

A Review on Quality Evaluation of *Kunun-zaki* in Nigeria



S. I. Kolo^{1*}, J. C. Anuonye^{1,2}, C. E. Chinma^{1,2}, H. A. Makun²

¹Department of Food Science and Technology, Federal University of Technology, Minna, Niger State.

²Africa Center of Excellence for Mycotoxins and Food Safety, Federal University of Technology, Minna, Niger State.



ABSTRACT: *Kunun-zaki* is a traditional non-alcoholic cereal-based beverage widely consumed in Nigeria. However, its large-scale production and commercialization remains limited by persistent challenges in product quality and processing. This review examines the overall quality and timeline status of *Kunun-zaki* with emphasis on the technological constraints especially in scaling up its artisanal production ways. Several past studies have primarily focused on improving individual aspects of product quality; however, a major research gap discovered is the lack of integrated process engineering approaches. These are the processes that would address the issues of heat transfer limitations, uncontrolled fermentation kinetics, inefficient solid–liquid separation, and inadequate packaging systems. The review captures findings from previous studies and analysis modern processing techniques, such as pasteurization, use of starter culture, carbonation, and hurdle technology. The trade-offs between microbial safety and nutrient retention during heat application, and the need for controlled fermentation systems to ensure product consistency was also addressed. Particular attention was also on the challenges of scaling up from artisanal to commercial production were explicitly discussed. Overall, the study stresses that the major limitation in *Kunun-zaki* production is not the absence of technological solutions, but the lack of scalable, cost-effective, and integrated processing systems. Future research should therefore focus on the development of production line that includes energy-efficient thermal processing units, low-cost fermentation systems, and hygienic packaging technologies specifically to small- and medium-scale producers. Focus on these gaps will be important in enhancing the shelf-life, safety, and commercial viability of *Kunun-zaki* in both local and international markets.

KEYWORDS: *Kunun-Zaki*, Non-Alcoholic Beverages, Quality Parameters, Stabilization, Quality Assessment

[Received Jan. 30, 2026; Revised Apr. 10, 2026; Accepted Jun. 18, 2026]

Print ISSN: 0189-9546 | Online ISSN: 2437-2110

I. INTRODUCTION

In Nigeria, *Kunun-zaki*, often simply referred to as "*Kunu*," is a common indigenous beverage made from grains, predominantly millet or sorghum (Jolayemi et al., 2023b). It holds cultural significance and has a long history of consumption in Nigeria. Although *Kunun-zaki* is widely consumed across Nigeria, it is unique to the northern parts of the country (Nwiye and Elechi, 2022). Different types of *Kunun-zaki* are produced in Nigeria, but their names depend on the variety and type of ingredients used, the method of production, and, in some cases, individual tastes (Ndukwe et al., 2023, Patra et al., 2023). Some of the variants of *Kunun-zaki* are identified and named by the major ingredient used in production (see table 1) and the sensory attribute perceived (Gaffa et al., 2002a). Some of the identified types of *Kunu* includes *Kunu-zaki*, *Kunu-gyada*, *Kunu-tsamiya*, *Kunu-akamu*, *Kunu aya*, *Kunu-koko*, *Kunu-aduwa*, *Kunu-acha*, *Kunu-kanwa*, *Kunu-jiko*, *Kunu-banle*, *Kunu-gayamba* and *Kunu-amshau*. However, the sensory properties and overall quality of the drink can be influenced by the ingredients (Ndukwe et al., 2023, Olatoye et al., 2023).

The overall quality of *Kunun-zaki* is dependent on different cultural practices due to the different compositions, and processing techniques. This is unique to ethnic groups that created them (Musa et al., 2023). However, the aforementioned challenges are primarily due to the fact that the preparation of various *Kunun-zaki* beverages is still artisanal and is characterized by inconsistent

raw materials supply, poor process control and poor hygienic conditions, which collectively contribute to variability in quality and reduced shelf-life. (Nwaiwu et al., 2020). The socioeconomic lives of most Nigerians are linked to the production of *Kunu* beverages. As many families rely on these beverages for commercial purposes by housewives and unemployed personnels as additional income. Furthermore, because *Kunun-zaki* is a form of cultural identity in northern Nigeria, it is known to serve as a symbol of tradition and heritage, connecting people to their roots and preserving culture.

Serving *Kunun-zaki* to guests during social activities or events in Nigerian societies helps bring people together, encourages interactions, and fosters a sense of belonging and togetherness (Xiong et al., 2022). Most importantly, apart from the cultural diversification of *Kunun-zaki*, it is known to be a nutritious beverage, rich in vitamins, minerals, and carbohydrates. It provides essential energy and nutrients, making it an important dietary component, especially in regions where it is mostly consumed (Patra et al., 2023, Siby, 2023). Additionally, *Kunun-zaki* is an excellent source of hydration, especially in hot and arid regions of Nigeria. It helps quench thirst and provides relief from the heat given its refreshing nature (Giri et al., 2023).

Beyond its nutritional value, other ingredients added to *Kunun-zaki* is often believed to contribute to the claims of its various health benefits (Mishra et al., 2023). For example,

*Corresponding author: mtkolo6@gmail.com

ginger which is a natural probiotic helps to aid digestion (Panse, 2023). In order to improve the protein and amino acids content and their antioxidant properties, additional ingredients such as soybeans, sweet potato and so many types of spices (Ndukwe et al., 2023). Over the years, *Kunu* processing techniques have been evolving. The most common practice involves malting, boiling, pasteurization, fermentation and distillation (Ndukwe et al., 2023, Nwaiwu et al., 2020). The overall quality has been improved on by numerous recipe formulations and techniques to standardize the production process, preserve its organoleptic properties, overall acceptance and shelf-life of the products. These techniques have greatly improved the beverage flavor, digestibility complex and it has also helped to eliminate or reduce toxic and hazardous substances and degraded anti-nutrients (Ezekiel et al., 2019, Ezekiel et al., 2018, Ndukwe et al., 2023).

Over the years, there has always been a reoccurring interest in this traditional beverage, both domestically and internationally. However, the persistent perishable nature of these beverages often challenges its shelf stability and quality maintenance (see Table 2). This review aims to shed light on the quality evaluation of *Kunun-zaki*, timeline which is essential for its continued popularity and market expansion.

II. INGREDIENTS USED IN THE PRODUCTION OF KUNUN- ZAKI

A. Cereals

Cereals are everyday foods that are available all year round. They are affordable and consumed around the world especially in Africa, Asia and some parts of America. They are known to be rich in bioactive compounds and significant amounts of calories. They are also known to be good sources of macro and micronutrients, phytochemicals, and antioxidants (Arendt and Zannini, 2013, Basinskiene and Cizeikiene, 2020,

Serna-Saldivar, 2016). Amongst the most common types of cereals are the, Rice, rye, maize barley, millets sorghum, and wheat (McKevith, 2004). The global food trade has provided the avenue for cereal grains to be available worldwide as it contributes to about 56% energy and 50% protein to the population (Basinskiene and Cizeikiene, 2020). Generally, Cereal grains are major sources of nutrients (e.g. carbohydrates, proteins, lipids), micronutrients (vitamins and minerals), and other phytochemicals (carotenoids and phenolic compounds).

Cereals are usually processed before consumed and its conversion into secondary food products is achieved through various traditional and modern techniques. Some of these techniques include steeping, malting, roasting, fermentation, boiling, baking, frying, nixtamalization, micronization, extrusion, etc. Final food products from cereals have created innovations from different cultures especially in the beverage industries, baked food items and a mix of cereal with vegetables, legumes and fibres. These innovations have either improved or degraded the quality of the nutrient compositions of the cereal based foods (Basinskiene and Cizeikiene, 2020, Beta et al., 2005, Giordano et al., 2016).

Beverages from cereals are an extract of the grains suspension which is sifted and filtered. It is fermented by the lactic acid bacteria (LAB) which leads to a unique sensory property especially the flavour, improves the nutritional property as well as the shelf life (Leroy and De Vuyst, 2004; Ma^ortensson et al., 2000; Zannini et al., 2012). This is seen in the case of the non-alcoholic beverage *Kunun-zaki* produced in Nigeria. According to (Gaffa et al., 2002a)), in descending order of preference, the most frequently cereal grains used in *Kunun-zaki* production are millet, sorghum, and maize.

Table 1 *Kunu* beverage varieties and their different formulating ingredients

Name of beverage	Major ingredients	Other ingredients/ Additives
<i>Kunun-zaki</i>	Millet, Maize, sorghum	Ginger, clove, red pepper, sweet pot and sweetener
<i>Kunun-gyada</i>	Groundnut	Sweetener
<i>Kunun-tsamiya</i>	Tamarind	Ginger, Sweetener
<i>Kunun-akamu</i>	Millet, Maize	Ginger, clove, red pepper, and sweetener
<i>Kunun-aya</i>	Tigernut	Ginger, clove, red pepper and Sweetener
<i>Kunun-acha</i>	Fonio	Sweetener
<i>Kunun-kanwa</i>	Millet	Potash, Gineger, sweetner
<i>Kunun-shinkafa</i>	Rice	Sweetner

Table 2 Timeline of quality assessment of *Kunun-zaki*

RESEARCH GAP	RESEARCH FINDINGS/ACHIVEMENTS	REFERENCES
Shelf instability	The traditional methods employed in <i>Kunun-zaki</i> production provide the ideal environment for microbial, physical and chemical change the product leading to a short shelf life of approximately 24 hours, ambient temperature. Despite the use of refrigeration and chemicals, <i>Kunun-zaki</i> still has short shelf life	Adeyemi and Umar (1994)
Nutrient deficiency	Soybean fortified <i>Kunun-zaki</i> to produce a more nutrient dense beverage and retained of organoleptic properties	Anounye et al., (1995)
Persistent shelf instability and safety concerns	The research showed that with addition of chemical preservatives, shelf life was extended by 8 days after pasteurizing and refrigeration. However, due to inconsistency power supply, procedure for production.	Gaffa and Ayo (2002) Osuntogun and Aboaba (2002)
Possibility of mycotoxin presence	HACCP was mandatory on production of <i>SoyKunun-zaki</i> to identify critical points. This exposed that the beverage would require strict monitoring during production due to the presence of fungal isolate ensure safety.	Danbaba et al., (2014)
unstandardized Quality and specifications	<i>Kunun-zaki</i> production is still artisanal leading to variation in the sensory and overall quality of the product.	Aboh and Oladosu (2014)
non-compliance and awareness safety practices and exposure different environment during sale.	Comparative study between local producers and laboratory control sample revealed persistent microbial presence in the locally produced samples.	Omoleke et al., (2018)
Hurdle technology and HACCP	<i>Zobo</i> drink was also preserved for about 6 months at ambient temperature without altering the nutritional and sensory properties the beverage. This was achieved using methods of HACCP, Carbonation, preservatives and heat treatment.	Chukwu et al., (2019)
Safety concerns from <i>Kunun-zaki</i> ingredients	Organic food spices, including cinnamon, garlic, and nutmeg were used to extend <i>Kunun-zaki</i> shelf-life. The study revealed a number of harmful isolated microorganisms which can cause health hazards	Williana et al., (2020)
Public health risks	In this study, it was reported that the presence and abundance of microbes in fresh locally produced, packaged and distributed <i>Kunun-zaki</i> drinks were highly contaminated by foodborne microbial pathogens and it makes it unsafe for human consumption especially from unverified sources.	Samuel et al., (2021)

1) Millet

Millet (*Pennisetum gambiense*) is one of the most common cereals in Africa. It grows in different varieties such as the pearl, bulrush, spiked, finger and cattail millet (Baryeh, 2002). Pearl millet is the most utilized type of millet in Nigeria especially as the major ingredient for the production of *Kunun-zaki* and *kunun-akamu* (Aka et al., 2014). It is known to provide required amount of nutrients such as fibre,

antioxidants, vitamins, minerals and essential amino acids to all age groups when added to diet plans (Jideani et al., 2021). Previous studies have proven positive outcome in the nutrient composition, antioxidant properties, and sensory characteristics of *Kunu* using pearl millet.

A beverage was produced using pearl millet and augmented with African locust bean pulp. The study showed improvement in the nutritional and sensory composition of the

drink (Olatoye et al., 2023). Similarly in another research conducted by (Jolayemi et al., 2023a), *Kunun-zaki* was sweetened using organic sweeteners *Thaumatococcus daniellii* (Miracle fruits) and *Dioscoreophyllum cumminsii* (Serendipity berry) in comparison to refined Sugar. The outcome was successful, and the resultant beverage was recommended for people with obesity, Type-2 diabetes, cardiovascular illnesses, and dental health issues.

2) Sorghum

In Nigeria, Sorghum is usually not the first choice when it comes to *Kunun-zaki* production. It is most used as a mixture with millet and maize as the base. This often happens when there is shortage of pearl millet. As a grain and just like the millet, sorghum is also widely cultivated and consumed in Africa. It belongs to the *Poaceae* family, and is known to be highly beneficial possessing antioxidant, anti-obesity, anti-diabetic, anti-cardiovascular, anti-inflammatory, antimicrobial, and anti-cancer effects (Rashwan et al., 2021).

