaining the cultural and economic vitality of kunu, zobo, and nono production

Conclusion

This study underscores that the quality of locally fermented beverages in Edo North specifically kunu, zobo, and nono is a systemic and emergent phenomenon, shaped by the interplay of procurement practices, microbial ecology, physicochemical variability, and decentralised supply chain dynamics. Rather than being a static or solely artisanal attribute, biochemical quality emerges from the cumulative effects of decisions and conditions spanning from raw material sourcing to post-production handling. Upstream procurement establishes the baseline microbial and physicochemical parameters, while fermentation, environmental exposure, and transport amplify or modulate variability, producing outcomes that are context-specific, temporally dynamic, and highly sensitive to local socio-technical realities.

The analysis demonstrates that informality, experience, and the logic of practice are central to understanding quality in Edo North's beverage sector. Producers rely on tacit knowledge and adaptive strategies to navigate variability in raw materials and environmental conditions, illustrating a contextually rational approach to quality management. At the same time, decentralisation within supply chains leads to cumulative effects that can amplify minor

differences, making systemic interventions necessary to stabilise biochemical and sensory attributes without undermining traditional practices.

Conceptually, this work positions quality as an emergent property of socio-technical networks, where procurement, fermentation, microbial dynamics, physicochemical properties, and supply chain mediation are mutually constitutive. Recognising these interdependencies provides a foundation for adaptive governance and practical interventions, emphasizing upstream standardisation, context-sensitive monitoring, cooperative supply strategies, and the integration of local knowledge. Such an approach balances scientific rigour with cultural and economic feasibility, offering pathways to enhance consumer safety, consistency, and confidence while sustaining the artisanal character of locally fermented beverages.

Ensuring the quality of *kunu*, *zobo*, and *nono* in Edo North requires a holistic, system-oriented perspective that integrates procurement standards, emergent biochemical dynamics, and adaptive socio-technical practices. By foregrounding the structural, ecological, and temporal determinants of variability, this study contributes both to theoretical understanding of emergent food quality and to practical strategies for improving safety, consistency, and sustainability in informal, culturally embedded beverage systems in Nigeria.

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