This characteristic makes the sorghum based *Kunun-zaki* results in a high-quality beverage just like the other grains. In other to justify the quality, several research ideas were put to test. For example, (Folasade and Oyenike, 2012), produced a sorghum based *Kunun-zaki* with addition of sesame seed. The chemical and sensory qualities presented a highly nutritional and overall acceptable drink. Furthermore, trials were also carried out using starter cultures in sorghum-based *Kunun-zaki*. This was carried out to assess and improve on the production process of *Kunun-zaki*. This was aimed at reducing how much contact is had while preparing the beverage. It was observed that the starter culture not only improved on the hygiene during production but improved the protein content and organoleptic acceptability (Onyimba et al., 2017).

i. Maize

Maize is one of the most used grains in Nigeria especially to produce *Ogi* or *Akamu*. It however turns out to be the least used for production of *Kunun-zaki*. It has been found to be most appreciated when combined with other cereals such as the pearl millet and sorghum for production of *Kunun-zaki* (Maji et al., 2011). Maize grains is more appreciated in the agro based sectors for production of flour, breweries, confectioneries and animal feeds (Utono and Adamu, 2023).

B. Water

According to (Tireki, 2021), Beverages are composed of about 85–98% of water. Water has the most important role in beverage production as it makes or mars the taste, shelf life and overall quality. It is in most cases responsible for the introduction of contaminants to the product and alters the stability and wholesomeness overtime (Ashurst, 2016). Several issues have been reported on the quality of *Kunun-zaki* in Nigeria. These issues were investigated and have been attributed to the sources of water used during production. It was reported that at some point, well water was the main source of water in many localities in Zaria and several parts of the country especially in areas where the local beverages were being produced (Oranusi et al., 2003). However, more recently,

untreated boreholes serve as the major source of water hence for beverage production. This may likely introduce toxic chemicals in the beverage (Bashar, 2022). Every stage of *Kunun-zaki* production is considered critical as it involves the introduction or addition of water at almost every point.

C. Sweeteners

Sweeteners are substances or compounds that provide a pleasant taste to food. They are capable of causing interactions within a mix of beverages (Tireki, 2021). Normally, the common Table sugar is added to *Kunun-zaki* for sweetness. Overtime, people have become aware of how unhealthy the Table sugar can be especially when consumed frequently in large doses. Diseases such as type 2 diabetes, hypertension, and cardiovascular disease have been attributed to consumption of drinks or beverages with high sugar content. The prevalence of such diseases has prompted investigations into finding substitute sweeteners for the beverage industry. Over the years there has been great improvement in provision of alternative beverages targeted towards health-conscious consumers with several successful outcomes.

A highly acceptable *Kunun-zaki* was produced by using orange fleshed sweet potato syrup as sweetener. The nutritional and sensory analysis of the beverage shows that it can serve as a dietary drink by improving on the vitamin A deficiency of people and also help in regulating the consumption of refined sugar (LOLA et al., 2018). A similar study was also carried out where *Thaumatococcus daniellii* (Miracle fruits) and *Dioscoreophyllum cumminsii* (Serendipity berry) were used to replace sugar in *Kunun-zaki* production. It turned out that the *Kunun-zaki* with plant based sweeteners was more acceptable in terms of physiochemical and sensory property (Jolayemi et al., 2023b). Likewise, an acceptable beverage was also produced by sweetening *Kunun-zaki* with black velvet tamarind (*Dialium guineense*) (Abiodun et al., 2017). Furthermore, and more recently, the nutritional and sensory qualities of *kunun-zaki* produced from sorghum and date Fruit flour (*Phoenix dactylifera*) was investigated. The study suggests that date fruit flour as sweetener should be encouraged as it improves quality of food generally (Noah and Yusuf, 2020).

D. Spices

Apart from the sensory properties spices contribute to food, it is also known to possess tremendous health benefits. Since ancient days, spices have been identified to act as antioxidants and antimicrobials on different foods. This has encouraged the addition of spices to almost every food (Dada et al., 2013). Additionally, it can change the overall quality of a basic drink to a more complex one and boost the acceptability of beverages. Typically, spices are added in different forms, including mixed spices, whole spices, powdered forms or as part of blends. This is dependent on personal preference especially on the influence it will have on the taste and aroma of the beverages (Köster and Mojet, 2015). Ginger (*Zingiber officinale*), cloves (*Syzygium aromaticum*), black pepper (*Piper nigrum*), red pepper and garlic are some of the spices commonly used in beverage production such as the *kunun-zaki* (Gaffa et al., 2002b). several

investigations were carried out on *kunun-zaki*, experimenting with different spices. In some cases, the spices (cinnamon, garlic, and nutmeg) added were discovered to act as preservatives to the beverage and also helped to boost the nutritional composition (Williamina et al., 2021). While, Similarly, *Kunun-zaki* spiced with ginger and garlic was observed to extend the shelf life for 10 days at room temperature. The outcome presented a beverage with low microbial load and attributed it to a combined effect of both spices (Edward and Ohaegbu, 2012).

E. Other ingredients

Overtime, with innovations and new product development, some other ingredients were added to beverages such as the *Kunun-zaki*. Some of these ingredients were commonly the sweet potatoes (dry or fresh), malted sorghum or rice, and Cadaba farinose extract (Dangarafa or Legel in Hausa). As reported by (Gaffa et al., 2002b), most of this ingredients are known to contribute to the sweetness of the beverage. Scientifically, they appear to aid in saccharification thereby reducing the added sugars of *Kunu*. Furthermore, malting of these other ingredients presents a *Kunun-zaki* type with desirable qualities. This plays a role in improving the nutrient and sensory compositions (Terna et al., 2002). Likewise, a mix of different ingredients, from spices to grains and sweeteners may produce a high-quality beverage. This was experimented by (Ayo, 2004), where Acha (*Digiteria exiles staph*) was used in combination with Millet, ginger (*Zingiber officiale*), red pepper (*Capsicum annum*), clove (*Eugenia caryophyllata*), sweet potato (*Ipomoea batatas*) and sugar to produce *Kunun-zaki*. The outcome was found to be favourable as all the ingredients did not affect the overall quality and acceptance of the *Kunun-zaki*. However, in terms of the organoleptic properties, with Acha-based *Kunun-zaki* exhibited a highly acceptable beverage, which could be an advantage over that of millet.

III. THE TECHNOLOGY OF KUNUN-ZAKI PRODUCTION

The technology behind *Kunun-zaki* preparation constitute a blend of the traditional and modern methods of production. This way the cultural significance of the taste, nutrients and other qualities of the drink are preserved. This review explores the challenges of *Kunun-zaki* production with focus on the techniques used over the years.

A. The traditional method of Kunun-zaki production

The traditional method of preparing *Kunun-zaki* is still done using domestic utensils and local equipment and water obtained from wells, bore holes and occasionally taps (Terna et al., 2002). The use of this traditional method constitutes cleaning and soaking in water of grains for a few days (1-3 days) using plastic buckets, clay pots, calabashes, or metal drums. This first step is done to remove impurities and activate the enzymes in the grains thereby softening the kernels. The next step is to wet mill using grinding machines. The final

product after wet milling is a free-flowing paste. The product is then sieved using a muslin cloth which separates the shaft and the resultant *kunu*. After sieving, the *kunu* is collected and sweetened with sugar to taste. The *kunu* is then stored in plastic buckets or bottles and polyethylene sachets (Figure 1). Usually, using the traditional method, if produced under sanitary conditions, the shelf life of *Kunun-zaki* can last more than 24 hours at room temperature or 4 days under refrigeration. This was acceptable as the beverage was mostly produced for immediate consumption.

B. Modern technology employed in Kunun-zaki production

The uniqueness of *Kunun-zaki* is deeply connected to the old recipes and inclined towards cultural practices. However, with advancement of modern technology, there has been significant increase in enhanced quality, consistency and efficiency. These new methods which may involve mechanized milling, controlled fermentation, and use of hygienic packaging have brought about advancement into the traditional *Kunun-zaki* production process (figure 1). These modern innovations not only preserve the drink but has brought about exposure to the beverage worldwide.

Furthermore, with several trials and use of modern techniques, the production process of *Kunun-zaki* was shortened. Normally, the standard was to soak the grains overnight which made the production method last up to 24-hour. However, by steeping in hot water and with the aid of chemicals such as sodium metabisulphite the production process was reduced to a maximum of 12 hours. The addition of sodium metabisulphite helps to grains to soften faster (Gaffa and Ayo, 2002). Another modern technological improvement is the transformation of grains into flour, this also shortens production process time, increases shelf life of raw materials, improves nutrient availability and reduces the chances of longer exposure to contaminants in the *Kunun-zaki* beverage.

In addition to technological advancements, the use of starter cultures has been applied as a means of improving the efficiency and consistency of *Kunun-zaki* fermentation. These cultures are often isolated from naturally fermented *Kunun-zaki*. They are then added into fresh batches again to shorten fermentation time. Some of the most common strains include *Lactobacillus fermentum*, *Lactobacillus plantarum*, and *Lactobacillus acidophilus*. fermentation time has been significantly reduced from approximately 120 hours to 10–12 hours with the use of starter cultures, alongside reported improvements in microbiological, sensory, and nutritional attributes *Kunun-zaki* (Onyimba et al., 2017). Similar results were obtained by (Agarry et al., 2010), where controlled fermentation using selected cultures improved the quality of *Kunun-zaki* produced from millet and composite substrates. On the contrary, while these findings show the potential of starter cultures, their effect on beverages or food samples is highly dependent on the degree of process control. In most local systems, fermentation conditions such as temperature, pH, and contamination levels are not regulated. This can cause limitations on the performance of the starter cultures if introduced. resultantly, the expected

outcome and improvements in product overall quality may not be fully achieved. This suggests that the benefits of starter cultures can only be achieved in a controlled fermentation system. Therefore, a critical gap between laboratory-scale success and practical application needs to be addressed.

Furthermore, even though beverages produced with starter cultures have been reported to retain higher nutrient composition compared to street-vended *Kunun-zaki Kunun-zaki Kunun-zaki* (NA and Odunbaku, 2009). Such comparisons doesn't really represent the complexity of real production environments where factors such as raw material quality and variability, hygiene practices, and post-processing contamination also play major roles in determining final product quality. Therefore, attributing improvements solely to starter culture application without considering these interacting variables may lead to overestimation of their impact.

Pasteurization, on the other hand, has long been established as an effective method for microbial inactivation in beverages. While pasteurization has been extensively studied in fruit juice systems, its application to *Kunun-zaki* presents additional challenges due to its higher viscosity and suspended solids, which affect heat transfer and microbial inactivation efficiency. Its adoption in processing local drinks is mainly due to its simplicity and proven effectiveness. However, pasteurization as a heat-based process involves a trade-off between microbial safety and nutrient retention. This is particular to for heat-sensitive and volatile compounds such as vitamin C. For example, Egberet al. (2009) reported a trend in the decrease in vitamin C content during pasteurization of sorghum-based *Kunun-zaki*. Alongside, there was progressive microbial reduction in the beverage due to pasteurization. This highlights the effects of conventional pasteurization where a significant microbial safety is achieved but in turn speeds up nutrient loss and degrades overall product quality. Aside the microbial inactivation, the selection of appropriate time-temperature combinations is of high importance while pasteurizing in order not to cause further nutrient degradation.

High-temperature short-time (HTST) treatments are more effective in minimizing nutrient loss compared to low-temperature long-time (LTLT) processes (Kontopodi et al., 2022). However, the application of such conditions in *Kunun-zaki* must consider its semi-viscous nature, which may affect

heat transfer and may require agitation to ensure uniform temperature distribution. For small-scale production systems such as jacketed vessels with manual or mechanical agitation, or batch heating systems with temperature monitoring should be employed to retain product quality. The design should focus on simple low-cost pasteurization, temperature control and energy-efficient configurations. This way success is achieved by providing significant microbial reduction while limiting excessive nutrient degradation.

Consequently, the application of Hazard Analysis and Critical Control Points (HACCP) has also been proposed to enhance the safety of *Kunun-zaki* production. The identification of critical control points (CCP), such as raw materials, steeping, milling, and final product handling, provides a structured approach to managing contamination risks. Akani and Nwankwo (2018) reported the presence of bacterial and fungal contamination (including *Escherichia coli*, *Staphylococcus aureus*, *Aspergillus spp.*, and *Rhizopus spp*) in all stages of the traditional beverage production. This underscores the significant microbiological hazards associated with traditional production. However, the practical implementation of HACCP in small-scale *Kunun-zaki* production remains limited due to the lack of technical expertise and standardized processing environments needed to enforce control measures. As a result, HACCP often remains a theoretical framework rather than a functional system in many local production settings. Therefore, it has become paramount to provide simplified and cost-effective solutions, such as basic temperature and pH control devices, that can support the adoption of HACCP principles.

Overall, while starter cultures, pasteurization, and HACCP offer promising avenues for improving *Kunun-zaki* quality, their effectiveness is limited by the lack of an effective designed processing system where fermentation, thermal process and contamination is put into consideration. Most existing studies evaluate and focus on these technologies in isolation, without considering their interactions. There is therefore the need to emphasize on this limitation to be more applicable in larger scale production and real-world applications by developing a systems-based engineering strategy for *Kunun-zaki* production.

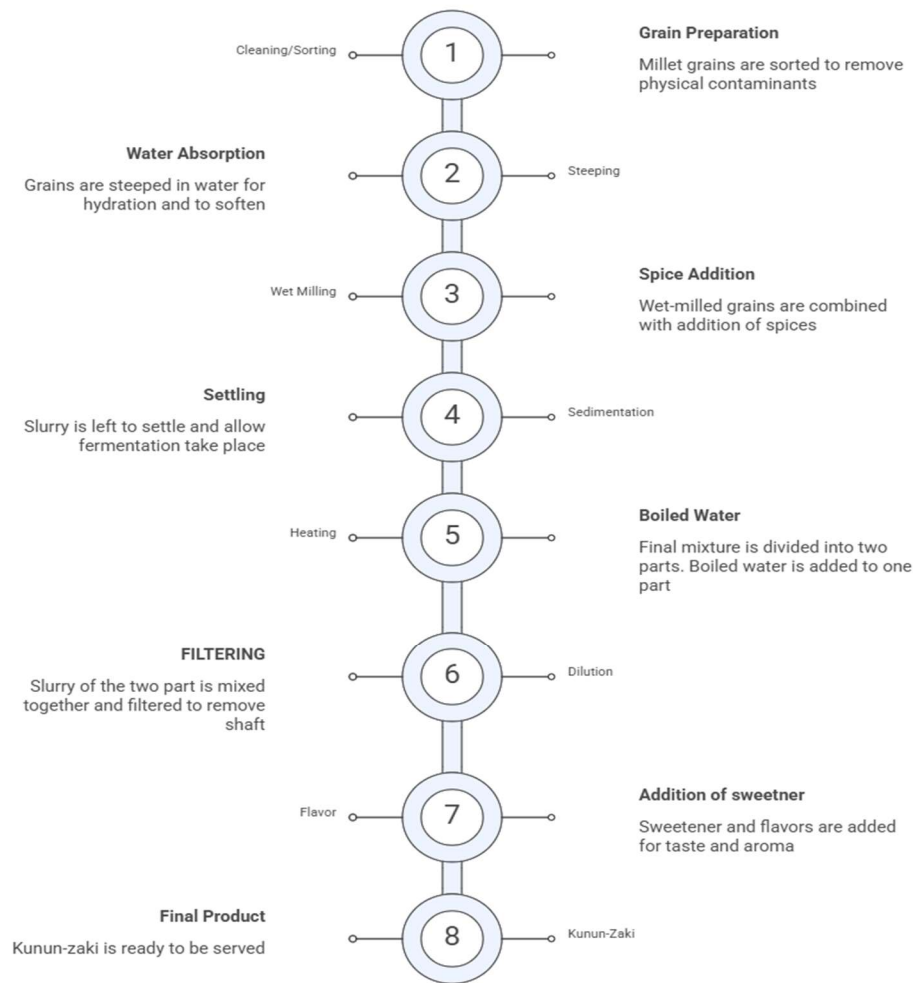


Figure 1 Traditional Kunun-zaki preparation process of *Kunun-zaki*

C. Fermentation Kinetics and Process Control in Kunun-zaki Production

Another critical approach that determines the success of fermentation is understanding its kinetics and microbial growth behavior which goes beyond the use of starter culture. Typically, *kunun-zaki* fermentation follows a pattern of a microbial growth curve which consists of three phases (lag, exponential, and stationary phases) (Towobola, 2021). In the lag phase, microorganisms begin to adapt to the substrate, then the exponential phase where there is a rapid growth and metabolite release leading to organic acids production and a decrease in pH. Finally, at the stationary phase the nutrients begin to deplete due to reduction in microbial activity and accumulation of metabolic by-products. The confirmed knowledge of these growth dynamics is therefore needed for establishing product consistency. Although in the traditional *Kunun-zaki*, spontaneous fermentation is used in its production.

This has caused limitations in the kinetic parameters where the lack of control contributes significantly to batch-to-batch variability (Williana et al., 2021).

To control these fermentation kinetics, bioreactors are employed to ensure the effective use of starter cultures (Demirkaya et al., 2022). These bioreactors may be complex and expensive; however, simplified batch fermentation systems can be developed for *Kunun-zaki* production. There is need therefore to develop simple predictive models of microbial growth which can be used to determine optimal fermentation time and improve process standardization, even in traditional settings. These systems would employ the use of low-cost tools such as thermometers, pH meters, and practice proper hygiene to ensure the dominance of desirable microorganisms and reduce contamination risks.

Consequently, starter culture benefits are only fully realized with an understanding of fermentation kinetics and the implementation of appropriate control systems. This highlights

the need for further research into the design of affordable and scalable fermentation units tailored to small- and medium-scale *Kunun-zaki* producers.

IV. QUALITY PARAMETERS AND EVALUATION OF *KUNUN-ZAKI*

A. Physicochemical Properties

The quality of *Kunun-zaki* involves several complex approaches where there is need to assess the physicochemical properties, microbiological quality, nutritional composition, and sensory attributes. These parameters indicate the quality and how safe the beverage is, it checks with consumer expectations and regulatory standards. Often, if the producers of such beverages are familiar with these quality indicators, there is assurance of the standards, consistency and appeal of the product (figure 2). This will greatly contribute to the popularity and cultural significance of *Kunun-zaki*, not just in Nigeria but also internationally.

One of the key indicators of quality is physicochemical properties. Some of the major parameters such as the pH, titratable acidity, and total soluble solids are key indexes for high quality and stable *Kunun-zaki*. *Kunun-zaki* is typically known to be slightly acidic. This is an advantage to the beverage as it helps slows down the growth of microorganisms responsible for spoilage. The titratable acidity also plays an

important role indicating the acid content which is good for the keeping quality and sourness of *Kunun-zaki*. Just like other parameters, the Total Soluble Solid (TSS) value of the beverage is responsible for the sweetness, body, and mouthfeel of the beverage.

Generally, as mentioned earlier, the Ph and TA values of *Kunun-zaki* is low which was confirmed in the study by (Ogunyemi et al., 2021). The pH values of the samples ranged from 3.87 to 4.28, indicating that the samples are acidic suggesting low susceptibility to spoilage. The titratable acidity varied between 0.18 to 0.43, contributing to its overall taste and preservation qualities. Also in the same study, the specific gravity of the samples ranged from 0.738 to 0.748, which is known to influence the mouthfeel and consistency of the beverage. most of the parameters indicates that they are important for the development and consumer acceptance of beverages. In another study by (Ibrahim et al., 2022), the addition of orange-fleshed sweet potato (OFSP) to sorghum-based *Kunun-zaki* increased the pH of the *Kunun-zaki* with increased in the addition of OFSP puree. This, however, made the beverage much safer for consumers with health conditions such as ulcers. Other parameters such as the TSS, Total Solids (TS), and specific gravity also increased which could be good for energy content and beneficial for improving bowel movement.

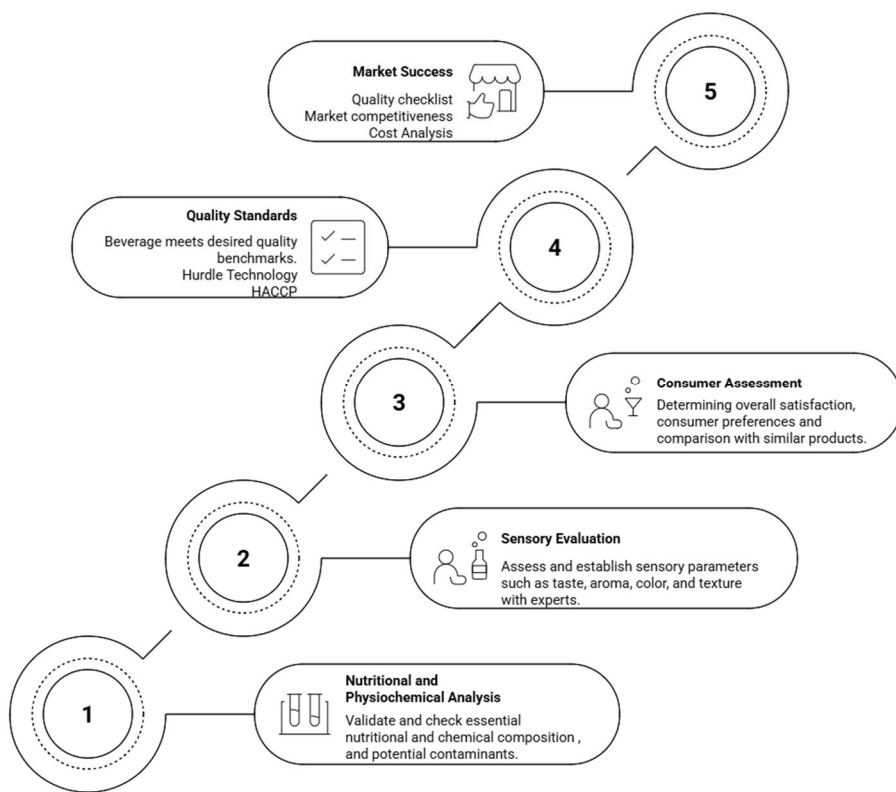


Figure 2 Quality Assessment of Kunun-zaki

B. Microbiological Quality

The most critical indicator for quality of such beverages as *Kunun-zaki* is microbiological aspect. It determines how safe and how long the product lasts on the shelf. The microbiological quality is disrupted by the presence of pathogenic organisms which pose health risks. This microbiological quality is assessed by carrying out a total viable count (TVC). The TVC is used to assess the microbial load in *Kunun-zaki* which is determined by performing serial dilutions and incubating the beverage on agar plates and counting the number of colony-forming units (CFUs). A high CFU count usually means poor quality due to contamination by microbes. This was proven in an investigation on freshly prepared *Kunun-zaki* drinks by (E Odo et al., 2021). The findings revealed that 70% of samples observed were contaminated with *Staphylococcus*, 60% with *Salmonella* spp, and 45% with *Escherichia coli*. This suggests a highly contaminated product and serious quality control check and hygiene practices need to be implemented. The presence of microorganisms, depending on the type also plays a crucial role in most beverages. Lactic Acid Bacteria (LAB) has been discovered to be one of the most beneficial microorganisms found in *Kunun-zaki*. It is responsible for improving its microbiological safety by producing organic acids. (Onyimba et al., 2017), used combinations of *Lactobacillus fermentum*, *Lactobacillus plantarum*, and *Lactobacillus acidophilus* as starter cultures in the production of *Kunun-zaki*. The fermentation process was monitored for pH, titratable acidity, and crude protein content. The study presented beverage samples with better protein content and sensory properties.

In addition, with safety regulations and standards established by the Nigerian Standards Organization (SON) and international organizations like the World Health Organization (WHO), the microbial safety of beverages such as *Kunun-zaki* is mostly taken care of. A common attribute of these kinds of products is that they are produced outside government regulation without any rules or regard to standard food safety guidelines. They could be home-made, surrogate, and counterfeit beverages that predispose people to hazardous substances (Nwaiwu et al., 2020).

C. Nutritional Composition

Kunun-zaki has one of the most interesting nutritional compositional. A lot of the health benefits and its suitability for consumption lie in the art of ingredients combined. Formerly, *Kunun-zaki* apart from its occasional use during festivities, it is often suggested as weaning food beverage for infants in Nigeria. However, the composition of the regular *Kunun-zaki* beverage makes it deficient of some other essential nutrient. This is majorly because the nutrient is cereal based. This deficiency has brought about the need for supplementation with some micro and macro nutrients (Giri et al., 2023, Taylor and Kruger, 2019). Overall, the nutritional composition of *Kunun-zaki* is dependent on the type of cereal used, the cereal combinations and most importantly the type of ingredients added. These ingredients are typically other cereals, fruits and

legumes for enhancement or fortification. The nutritional qualities of *Kunun-zaki* produced from sorghum and date Fruit flour (*Phoenix dactylifera*) was investigated (Egbera et al., 2021). The results obtained showed that there was significant increase in protein, fibre, fat and carbohydrate. However, there was decrease in the moisture and ash content. The minerals composition was also assessed and an increase was observed with increase fortification of date fruit especially in parameters such as calcium, Iron and Magnesium. (Olufunke and Oluremi, 2015), also conducted a comparative analysis between the commercial *Kunun-zaki*, the laboratory prepared *Kunun-zaki* and the soybean enriched *Kunun-zaki*.

The commercially prepared *Kunun-zaki* had the highest moisture content followed by Laboratory-prepared *Kunun-zaki*. Soybean-enriched *Kunun-zaki* had the highest value of protein, fat, carbohydrates and ash. Organically sweetened *Kunun-zaki* beverages using miracle fruits and serendipity berry was formulated from sorghum and pearl millet. Their nutritional and quality characteristics were profiled and compared to those of sucrose-sweetened and unsweetened ones. The beverages showed improved quality indicators, and more micronutrients (vitamins and minerals) (Jolayemi et al., 2023c). Several studies has also been carried out on *Kunun-zaki* in the form of powder, the results obtained showed that despite subjecting the beverage to further processing, it was still able to retain significant amount of some nutrients such as the minerals and proximate properties (Ndulaka et al., 2014, Nkama et al., 2010, Ogungbemi et al., 2019, Sadiq and Atteh, 2023).

In terms of ingredient addition, spices have also been found to contribute greatly to the nutritional compositions of *Kunun-zaki*. Spices such as garlic, nutmeg and cinnamon increased the proximate composition and amino acid content where majorly leucine, proline and glutamate were most abundant (Mokoshe et al., 2021).

D. Sensory Evaluation

Sensory evaluation is an assessment tool used on food products to determine preference and acceptability. It is also used for keeping tabs on product quality and product development. It uses human sense organs to rate the quality attributes of food (de Almeida Costa et al., 2024). Some of the quality attributes may generally include taste, flavor, appearance, mouthfeel, aroma, and overall acceptability (Huey et al., 2024). The technique behind this form of evaluation is to use a group of people either trained or untrained to seek their opinion on presented food products. In addition to this, a scoring sheet is given during this exercise to grade the attributes required in relation to the product. Moreover, the scientific part of sensory evaluation is to authenticate the sensory appeal and consumer acceptance of food such as beverages. It connects and affirms the chemical or nutritional analysis and responses from consumer experiences. The responses therefore ensure that the final product is nutritionally beneficial and appealing to the consumers. Most importantly, sensory evaluation helps ascertain those new formulations and modifications retain the

desirable sensorial properties of the traditional *Kunun-zaki* (Ghosh et al., 2024).

In the terms of *Kunun-zaki*, sensory evaluation is used to differentiate between product formulations and processing methods. This is important especially when the *Kunun-zaki* beverage is formulated with new and several ingredients. Such example is seen in the study by (Kajihausa and Opara, 2023), where sorghum based *Kunun-zaki* was enriched with coconut milk. The study revealed a favourable outcome as most samples had a high sensory score. Similarly, sensory evaluation was conducted on *Kunun-zaki* enriched with almond nut flour. The result showed that it is possible to use almond nut flour to enrich and to produce an acceptable beverage (Ibiloye et al., 2024).

V. FACTORS AFFECTING KUNUN-ZAKI PRODUCTION PROCESS

The process involved in *Kunun-zaki* production is affected by several factors. They are either affected by the environment in which it is being prepared, the ingredients involved or the method of production.

A. Environmental Factors

Fermentation can be affected by the temperature and humidity of the environment where a food product is kept. This is found occurring in the preparation of beverages. With warmer temperatures, there is a high chance of fermentation occurring fast whereas in areas with cooler temperatures, the process is slower. However, in the case of Lactic acid bacteria (LAB), fermentation is spontaneous. LAB are the most common microorganisms involved in the fermentation process of *Kunun-zaki* (Ogunremi et al., 2022, Oguntoyinbo and Narbad, 2012). The process of fermentation begins when the cereal of choice is steeped in water (Adelekan et al., 2013, Ndukwe et al., 2023). Certain physicochemical and biological reactions occur during the steeping stage, causing grain swelling, the breakdown of soluble carbohydrates, and the removal of some pigments, microorganisms, and bitter substances (Ingbian and Agwu, 2010).

Furthermore, the dominance of *Lactobacillus* at the genus level during most stages of processing and in the final product. *Kunu* formulations was observed by several researchers (Ezekiel et al., 2019, INYANG and Dabot, 1997, Oguntoyinbo and Narbad, 2012). The storage environment has a great effect on the final product of *Kunun-zaki*. It was reported by (Adeyemi and Umar, 1994), that at ambient temperature the physical and chemical changes in the product lead to a short shelf life of approximately 24 hours. As a result of the persistent shelf instability and safety concerns caused by intermittent power supply and the production procedure which remained unchanged. Despite pasteurization and refrigeration, *Kunun-zaki* 's shelf life was only extended by about 8 days (Gaffa and Ayo, 2002, Osuntogun and Aboaba, 2004). (Omoleke et al., 2018), conducted a comparison between freshly processed and street-hawked *kunu* showing that the

fresh samples were free of coliforms whereas products found on the street were not. It can be deduced that the Persistent microbial count in *Kunun-zaki* products is due to non-compliance and awareness of safety practices and exposure to different environment during sale. Even more recently, it was investigated and reported that the presence and abundance of microbes in fresh locally produced, packaged and distributed *Kunun-zaki* drinks were highly contaminated by foodborne microbial pathogens and it makes it unsafe for human consumption especially from unverified sources (E Odo et al., 2021).

B. Ingredient-Related Factors

Since the production of *Kunun-zaki* is still locally done and practically based on consumer and cultural habits, there is always going to be tendencies that variations would occur in different quality aspect and specifications of the beverage (Aboh and Oladosu, 2014).

1) Quality of Grains

The choice and quality of grains (millet, sorghum, or maize) used in *Kunun-zaki* production significantly affects the taste and nutritional content. The quality of grains used in beverage production is determined by the genetic potential of cereal variety and the environment in which the grain is produced. It is also dependent on the post-harvest storage and handling of the grains (Henry and Kettlewell, 2012). The sensory properties, proximate composition, and overall consumer acceptability of *Kunun-zaki* using germinated and un-germinated *Sorghum bicolor* (sorghum), *Pennisetum americanum* (millet) and *Digitaria exilis* (acha) cereal grains were evaluated. The result showed that germination increased Fat values slightly, but the Ash content was relatively stable in both germinated and un-germinated drinks. *i* (Oluwajoba et al., 2013). *Kunun-zaki* produced from malted cereals enriched with malted soymilk at different substitution levels was investigated. Enrichment with soymilk and malting increased the protein, amino acid, ash and moisture content of the improved *Kunun-zaki* (Adelekan et al., 2013).

2) Water Quality

Water has significant effects on taste, appearance, physical and microbiological stability during storage. It also serves as a carrier function for other ingredients (Tireki, 2021). Ideally, water specification should be decided according to microbiological quality, hardness and freedom from toxic materials like heavy metals, hydrocarbons, pesticides, herbicides and dioxins (Ashurst, 2016). Water hardness level may influence acidity and pH and so variations in microbial stability and taste can occur. Therefore, the quality of water used for soaking and blending the grains should be clean and free from contaminants to prevent adverse effects in the final product.

3) Spices and Flavorings

Spices are aromatic plants that have been used for centuries to confer aroma and flavour to food and beverages.

Additionally, due to the antioxidant and antimicrobial activities of their constituents, medicinal and aromatic plants can act as stabilizer agents, playing an important role in the shelf-life of foods and beverages (Salgueiro et al., 2010). *Kunun-zaki* beverages are highly susceptible to contamination by food spoilage microbes. This has been established to be due to various process involved in their production. To mitigate this challenge of deterioration, researchers have delved into exploring various spices, which do not only enhance the taste of the beverage but also serve as preservatives. It has been reported that organic spices increase the nutritive value of *Kumu* varieties; however, these could also possibly be employed as natural preservatives for improving the *Kunun-zaki* shelf-life (Fapohunda and Adeware, 2012, Williana et al., 2021).

The type and quantity of spices and flavorings added, such as ginger or cloves, can impact the flavor profile of *Kunun-zaki* (Alcicek et al., 2003, Williana et al., 2021). The non-availability or inadequacy of standards for checking and assuring the quality of aromatic plants and spices is one of the main problems that arise for industry when using such raw materials. As many aromatic plants are harvested from the wild, standardization to assure their quality is important for their safe and effective utilization in food and beverage industries. On the other hand, there are numerous parameters that influence the chemical composition of plants, which play an important role in the final quality of the product and possibly in any risk arising to the consumer (Alcicek et al., 2003, Waimer et al., 2007).

C. Process-Related Factors

1) Fermentation

This is the most important tool used in cereal-based beverages. It is relatively simple and cheap. In history, fermented beverages stand out amongst other beverage and are driven by microbial metabolism (acid production, enzymatic breakdown of substrates, and increased nutrient bioavailability) The process time for fermentation is different for different beverage type depending on factors like temperature and the type of ingredient used. The duration of fermentation also has a great effect on the taste of the resultant beverage such as the *Kunun-zaki*. The longer the beverage is left to ferment the sourer the beverage becomes. The sourness is a key indicator of the beverage quality (Ignat et al., 2020). Furthermore, fermentation also functions as a preservation tool. This is evident for developing countries where preservative methods for indigenous food are still not yet fully established (Soro-Yao et al., 2014). Considerably, a lot of efforts have been made in harvesting and characterizing microorganisms from local foods to serve as starter culture for producing another food. This is seen in especially cases of beverage and dairy products. Usage of this starters for beverages such as *Kunun-zaki* improves the fermentation process by reducing the production time and encourages safety from consumer contact thereby reducing hygienic risks (Onyimba et al., 2017).

2) Hygiene and Sanitation

The production of local beverages such as *Kunun-zaki* presents settings where contamination can happen at any time. To ensure the safety of the product, a number procedures have to be implemented (Gebre et al., 2024, Pola et al., 2024). During production, these procedures are essential for avoiding spoilage and health hazards. The production method of the traditional *Kunun-zaki* is susceptible to contamination because of the usage of repurposed packing material and the artisanal processing conditions earlier mentioned of how lack of process control compromises overall quality (Egbere et al., 2021, Nahemiah et al., 2014). Use of clean equipment, treated water, trusted suppliers of ingredients/raw materials, good hygienic practices are some of the standards provided to ensure safe and quality beverages (Aadil et al., 2019, Jebichi, 2018, Schmidt and Piotter, 2020). In addition, implementing quality principles such as Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP) can help maintain and prevent contaminations. These principles help manufacturers point out critical points where contamination can occur and help present preventive measures before they occur (Ibrahim, 2020). The challenge with this type of system is that it must be adhered to strictly to ensure continuous production of high-quality products that would meet consumer expectations and regulatory requirements.

3) Packaging and Storage

The susceptibility of beverages to microbial contamination is due to its high moisture content. This has made factors like the packaging and storage very critical in the production of *Kunun-zaki* (Madilo et al., 2024, Nwaiwu et al., 2020). Lack of proper packaging exposes beverages to physical contaminants, air and moisture uptake which causes rapid spoilage and public health implications (Karanth et al., 2023). The type of package or container used for beverages is supposed to be a food grade plastic material or a container that can be sealed tightly. This is to prevent contamination and preserve the beverage sensory properties. However, in the case of *Kunun-zaki*, it used to be previously packed in reusable plastic bottles and transparent polyethylene sachets (Ogunlade and Adeleke, 2021, Tersoo-Abiem and Orinya, 2024). This was mostly practiced by small and medium-scale producers for commercial purposes and mostly for immediate consumption. Overtime, with awareness of safety practices, the producers of *Kunun-zaki* started taking precautions to ensure quality of their products. One of such practices is the use of sterile bottles for packaging. (Egbere et al., 2021), conducted a microbial analysis on a laboratory produced *Kunun-zaki*. The study proved that using sterile screw-capped bottles for packaging could help prevent microbial contamination especially for large scale producers.

To maintain stability, with the right packaging the storage conditions, such as temperature and humidity, also plays a significant role in the quality of beverages (Aadil et al., 2019, Kong and Singh, 2016). Refrigeration or cold storage is often a requirement to maintain and extend the product's shelf-life. Additionally, with developments such as the use of chemical

preservatives, beverages have now been able to withstand environmental conditions and are able to thrive well at ambient temperatures (Kalpana and Rajeswari, 2019). Several attempts have been made to preserve and stabilize *Kunun-zaki* with a few successes. However, there hasn't been any success recorded for a complete stabilization in terms of nutrient, shelf life and sensory attributes. Therefore, there is need to investigate the optimization of packaging and storage conditions which can significantly enhance the shelf-life and acceptability of *Kunun-zaki*, to ensure its safety and high quality throughout its intended shelf-life.

D. Consumer Preferences

Consumer preferences are just as important as any other factor in beverage production. This is because it has a dominant role in shaping the production and formulation of beverages (Kilders et al., 2021). The preferences of consumers on *Kunun-zaki* have influenced choices of raw materials used in its production. Some people are specific about the unique sourness, and some are more drawn to its spiciness and sweetness, its consistency and most of the times the color. However, as mentioned severally, the production method is still at the local level, which has caused a lot of variations in the attributes.

More recently, evolving health and dietary conditions have created a shift towards modifications of local drinks like *Kunun-zaki*. This is to provide healthier alternatives for people with targets in maintaining a healthier lifestyle. In many cases, protein enrichment and natural sweeteners have been the trend in the beverage industry (Abiodun et al., 2017, Ayo, 2004, Kajihansa and Opara, 2023, Noah and Yusuf, 2020, Olatoye et al., 2023, Terna et al., 2002). This diversification has become a marketing strategy for a lot of food products and through sensory and preference testing there's continuous popularity and relevance of the *Kunun-zaki*.

VI. SYNTHESIS OF RESEARCH GAPS AND QUALITY CHALLENGES

The research gaps identified in Table 2 is directly corresponding to the quality parameters presented in Figure 2. It provides foundation for incorporating existing findings and pointing out the challenges in *Kunun-zaki* production. For instance, shelf instability, as highlighted in Table 2, is closely linked to microbiological and physicochemical factors such as pH, water activity, and microbial load discussed earlier. While various technologies have been employed; including thermal processing, controlled fermentation, and improved packaging, the exploration still doesn't address the issues. Their effectiveness remains a challenge even in recent times particularly for small- and medium-scale producers in developing countries such as Nigeria. Therefore, the persistence of these quality challenges is not due to lack of research on how to translate existing solutions into integrated and economically feasible processing systems.

VII. COMPREHENSIVE MEASURES TO ENHANCE THE QUALITY AND MARKET POTENTIAL OF *KUNUN-ZAKI*

A. Nutrient enrichment

Considering the significance of non-alcoholic beverages in the diet, it is critical to examine the sources of energy and nutrients in this category of foods to ensure the nutritional quality of the products. According to Petraccia *et al.*, (2006), Non-alcoholic beverages provide approximately 800-1500 mL of daily fluid intake in the diet. Fluid intake in the diet is necessary for life and maintaining optimal levels of hydration, digestion and absorption of ingredients, excretion of metabolic products and toxins, and nerve transmission in order for humans to function properly (Benelam and Wyness, 2010, Petraccia *et al.*, 2006). Various ingredients have been added over time to improve the taste of non-alcoholic beverages and to make their consumption more appealing and, more recently, beneficial to the consumer's health (Rejman *et al.*, 2020). The current non-alcoholic beverage market is dynamic, expanding rapidly, and highly innovative, allowing consumers to make choices based on their specific needs and preferences.

The dietary and sensory qualities of cereal products are sometimes thought to be inferior to those of milk and milk-based foods. Smaller protein amounts, a lack of certain amino acids (lysine), the presence of anti-nutrients (phytic acid, tannins, and polyphenols), and the coarse nature of grains are some of the reasons for this (Blandino *et al.*, 2003). Several methods have been used to improve the nutritional qualities of cereals. Genetic enhancement and amino acid supplementation with protein concentrates or other protein-rich sources, such as grain legumes or defatted oil seed meals of cereals, are examples of these (Nkhata *et al.*, 2018).

Previous studies on the nutritional composition of *Kunun-zaki* (a cereal-based non-alcoholic) have shown that the protein content is relatively low (Anounye *et al.*, 1995, Bankole and Olatunji, 2001). This led to a great deal of fruitful research, where there was the fortification of the product with protein. Soybean was successfully added to *Kunun-zaki* to improve its nutritional profile to meet the daily protein, vitamins, and mineral requirements of vulnerable groups of the population in Nigeria. Soybean among other legumes, has the highest protein content (about 40%), whereas other legumes have 20-30% and cereals have a protein content of 8-15%. It is also one of the most excellent sourced and affordable source of protein for developing countries (Sowonola *et al.*, 2005). The technology serves as a cheaper alternative for the food industry in the production of high protein drinks using local sources (Adelekan *et al.*, 2013, Anounye, 1997, Danbaba *et al.*, 2014, Olufunke and Oluremi, 2015). Fortifying *Kunun-zaki* with soybean gave a nutritious beverage, but had no challenges of organoleptic acceptance (Anounye, 1997).

B. Safety practices

1) Pre-Treatment of Raw Materials

Pre-Treatment of raw materials is an essential part of production in cereal based non-alcoholic beverages. It affects

the overall quality of the final product. Typically, cleaning, soaking, germination, fermentation, or roasting are some of the pre-treatments used in the process (Ignat et al., 2020, Tofanā et al., 2021). This process is also dependent on the type or characteristics required by the producer. These pre-treatment methods are essential for improving the sensory and nutritional properties of beverages, to ensure that the final product is both acceptable to consumers and nutritionally beneficial.

Cleaning of cereal grain is usually the first step in the production. It involves removal of dirt, stones, and other impurities, to ensure onset of contamination from beginning (Kaushal and Kumar, 2022). The next step is to soak the grains. This step is important as it helps soften the grains and activate the enzymes that breakdown starch and protein (El Halal et al., 2019). Germination is another pre-treatment technique in some beverages. It involves allowing the grains to germinate which encourages enzymatic activities and improves the aroma and taste of the drink. A comparison was made to assess the quality attributes between germinated and ungerminated Kunun-zaki samples. The study revealed preference for the germinated beverage over the ungerminated one. There was also significant increase in nutrient availability (Oluwajoba et al., 2013). Roasting is often applied to beverages of leguminous base. It is either achieved spontaneously through natural process or by applying inoculate cultures. It helps to enhance nutrient and imparts a desirable taste. Roasting is often used to beverages made from legumes. It is applied to develop Flavors and eliminate anti-nutritional compositions of the beverage. It is also used to extend the keeping quality of the drinks (Mishra et al., 2023, Nawaz et al., 2020).

2) HACCP (Hazard Analysis Critical Control Point)

HACCP is such an important component of modern food safety management applications. The design, implementation, control, and management of HACCP systems are critical to the production of safe food products. The HACCP system is a very good way to ensure the safety from the farm to the final consumption. It is aimed at reducing all hazards associated with food production, as well as developing preventive measures to ensure that the production process is monitored (Shalaby et al., 2018). Past research has shown that it is also applicable in the production of non-alcoholic beverages; HACCP was also conducted on *SoyKunun-zaki* which further revealed a significant number of critical points physically and microbiologically that may have public health implications. This showed that *SoyKunun-zaki* will require strict monitoring during production to ensure safety of the product (Danbaba et al., 2014).

C. Hurdle technology

Hurdle technology is practiced in the food industry in order to provide safe, stable and nutritious foods and it is usually used in combination with HACCP (Hazard Analysis Critical Control Point) (Singh and Shalini, 2016). It entails the use of several preservative factors in situations where microorganisms are present in the food. It causes the food to overcome microbial

instability and the safety of most traditional and novel foods (Rajendran and Bharathidasan, 2018).

In practical terms, employing hurdle technology in *Kunun-zaki* production will require adjustments across the processing line. For example, controlled fermentation can be used to establish a target pH, followed by optimized pasteurization to reduce microbial load, and finally hygienic packaging and refrigeration to maintain stability. These interacting factors will require pH control which can be achieved through standardized fermentation or acidification processes, Temperature control, both during processing (pasteurization) and storage, Water activity management, through formulation or concentration adjustments and finally Process sequencing, ensuring that hurdles are applied in an optimal order. Therefore, the successful application of hurdle technology in *Kunun-zaki* production depends majorly on the selection of suitable hurdles and on their implementation in a controlled and scalable processing system. However, the challenge in this case lies in keeping consistency across these steps, particularly in small-scale operations where process control is limited.

Studies conducted to standardize and preserve sugar cane juice by using some hurdle treatments which involved pasteurization of juice at 70 °C for 10 min after addition of 0.6 ml ginger, 0.3 ml lemon, 0.7 ml mint, 1.0 gm salt and addition at the rate of 225 ppm of potassium metabisulfite (KMS) per 100 ml of sugarcane juice (Rajendran and Bharathidasan, 2018). The hurdles were good in preventing the growth of microorganisms in sugarcane, but the sensory scores reduced significantly with the advancement of storage time in the sugarcane juice. These principles of hurdle technology are also relevant to *Kunun-zaki*, where the combined effects of use of preservatives, thermal treatment, and storage conditions can be optimized to improve shelf stability.

D. Stabilization

Stabilization in food is a process in which an agent or additive is added to food products to help preserve or improve their original texture, physical and chemical characteristics (Himashree et al., 2022). They serve both the practical purpose of preservation while also making products far more appetizing to consumers. It is essential in the overall quality of food, most especially in preserving the microbial quality of beverages. This way the economic value and keeping quality of stabilized food products is increased. In Cereal-based non-alcoholic beverages, like *Kunun-zaki*, there is presence of insoluble particles and the tendency to separate during storage. This causes stability issues and would require a stabilizing agent to form a homogenous mix (Basinskiene and Cizeikiene, 2020). Stabilizing agents are natural and chemical substances used in beverages for stabilization over a longer period. Common stabilizers used in beverages include Gums (guar gum, xanthan gum, and gum arabic), Pectin, Carrageenan, modified starches, Cellulose Derivatives and emulsifiers etc. The choice of stabilizer is very important because it is dependent on the type of beverage, desired sensory attributes, and processing conditions. Selecting the right stabilizers is crucial to the

outcome of the resultant product retains (Krempel et al., 2019). However, Gums and Carageenans are best suitable for increase in viscosity, improved mouthfeel, prevents separation and stabilize emulsions in beverages like plant based and dairy-based drinks, hence, *Kunun-zaki* (Mishra et al., 2023).

Also, as reported by (Chenlo et al., 2009, Rosell et al., 2001), using hydrocolloids as stabilizing agents have neutral taste and aroma which enable them easy access to food addition without affecting the existing quality of the food product. (Krasaekoopt and Lokuliyana, 2011), reported that stabilizer application on the sensory properties of the fermented whey beverage from different types of milk; it showed a great improvement in the sensory properties of cow, goat and buffalo milk but cow milk whey beverage was most preferred. Similarly, the effect of stabilizers on physico-chemical and sensory quality of whey beverages was analysed and there was significant improvement on the sensory attributes like appearance/colour, odour/aroma, body/texture and taste/flavor without affecting the chemical characteristics of whey (Talpur et al., 2017). Hydrocolloids extracted from Achi, a local seed from a leguminous plant (*Brachystegia eurycoma*) was also evaluated on watermelon beverage and it shows that it can compete favourably with the existing hydrocolloids in the food industry (Nwakaudu et al., 2017).

Studies have shown that the effect of hydrocolloids is dependent on type of hydrocolloid used, its concentration, the food system in which it is used and the pH of the food system and temperature (Javanmard et al., 2012 and Crobotova et al., 2013). As reported by Shakeel et al., (2013), the cloud stability and nutritional properties were assessed with the addition of hydrocolloids, and it was concluded that the use of cellulytic and pectolytic enzyme preparations increased cloudy carrot juice yield and improved its quality. The color and β - carotene content of carrot juice changed a little during 6months storage, and the other nutritional characteristics became more stable. Guar gum and flaxseed gum stabilized the cloudy carrot juice. Moreover, flaxseed gum was able to reduce the creaming of cloudy carrot juice because of its ability to emulsify.

E. carbonation

Carbonation is a technique used in dissolving carbon dioxide (CO₂) gas into a drinks or beverages to create effervescence or bubbles that improves sensory appeal. Particularly, in dairy beverages, Carbonation occurs in two ways. The first type involves carbonated dairy beverages by adding yeast to the fermentable substrate. This helps the release of carbon dioxide during the fermentation. The second type is by mechanical or physical means during regular food plant processing. This is the most common and easy type (Table 3) (Newbold and Koppel, 2018). This process creates a refreshing effect and slightly imparts the taste of the beverage. It is also known to extend the shelf life of beverages by reducing the pH and inhibiting microbial growth. Carbonation is widely used in soft drinks, sparkling waters, and alcoholic beverages like beer and sparkling wine.

Carbonating beverages such as *Kunun-zaki* involves a controlled process where carbon dioxide (CO₂) is being dissolved into them. This process is governed by simple mass transfer principles following Henry's law, where gas solubility increases with increasing pressure and decreases with increasing temperature (Hussain and Gupta, 2025). However, unlike the conventional carbonated soft drinks, *Kunun-zaki* presents additional challenges due to its nature of semi-viscous and suspended particulates. These characteristics may reduce gas-liquid mass transfer efficiency and can lead to non-uniform CO₂ distribution. This process will therefore need the use of agitation-assisted carbonation or controlled gas injection systems to enhance contact between CO₂ and the liquid phase.

On a small scale, carbonation of beverages is typically carried out using simple batch carbonation systems. The beverage is first cooled to allow carbon dioxide (CO₂) solubility, then transferred into a sealed, pressure-resistant container or bottles. CO₂ gas is then introduced into the beverages by applying controlled pressure. Gentle agitation or shaking is then applied to enhance uniform dissolution. Once the desired level of carbonation is achieved, the beverage is filled into airtight containers under pressure to minimize CO₂ loss. Although this method is relatively simple and cost-effective, maintaining consistent pressure, temperature, and hygienic conditions remains a challenge, particularly in small-scale operations (Kolo et al., 2025, Newbold and Koppel, 2018).

In addition, the integration of carbonation with downstream packaging is critical. CO₂ retention is highly dependent on minimizing pressure loss during filling; therefore, the use of pressure-resistant containers and controlled filling systems is essential. For small- and medium-scale producers, the development of simplified batch carbonation units with basic pressure and temperature control offers a practical pathway for adopting this technology. From a market selling point, adding carbonation to local beverages out of curiosity will increase customer interest, market competitiveness and add to the uniqueness of the product. (Walsh et al., 2014), reported the effect carbonation had on the Probiotic Survivability, Physicochemical, and Sensory Properties of Milk-Based Symbiotic Beverages. The study showed that the beverages retained the same level of probiotics for 9 weeks at normal refrigerated temperature. It was also well accepted by the panellists even though the commercial samples had higher ratings.

A local drink from *roselle calyces* (*Zobo*) was successfully carbonated. The study showed that carbonation increased the shelf stability of *Zobo* drink by creating an anaerobic environment that prevented the growth of microorganisms which are aerobic. This prevented spoilage and extended the shelf life for up to 6 months without refrigeration (Chukwu et al., 2019). Studies on carbonated beverages (dairy and fruit juices etc) provide useful insights into the gas performance however, these principles are applicable to *Kunun-zaki*, particularly in understanding CO₂ dissolution and retention in a semi-viscous fermented kinetics. In a more relatable cereal-

based beverage, carbonation was added to *Kunun-zaki* to see the possibility of extending its shelf life. The samples were observed under ambient temperature for the period of storage. The sample with the highest gas volume had the best shelf-life and the non-carbonated sample yielded easily to spoilage from microbial growth. Therefore, the showed that the *Kunun-zaki* can be carbonated and compete with other available carbonated drinks in the market (Otaru et al., 2013). In more advanced research, (Thakur et al., 2022), a grain based carbonated beverage premix was developed in the form of dry powder. The resultant products showed a beverage premix with adequate nutritional composition that maintained a fizzy effect. Although, the instant version of the non-alcoholic beverages like *Borde*, *Kunun-zaki*, *Mahewu*, *Pozol*, and *Sattu* are produced in different countries, carbonation in dry form has never been added (Thakur et al., 2022). Therefore, by using a carbonation powder, an acceptable carbonated beverage premix can be made.

Furthermore, carbonated dairy beverages (as presented in Table 3) have different raw material composition from *Kunun-zaki*, however, the intent of using them as a reference is to provide their technological processes as insights that can be used to improve *kunun-zaki* production systems. These carbonated dairy beverages present challenges in terms of carbonation efficiency (right use of carbonation tank, filling nozzle, pressure control valves), phase stability (such as addition of stabilizers or agitation before filling), microbial safety, and packaging integrity (e.g. pressure-resistant PET/glass bottles, seal integrity, aseptic filling). Employing process control techniques such as CO₂ dissolution under controlled pressure and temperature conditions, selection of pressure-resistant packaging materials, and stabilization strategies to minimize sedimentation and phase separation are directly transferable to *Kunun-zaki* processing. In addition, these techniques can guide the optimization of carbonation pressure and temperature in *Kunun-zaki*.

Table 3. Types of Carbonated Beverages

Beverage	Type	Ingredients	Notes
Kefir	Carbonated by yeast addition prior fermentation	Bovine milk, kefir grains (wildly cultivated yeasts, lactic acid bacteria, acetic acid bacteria, and molds)	Originated in Russia, popular in the United State
Koumiss	Carbonated by yeast addition prior fermentation	Mares milk, thermophilic lactic acid bacteria (<i>Leuconostoc</i> , <i>Lactobacilli</i>), yeast	Traditionally consumed in the Middle East
Sparkling milk	Carbonated milk (carbonated through processing)	E-moo: Non-fat milk, calcium flavorings, fructose. Raging Cow: Milk, flavorings sweeteners, etc. Swerve: Milk flavorings, sugar, sucralose vitamins	E-moo: Launched in 2001 with the collaboration of Cornell University. Raging Cow: Created by Pepper/Snapple in 2003 Swerve: Introduced by Coca-Cola in 2003, it was discontinued in 2005

Source: (Newbold and Koppel, 2018)

VIII. PROCESS-RELATED FACTORS IN SCALING UP KUNUN-ZAKI PRODUCTION

The upgrade from small-scale (local) production of *Kunun-zaki* to industrial processing presents significant challenges that are beyond the basic principles previously discussed. While simple processes such as fermentation, heating, and filtration remain the same, their effectiveness is highly influenced by scale. This requires modifications and advancements in equipment design, process control, and system integration (Aworh, 2023).

A. Mixing and Agitation

At small scale, mixing of *Kunun-zaki* is achieved manually, which is adequate for small productions. However, to achieve uniform distribution and consistency in product composition becomes difficult as production volume increases.

Failure to achieve this can cause variability the quality of such beverages (Vasudevan and Chengaiyan, 2025).

As previously discussed, the composition of *Kunun-zaki* contributes to phase separation. At larger scales, this challenge is magnified due to reduced mixing efficiency. Therefore, mechanical agitation systems must be designed to ensure homogeneity. This includes the use of appropriately selected impellers and controlled agitation speeds that can maintain uniform suspension of solids without damaging product structure (Karaca and Jafari, 2025).

B. Heat Transfer During Processing

As earlier highlighted, application of heat processes, particularly pasteurization, is one of the key method for improving microbial safety. However, scaling up heat

treatment introduces significant challenges in achieving uniform temperature distribution (Faraldo and Byrne, 2024). In small batches, heat penetration is relatively rapid, but in larger volumes, temperature gradients can develop, resulting in under-processed and over-processed regions (Shuai et al., 2026). *Kunun-zaki's* semi-viscous nature may reduce heat transfer efficiency, especially at larger scale necessitating enhanced system design. Solutions include the use of jacketed vessels with agitation or continuous flow heat exchangers, which improve heat transfer rates and ensure consistent thermal treatment (Reis, 2023). These same processes have been applied successfully to various milk products. They are required in the process of heating or cooling of milk and the evaporation, freezing, or crystallization of milk for the manufacture of dairy products such as yogurt, cream, and ice creams (Rehman et al., 2023). This technique could be advantageous to *kunun-zaki* variants.

C. Solid-Liquid Separation

Separation of solutes is a critical step in *Kunun-zaki* production. It is performed by filtration or sieving which is used to achieve the desired texture and remove coarse particles (shaft) (Ibiloye et al., 2024, Towobola, 2021). While manual sieving is adequate at household level, it becomes inefficient and inconsistent at larger scales. Therefore, Scaling up this process requires the adoption of mechanical separation systems such as rotary sieves, vibrating screens, or filter presses (Jafari and Karaca, 2025). These systems provide improved output and consistency over final product quality. However, this advanced equipment may cause some challenges such as clogging, effective cleaning requirements, and cost implications.

D. Packaging Line Integration

Packaging remains a big challenge in the beverage industry and it represents a critical control point in maintaining the quality and safety of *Kunun-zaki*. While small-scale production often involves manual filling and repurposed plastic bottles, this exposes the beverage to risk of post-processing contamination (Egbera et al., 2021, Oranusi et al., 2003). As discussed earlier, microbial contamination can occur at different stages of production. Without proper packaging systems and hygiene regulations, the success of processing steps such as pasteurization may be lost. Therefore, scale-up requires the use of controlled filling systems, proper sealing mechanisms, and aseptic handling techniques.

E. Process Integration and Scale-Up Considerations

A key limitation in current *Kunun-zaki* production systems is the lack of integration between processing steps (Abubakar et al., 2026). At larger scales, optimal results are obtained when individual unit operations function as a coordinated system. A successful scale-up requires not only the effective application of individual processes but also their integration into a continuous or semi-continuous production line. This includes simultaneity of processing steps and adoption of cost-effective technologies suitable for local conditions.

IX. CONCLUSION

Kunun-zaki is known to have significant potential for both local and international markets. However, to scale up commercialization so many challenges are encountered. This review highlights that the limitations of *Kunun-zaki* production which is not only due to raw material variability or local practices but are basically linked to inadequate process control and lack of scalable processing technologies. The Key challenges that have been persistent are identified as inefficient heat transfer during pasteurization, lack of controlled fermentation systems, difficulties in achieving uniform mixing and stable suspension of particulates at larger scales and the inefficiency of traditional separation techniques. In addition, there is challenge in the risk of post-processing contamination due to the absence of integrated and hygienic packaging systems, thereby limiting shelf-life and commercialization.

To address these challenges there is need to shift from traditional processing methods to advanced or technological-driven system design. Research efforts should explore the use of synchronised production lines, improved mixing systems, modern filtration technologies, and affordable and hygienic packaging. Furthermore, the integration of hurdle technology, controlled pasteurization and fermentation, and appropriate storage conditions, also presents a promising approach for ensuring shelf stability without compromising overall product quality. Finally, future research should therefore focus on the optimization of thermal processing systems for the rheological properties of *Kunun-zaki*, as well as the design of low-cost, energy-efficient pasteurization units suitable for small- and medium-scale producers. There is also a need for the development of simple and basic fermentation systems, such as low-cost bioreactors to ensure consistent product quality.

REFERENCES

- aadil, R. M., Madni, G. M., Roobab, U., Ur Rahman, U. and Zeng, X.-A. 2019.** Quality control in beverage production: An overview. *Quality control in the beverage industry*, 1-38.
- Abiodun, O., Dauda, A., Adebisi, T. and Alonge, C. 2017.** Physico-chemical, microbial and sensory properties of kunu zaki beverage sweetened with black velvet tamarind (*Dialium guineense*). *Croatian journal of food science and technology*, 9, 46-56.
- Aboh, M. and Oladosu, P. 2014.** Microbiological assessment of kunun-zaki marketed in Abuja Municipal Area Council (AMAC) in The Federal Capital Territory (FCT), Nigeria. *African Journal of Microbiology Research*, 8, 1633-1637.
- Abubakar, M., Gana, I. and Usman, M. 2026.** Development and Testing of a Retort for Sterilization of a Packaged Grain Beverage.
- Adelekan, A. O., Alamu, A. E., Arisa, N. U., Adebayo, Y. O. and Dosa, A. S. 2013.** Nutritional,

- microbiological and sensory characteristics of malted soy-kunu zaki: an improved traditional beverage.
- Adeyemi, I. and Umar, S. 1994.** Effect of method of manufacture on quality characteristics of kunun-zaki, a millet-based beverage. *Nigerian Food Journal*, 12, 34-41.
- Agarry, O., Nkama, I. and Akoma, O. 2010.** Production of Kunun-zaki (A Nigerian fermented cereal beverage) using starter culture. *International Research Journal of Microbiology*, 1, 18-25.
- Aka, S., Konan, G., Fokou, G., Dje, K. M. and Bonfoh B. 2014.** Review on African traditional cereal beverages. *Am. J. Res Commun*, 2, 103-153.
- Akani, N. and Nwankwo, C. 2018.** Monitoring the microbial load at chosen critical control points in the production of Kunun-zaki. *IOSR J. Environ. Sci*, 12, 41-46.
- Alcicek, A., Bozkurt, M. and Çabuk, M. 2003.** The effect of an essential oil combination derived from selected herbs growing wild in Turkey on broiler performance. *South African Journal of Animal Science*, 33, 89-94.
- Anouye, J. C. 1997.** *Development and Evaluation of Soybeans-Millet blend for Soy-kununuzaki preparation.* MSc Thesis of Department of Food Science and Technology, University of Makurdi.
- Anouye, J. C., Ndaeki, C. F. and Osho, S. M. 1995.** The Effect of Soybean Incorporation and Temperature on the Nutritional Status and Shelf-life of Kunuzaki. *Postharvest Technology and Commodity Marketing*.
- Arendt, E. K. and Zannini, E. 2013.** *Cereal grains for the food and beverage industries*, Elsevier.
- Ashurst, P. R. 2016.** *Chemistry and Technology of Soft Drinks and Fruit Juices.*
- Aworh, O. C. 2023.** African traditional foods and sustainable food security. *Food control*, 145, 109393.
- Ayo, J. 2004.** Effect of acha (*Digitaria exilis* staph) and millet (*Pennisetum typhodium*) grain on kunun zaki. *British Food Journal*, 106, 512-519.
- Bankole, A. and Olatunji, O. 2001.** Development of unfermented malted cereal-Soy beverage. *Nigerian Food Journal* 19, 106-114.
- Baryeh, E. A. 2002.** Physical properties of millet. *Journal of Food Engineering*, 51, 39-46.
- Bashar, M. A. 2022.** HACCP and microbiology qualities of sea-foods as affected by handler's hygienic.
- Basinskiene, L. and Cizeikiene, D. 2020.** Cereal-based nonalcoholic beverages. *Trends in Non-alcoholic Beverages*, 63-99.
- Benelam, B. and Wyness, L. 2010.** Hydration and health and a review. *Nutrition Bulletin*, 35, 3-25.
- Beta, T., Nam, S., Dexter, J. E. and Sapirstein, H. D. 2005.** Phenolic content and antioxidant activity of pearled wheat and roller-milled fractions. *Cereal chemistry*, 82, 390-393.
- Blandino, A., Al-Aseeri, M., Pandiella, S., Cantero, D. and Webb, C. 2003.** Cereal-based fermented foods and beverages. *Food research international*, 36, 527-543.
- Chenlo, F., Moreira, R., Pereira, G. and Silva, C. 2009.** Rheological modelling of binary and ternary systems of tragacanth, guar gum and methylcellulose in dilute range of concentration at different temperatures. *LWT-Food Science and Technology*, 42, 519-524.
- Chukwu, V. C., Oyeleke, S. B., Anuonye, J. C. and Bala, J. D. 2019.** Comparative Effects of Some Preservative Hurdles on the Quality of Zobo Drink Stored at Ambient Temperature. *Microbiology Research Journal International* 27, 1-10.
- Dada, A. A., Ifesan, B. O. T. and Fashakin, J. F. 2013.** Antimicrobial and antioxidant properties of selected local spices used in "Kunun" beverage in Nigeria. *Acta Scientiarum Polonorum Technologia Alimentaria*, 12, 373-378.
- Danbaba, N., Oyeleke, S., Maji, A., Kolo, I., Hauwau, H. and Kolo, I. 2014.** Chemical and microbiological characteristics of Soy-Kununuzaki (a nonalcoholic beverage) produced from millet (*Pennisetum typhodeum*) and soybean (*Glycine max*). *International Journal of Current Microbiology and Applied Sciences*, 3, 649-656.
- De Almeida Costa, A. I., Monteiro, M. J. P. and Lamy, E. 2024.** *Sensory Evaluation and Consumer Acceptance of New Food Products: Principles and Applications*, Royal Society of Chemistry.
- Demirkaya, E., Ciftcioglu, B., Ozyildiz, G., Zengin, G. E., Pala-Ozkok, I., Cokgor, E. and Tas, D. O. 2022.** Comprehensive evaluation of starter culture impact on the bioreactor performance and microbial kinetics. *Biochemical Engineering Journal*, 177, 108233.
- E Odo, S., A Nwaubani, D., N Ebe, G., I Idume, J. and W Okengwu, O. 2021.** Determination of Microbial Pathogens and its Abundance in Fresh Kunun-Zaki Drinks: Huge Threat to Public Health. *Journal of Advances in Microbiology*, 21, 38-42.
- Edward, K. and Ohaegbu, C. 2012.** The effect of ginger and garlic on the microbial load and shelf life of Kunun-zaki. *Journal of Applied Pharmaceutical Science*, 2, 150-153.
- Egbere, J., Odu, C., Onyimba, I., Ngene, A., Yusuf, A., Ogaji, A., Dashen, M., Hemen, W. and Entonu, E. 2021.** Microbiological and Organoleptic Quality Characteristics of Laboratory Produced Date Fruit-based Kunun-zaki. *European Journal of Biology and Biotechnology*, 2, 97-104.
- Egbere, O., Pam, K., Adeshyan, K., A'kadir, T. and Oyero, S. 2009.** Effects of pasteurisation on survival patterns of microorganisms and vitamin C retention in kunun-zaki. *African Journal of Biotechnology*, 8.
- El Halal, S. L. M., Kringel, D. H., Zavareze, E. D. R. and Dias, A. R. G. 2019.** Methods for extracting cereal starches from different sources: A review. *Starch-Stärke*, 71, 1900128.
- Elderwy, Y., Kalita, R., Hamouda, M. E., Chaudhary, P., Elfaruk, M. S., Don, P. U. and Abdelsater, O. A. 2025.** Influence of guar gum and xanthan gum on the rheological behavior, texture, and microstructure of probiotic low-fat yogurt. *Processes*, 13, 3301.
- Ezekiel, C. N., Ayeni, K. I., Ezeokoli, O. T., Sulyok, M., Van Wyk, D. A., Oyedele, O. A., Akinyemi, O. M., Chibuzor-Onyema, I. E., Adeleke, R. A. and Nwangburuka, C. C. 2019.** High-throughput sequence analyses of bacterial communities and multi-mycotoxin profiling during processing

- of different formulations of Kunu, a traditional fermented beverage. *Frontiers in microbiology*, 9, 3282.
- Ezekiel, C. N., Ayeni, K. I., Misihairabgwi, J. M., Somorin, Y. M., Chibuzor-Onyema, I. E., Oyedele, O. A., Abia W. A., Sulyok, M., Shephard, G. S. and Krska, R. 2018.** Traditionally processed beverages in Africa: a review of mycotoxin occurrence patterns and exposure assessment. *Comprehensive Reviews in Food Science and Food Safety*, 17, 334-351.
- Fapohunda, S. and Adeware, A. 2012.** Microbial load and keeping Quality of kunu under various Preservative Regimes. *Nutrition & Food Sciences*.
- Faraldo, F. and Byrne, P. 2024.** A review of efficient technologies and decarbonating solutions for process heat in the food industry. *Energies*, 17, 3051.
- Folasade, M. and Oyenike, O. 2012.** Effect of seed addition on the chemical and sensory qualities of sorghum based kunun-zaki drink. *African Journal of Food Science and Technology*, 3, 204-212.
- Gaffa, T. and Ayo, J. 2002.** Innovations in the traditional kunun zaki production process. *Pakistan Journal of Nutrition*, 1, 202-205.
- Gaffa, T., Jideani, I. and Nkama, I. 2002a.** Traditional production, consumption and storage of Kunu—a non alcoholic cereal beverage. *Plant Foods for Human Nutrition*, 57, 73-81.
- Gaffa, T., Jideani, I. and Nkama, I. 2002b.** Traditional production, consumption and storage of Kunu—a non alcoholic cereal beverage. *Plant foods for human nutrition*, 57, 73-81.
- Gebre, T. S., Emire, S. A., Aloo, S. O., Chelliah, R., Vijayalakshmi, S. and Oh, D. H. 2024.** Unveiling the potential of African fermented cereal-based beverages: Probiotics, functional drinks, health benefits and bioactive components. *Food Research International*, 114656.
- Ghosh, P., Upadhyay, S., Khan, M. and Mujahid, B. M. 2024.** Exploring the Diversity of Fermented Plant-Based Beverages with an Emphasis on the Therapeutic Role of Probiotics: A Review. *Pakistan journal of life and social Sciences*, 22, 1537-1552.
- Giordano, D., Reyneri, A. and Blandino, M. 2016.** Folate distribution in barley (*Hordeum vulgare* L.), common wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum durum* L.) leaf powder: Nutritional and sensory characteristics. *Processes*, 4, 2125.
- Giri, N. A., Sakhale, B. K. and Nirmal, N. P. 2023.** Functional beverages: an emerging trend in beverage world. *Recent Advances in Food Science and Technology*, 123-142.
- Henry, R. and Kettlewell, P. 2012.** *Cereal grain quality*, Springer Science & Business Media.
- Himashree, P., Sengar, A. S. & Sunil, C. 2022.** Food thickening agents: Sources, chemistry, properties and applications. A review. *International Journal of Gastronomy and Food Science*, 27, 100468.
- Huey, S. L., Bhargava, A., Friesen, V. M., Konieczynski, E. M., Krisher, J. T., Mbuya, M. N., Mehta, H., Monterrosa, E., Nyangaresi, A. M. and Mehta, S. 2024.** Sensory acceptability of biofortified foods and food products: a systematic review. *Nutrition Reviews*, 82, 892-912.
- Hussain, M. A. and Gupta, R. 2025.** Mass Transfer in Gas–Liquid Taylor Flow in Microchannels: Effect of Henry’s Constant, Two-Phase Velocity, Bubble Length, and Slug Length. *Langmuir*, 41, 23325-23342.
- Ibiloye, I., Adetunji, R., Oguntuase, S., Talabi, J., Ifesan, B. and Ifesan, B. 2024.** Chemical Properties of Kunu Beverage Enriched with Almond (*Terminalia catappa*) Nut Flour. *Applied Tropical Agriculture*, 29, 48 - 54.
- Ibrahim, A., Ayo, J. and Joseph, H. 2022.** Effects of orange-fleshed sweet potato supplementation on the phytochemical composition, physicochemical, and sensory properties of sorghum-based kunu-zaki. *Research Journal of Food Science and Nutrition*, 6, 22-29.
- Ibrahim, O. O. 2020.** Introduction to hazard analysis and critical control points (HACCP). *EC Microbiology*, 16, 42-50.
- Ignat, M. V., Salanță, L. C., Pop, O. L., Pop, C. R., Tofană, M., Mudura, E., Coldea, T. E., Borșa, A. and Pasqualone, A. 2020.** Current functionality and potential improvements of non-alcoholic fermented cereal beverages. *Foods*, 9, 1031.
- Ingbian, E. K. and Agwu, O. 2010.** Effect of different steeping regimes on the microbiological, chemical and water characteristic of selected maize grain varieties. *Journal of Food Processing and Preservation*, 34, 426-439.
- Inyang, C. U. and Dabot, Y. 1997.** Storability and potability of pasteurized and sterilized “kunun-zaki”: A fermented sorghum beverage. *Journal of food processing and preservation*, 21, 1-7.
- Jafari, S. M. and Karaca, A. C. 2025.** *Mechanical Separation Processes in the Food Industry: Unit Operations and Processing Equipment in the Food Industry*, Elsevier.
- Jebichi, K. N. 2018.** *Hygienic design of equipment and hygiene practices of processors among the micro and small enterprises in the soft drink industry: case of Nairobi, Kenya*. University of Nairobi.
- Jideani, V. A., Ratau, M. A. and Okudoh, V. I. 2021.** *Leuconostoc mesenteroides* and *Pediococcus pentosaceus* non-Folate distribution in barley (*Hordeum vulgare* L.), common wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum durum* L.) leaf powder: Nutritional and sensory characteristics. *Processes*, 9, 2125.
- Jolayemi, O. S., Abiodun, A. O., Ayo-Omogie, H. N., Ndigwe, V. and Jolayemi, O. S. 2023a.** Nutritional and quality characterizations of organically-sweetened Kunun-zaki beverage—a 2 multifactorial approach.
- Jolayemi, O. S., Ojo, A., Ayo-Omogie, H. N. and Enujiughha, V. N. 2023b.** Multifactorial Characterization of Nutritional and Quality Profiles of Organically-sweetened Kunun-zaki Beverage. *Measurement: Food*, 100106.
- Jolayemi, O. S., Ojo, A., Ayo-Omogie, H. N. and Enujiughha, V. N. 2023c.** Multifactorial characterization of nutritional and quality profiles of organically-sweetened Kunun-zaki beverage. *Measurement: Food*, 11, 100106.
- Kajihusa, O. and Opara, C. 2023.** Proximate, Mineral Composition and Sensory Acceptability of Kunun-Zaki

- Produced from Sorghum and Coconut Milk. *Applied Tropical Agriculture* 28, 32 - 37.
- Kalpana, V. and Rajeswari, V. D. 2019.** Preservatives in beverages: perception and needs. *Preservatives and preservation approaches in beverages*. Elsevier.
- Karaca, A. C. and Jafari, S. M. 2025.** Introduction to mechanical separation processes in the food industry. *Mechanical Separation Processes in the Food Industry*. Elsevier.
- Karanth, S., Feng, S., Patra, D. and Pradhan, A. KH. W., Ogaji, A. O. and Ngene, A. C. 2023.** Linking microbial contamination to food spoilage and waste: The role of smart packaging, spoilage risk assessments, and date labeling. *Frontiers in Microbiology*, 14, 1198124.
- Kaushal, P. and Kumar, N. 2022.** Processing of Cereals. *Agro-Processing and Food Engineering: Operational and Application Aspects*. Springer.
- Kilders, V., Caputo, V. and Liverpool-Tasie, L. S. 2021.** Consumer ethnocentric behavior and food choices in developing countries: The case of Nigeria. *Food Policy*, 99, 101973.
- Kolo, S., Anounye, J., Chinma, C., Makun, H. and Oche, R. 2025.** Sensory Evaluation of Carbonated Soykunun-Zakunun Zaki: A Traditional Cereal-Based Fermented Beverage of Beverage Using Response Surface Analysis.
- Kong, F. and Singh, R. 2016.** Chemical deterioration and physical instability of foods and beverages. *The stability and shelf life of food*. Elsevier.
- Kontopodi, E., Boeren, S., Stahl, B., Van Goudoever, J. B., Van Elburg, R. M. and Hettinga, K. 2022.** High-temperature short-time preserves human milk's bioactive proteins and their function better than pasteurization techniques with long processing times. *Frontiers in pediatrics*, 9, 798609.
- Köster, E. P. and Mojet, J. 2015.** From mood to food and from food to mood: A psychological perspective on the measurement of food-related emotions in consumer research. *Food research international*, 76, 180-191.
- Krasaekoopt, W. and Lokuliyange, T. 2011.** Effect of hydrocolloids on sensory properties of the fermented whey beverage from different types of milk. *AUJT*, 14, 253-258.
- Krempel, M., Griffin, K. and Houryieh, H. 2019.** Hydrocolloids as emulsifiers and stabilizers in beverage preservation. *Preservatives and preservation approaches in beverages*. Elsevier.
- Lola, K. F., Adebanye, B. M., Adeoye, O. S., Damilolaye, S. H., Olamide, S.-O. H. and Bolaji, K. M. 2018.** Production and sensory evaluation of Kunun-zaki sweetened with orange fleshed sweet potato (*Ipomoea batatas*) syrup. *Croatian journal of food science and technology*, 10, 239-244.
- Madilo, F. K., Parry-Hanson Kunadu, A., Tano Debrah, K., Saalia, F. K. and Kolanisi, U. 2024.** Diversity of Production Techniques and Microbiology of African Cereal-Based Traditional Fermented Beverages. *Journal of Food Quality*, 2024, 1241614.
- Maji, A. A., James, O. and Chigozie, O. E. 2011.** Effect of chemical treatment and pasteurization on the shelf life of Kunun-zaki (sorghum and maize gruel). *European Journal of Nutrition and Food Safety*, 1, 61-70.
- Mckeivith, B. 2004.** Nutritional aspects of cereals. *Nutrition Bulletin*, 29, 111-142.
- Mishra, S., Singh, R., Upadhyay, A., Mishra, S. and Shukla, S. 2023.** Emerging Trends in Processing For Cereal and Legume-Based Beverages: A Review. *Future Foods*, 100257.
- Mokoshe, N., Osopale, A., Ezeamagu, O. and Fapohunda, S. O. 2021.** Role of organic spices in the preservation of traditionally fermented kunun-zaki.
- Musa, S., Egbere, J. O., Odu, C. E., Danladi, M. M., Onyimba, I. A., Dashen, M., Ochiheche, E. G., Nguhemen, A. O. and Ngene, A. C. 2023.** In-vitro inhibitory effect of lactic acid bacteria isolated from Kunun zaki against multi-drug resistant diarrhoegenic bacteria in HIV patients in Jos, Nigeria. *Microbes & Infectious Diseases*, 4.
- Na, A. U. and Odunbaku, O. 2009.** Microbiological and Nutritional Quality of Hawked Kunun (A Sorghum Based Non-Alcoholic Beverage) Widely Consumed in Nigeria. *Pakistan Journal of Nutrition*, 8, 20-25.
- Nahemiah, D., Bankole, O. S., Tswako, M., Nma-Usman, K. I., Hassan, H. and Fati, K. I. 2014.** Hazard Analysis Critical Control Points (HACCP) in the Production of Soy-Oche. *Am. J. Food Sci. Technol*, 2, 196-202.
- Nawaz, M. A., Tan, M., Øiseth, S. and Buckow, R. 2020.** An emerging segment of functional legume-based beverages: a review. *Food Reviews International*, 1-39.
- Ndukwe, J. K., Aduba, C. C., Ughamba, K. T., Chukwu, K. O., Eze, C. N., Nwaiwu, O. and Onyeaka, H. 2023.** Diet Diversification and Priming with Kunu: An Indigenous Probiotic Cereal-Based Non-Alcoholic Beverage in Nigeria. *Beverages*, 9, 14.
- Ndulaka, J., Obasi, N. and Omeire, G. 2014.** Production and Evaluation of Reconstitutable Kunun-Zaki. *Nigerian Food Journal*, 32, 66-72.
- Newbold, D. and Koppel, K. 2018.** Carbonated dairy beverages: challenges and opportunities. *Beverages*, 4, 66.
- Nkama, I., Agarry, O. and Akoma, O. 2010.** Sensory and nutritional quality characteristics of powdered 'Kunun-zaki': A Nigerian fermented cereal beverage. *Afr. J. Food Sci*, 4, 364-370.
- Nkhata, S. G., Ayua, E., Kamau, E. H. and Shingiro, J. B. 2018.** Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food science & nutrition*, 6, 2446-2458.
- Noah, A. A. and Yusuf, M. A. 2020.** Nutritional and Sensory Qualities of Kunu-Zaki (A Non-alcoholic Local Beverage) Produced from Sorghum and Date Fruit. *American Journal of Food Science and Nutrition Research*, 7, 1-5.
- Nout, M. and Motarjemi, Y. 1997.** Assessment of fermentation as a household technology for improving food safety: a joint FAO/WHO workshop. *Food Control*, 8, 221-226.
- Nwaiwu, O., Aduba, C. C., Igbokwe, V. C., Sam, C. E. and Ukwuru, M. U. 2020.** Traditional and Artisanal Beverages in Nigeria: Microbial Diversity and Safety Issues. *Beverages*, 6, 53.
- Nwiyi, I. and Elechi, J. O. G. 2022.** Evaluation of Food Safety and Nutritional Quality of Indigenous Beverages Vended in Informal Market of Nasarawa State, North Central,

- Nigeria. *Eurasian Journal of Food Science and Technology*, 6, 100-112.
- Ogunbemi, K., Ishola, D., Alejo, A., Ajanwachuku, C., Odeniyi, T., Zaka, K., Ugama, E., Oke, O. and Ilori, A. 2019.** Evaluation of the nutritional value and acceptability of powdered reconstituted kunu-zaki drink; an index of increasing shelf life of the drink. *Asian Food Science Journal*, 6, 1-7.
- Ogunlade, A. and Adeleke, M. 2021.** *Food, Technology and Culture in Africa*, African Books Collective.
- Ogunremi, O. R., Leischfeld, S. F., Mischler, S. and Schwenninger, S. M. 2022.** Antifungal activity of lactic acid bacteria isolated from kunu-zaki, a cereal-based Nigerian fermented beverage. *Food Bioscience*, 49, 101648.
- Oguntoyinbo, F. A. and Narbad, A. 2012.** Molecular characterization of lactic acid bacteria and in situ amylase expression during traditional fermentation of cereal foods. *Food Microbiology*, 31, 254-262.
- Ogunyemi, B. C., Ogunyemi, A. K., Odetunde, S. K., Olumuyiwa, E. O., Olalekan, A. O., Akinyemi, K. O. and Iwalokun, B. A. 2021.** Microbiological, physicochemical, nutritional and anti-nutritional evaluation of locally made non-alcoholic kunun Zaki beverage sold in Lagos state, Nigeria. *Food and Environment Safety Journal*, 20.
- Olatoye, K. K., Ironidi, E. A., Awoyale, W. and Adeyemo, O. I. 2023.** Nutrient composition, antioxidant properties and sensory characteristics of instant Kunu from pearl millet supplemented with African locust bean pulp. *Journal of Ethnic Foods*, 10, 21.
- Olawale, B. I., Iliyasu, M. Y., Musa, B., Abdulrahman A. and Umar, A. F. 2021.** Production of bioethanol by co-culture of *Aspergillus niger* and *Saccharomyces cerevisiae* using watermelon peels as substrate. *Traektoriā Nauki= Path of Science*, 7, 6001-6011.
- Olufunke, A. and Oluremi, K. 2015.** Assessment of nutritional and sensory quality of Zaki-A home-made traditional Nigerian beverage. *Journal of Nutrition and Food Sciences*, 5, 5-8.
- Oluwajoba, S. O., Akinyosoye, F. A. and Oyetayo, O. V. 2013.** Comparative sensory and proximate evaluation of spontaneously fermenting kunu-zaki made from germinated and ungerminated composite cereal grains. *Food Science & Nutrition*, 1, 336-349.
- Omoleke, S. A., Ajibola, O., Ajiboye, J. O. and Raji, O. 2018.** Quagmire of epidemic disease outbreaks reporting in Nigeria. *BMJ global health*, 3.
- Onyimba, I. A., Itelima, J. U., Job, M. O., Ogbonna, I. and Ode, C. O. 2017.** Production of sorghum based kunun zaki using selected starter cultures.
- Oranusi, S., Umoh, V. and Kwaga, J. 2003.** Hazards and critical control points of kunun-zaki, a non-alcoholic beverage in Northern Nigeria. *Food microbiology*, 20, 127-132.
- Osuntogun, B. and Aboaba, O. 2004.** Microbiological and physico-chemical evaluation of some non-alcoholic beverages. *Pak. J. Nutr*, 3, 188-192.
- Otaru, A., Ameh, C., Okafor, J., Odigure, J. and Abdulkareem, A. 2013.** Development, carbonation and characterization of loca millet beverage (Kunu). *Inter. J. Computational Engineer. Res*, 3, 80-86.
- Panse, R. J. 2023.** Nutraceuticals as Modulators of Gut Microbiota. *Anxiety, Gut Microbiome, and Nutraceuticals: Recent Trends and Clinical Evidence*, 187.
- Patra, M., Bashir, O., Amin, T., Shams, R., Chaudhary, K. S., Mirza, A. A. and Manzoor, S. 2023.** A comprehensive review on functional beverages from cereal grains-characterization of nutraceutical potential, processing technologies and product types. *Heliyon*.
- Petraccia, L., Liberati, G., Masciullo, S. G., Grassi, M. and Fraioli, A. 2006.** Water, mineral waters and health. *Clinical nutrition*, 25, 377-385.
- Pola, B. J., Ijabani, E. and Wadzamda, B. C. 2024.** Physicochemical and Bacteriological Assessment of Traditional Sorghum Beers in Jimeta, Nigeria. *Journal of Advances in Microbiology*, 24, 26-36.
- Rajendran, P. and Bharathidasan, R. 2018.** Standardization and Preservation of Sugarcane Juice by Hurdle Technology. *International Journal of Advances in Agricultural Science and Technology*, 5, 77-87.
- Rashwan, A. K., Yones, H. A., Karim, N., Taha, E. M. and Chen, W. 2021.** Potential processing technologies for developing sorghum-based food products: An update and comprehensive review.
- Rehman, A., Qunyi, T., Karim, A., Noreen, A., Ahmad, S., Usman, M. and Jafari, S. M. 2023.** Heat exchangers in the dairy industry. *Thermal Processing of Food Products by Steam and Hot Water*. Elsevier.
- Reis, F. R. 2023.** Heat exchangers in the beverages and sugar industry. *Thermal Processing of Food Products by Steam and Hot Water*. Elsevier.
- Rejman, K., Górska-Warsewicz, H., Czczotko, M. and Laskowski, W. 2020.** Nonalcoholic Beverages as Sources of Nutrients in the Average Polish Diet. *Nutrients*, 12, 1262.
- Rosell, C. M., Rojas, J. A. and De Barber, C. B. 2001.** Influence of hydrocolloids on dough rheology and bread quality. *Food hydrocolloids*, 15, 75-81.
- Sadiq, A. and Atteh, B. O. 2023.** Impact of Ingredients Formulation and Processing Parameters on the Nutritional Quality of Foam-mat Dried Kunun-zaki Powder (A Nigerian Fermented Cereal Beverage). *Chemical Engineering*, 3, 1-13.
- Salgueiro, L., Martins, A. and Correia, H. 2010.** Raw materials: the importance of quality and safety. A review. *Flavour and Fragrance Journal*, 25, 253-271.
- Schmidt, R. H. and Piotter, H. M. 2020.** The hygienic/sanitary design of food and beverage processing equipment. *Food safety engineering*, 267-332.
- Serna-Saldivar, S. O. 2016.** *Cereal grains: properties, processing, and nutritional attributes*, CRC press.
- Shalaby, M. T., Rabie, M. M., Boraie, N. A. E. and Toyour, M. H. 2018.** Application of Haccp System on Guava Nectar Production Line. *Journal of Food and Dairy Sciences*, 9, 237-244.
- Shuai, L., Huang, J., Chen, X. and Wang, L. 2026.** High-humidity Hot Air Impingement (HHAI) As a Pretreatment

- in Food Processes: Mechanisms, Applications, and Impacts On Food Quality. *Food and Bioprocess Technology*, 19, 149.
- Siby, N. 2023.** Cereal-based unfermented beverages: Processing techniques and nutritional attributes.
- Singh, S. & Shalini, R. 2016.** Effect of hurdle technology in food preservation: a review. *Critical Reviews in Food Science and Nutrition*, 56, 641-649.
- Soro-Yao, A. A., Brou, K., Amani, G., Thonart, P. and Djè, K. M. 2014.** The use of lactic acid bacteria starter cultures during the processing of fermented cereal-based foods in West Africa: a review. *Tropical life sciences research*, 25, 81.
- Sowonola, O., Tunde-Akintunde, T. and Adedeji, F. 2005.** Nutritional and sensory qualities of soymilk kunnu blends. *African Journal of Food, Agriculture, Nutrition and Development*, 5.
- Talpur, A. R., Soomro, A. H., Khaskheli, M., Shah, H., Mangsi, A. S. and Talpur, B. R. 2017.** Effect of Hydrocolloids on Physico-Chemical and Sensory Quality of Whey Beverages. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 10, 79-85.
- Taylor, J. R. and Kruger, J. 2019.** Sorghum and millets: Food and beverage nutritional attributes. *Sorghum and millets* Elsevier.
- Terna, G., Jideani, I. and Nkama, I. 2002.** Nutrient and sensory qualities of kunun zaki from different saccharification agents. *International journal of food sciences and nutrition*, 53, 109-115.
- Tersoo-Abiem, E. M. and Orinya, R. O. 2024.** Microbiological Quality of Home-made Street Vended Beverages in Reused Bottles Sold in Makurdi, Benue State, Nigeria. *European Journal of Nutrition & Food Safety*, 16, 284-293.
- Thakur, A., Pandey, P., Dalbhagat, C. G. and Mishra, H. N. 2022.** Development of grain-based carbonated beverage premix using maize (*Zea Mays*), Bengal gram (*Cicer Arietinum*) and finger millet (*Eleusine Coracana*). *Journal of Food Science and Technology*, 59, 1637-1648.
- Tireki, S. 2021.** A review on packed non-alcoholic beverages: Ingredients, production, trends and future opportunities for functional product development. *Trends in Food Science & Technology*, 112, 442-454.
- Tofană, M., Mudura, E., Coldea, T. E., Bors, A. and Pasqualone, A. 2021.** Current Functionality and Potential Improvements of Non-Alcoholic Fermented Cereal Beverages. *Qualitative and Nutritional Improvement of Cereal-Based Foods and Beverages*, 19.
- Towobola, M. 2021.** Production and Preservation of Kunun-Zaki From Millet and Groundnut Blend. Landmark University, Omu Aran, Kwara State.
- Utono, I. M. and Adamu, R. S. 2023.** Effect of belt expert (Flubendiamide+ Thiacloprid), Imidacloprid, Thiamethoxam seed treatment and economic impact on fall Armyworm (*Spodoptera frugiperda*) infestation on Maize in Nigeria. *Cogent Food & Agriculture*, 9, 2164117.
- Vasudevan, S. and Chengaiyan, J. G. 2025.** Ensuring beverage excellence: A quality control guide. *Food Science and Engineering*, 38-53.
- Waimer, F., Lang, F. and Stumpf, H. 2007.** The European Pharmacopoeia monograph extracts--implementation of the concepts for 'quantified' and 'standardised' extracts in industrial practice. *Pharmeuropa scientific notes*, 2007, 15-20.
- Walsh, H., Cheng, J. and Guo, M. 2014.** Effects of carbonation on probiotic survivability, physicochemical, and sensory properties of milk-based symbiotic beverages. *Journal of food science*, 79, M604-M613.
- Williana, N. M., Babasola, A. O., Cajethan, O. E. and Stephen, O. F. 2021.** Role of Organic Spices in the Preservation of Traditionally Fermented Kunun-zaki.
- Xiong, Y., Zhang, P., Warner, R. D., Shen, S. and Fang, Z. 2022.** Cereal grain-based functional beverages: From cereal grain bioactive phytochemicals to beverage processing technologies, health benefits and product features. *Critical reviews in food science and nutrition*, 62, 2404-2431.