Evaluating the Impact of Cereal Milling Practices on Nutritional Quality and Food Safety in Nigeria: A Review

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Received 2 December 2025, Accepted 3 February 2026, Published 4 February 2026

Direct Research Journal of Agriculture and Food Science

Direct RESEARCH JOURNALS

Vol. 14(1), Pp. 70-78, February 2026

https://journals.directresearchpublisher.org/index.php/drjafs; https://www.ajol.info/index.php/drjafs

Review Article
ISSN: 2354-4147

ABSTRACT

Cereal milling is a critical post-harvest operation that substantially influences nutritional quality, food safety, and public health outcomes, particularly in developing countries where informal processing systems dominate. This critical narrative review synthesizes evidence on cereal milling practices in Nigeria and their implications for nutrient retention, anti-nutritional factors, and food safety risks. Literature was sourced from Google Scholar, Scopus, Web of Science, and African Journals Online (AJOL), covering publications from 2000 to 2025. Inclusion criteria focused on peer-reviewed empirical and review studies addressing cereal milling technologies, nutrient composition, and contamination risks, with specific emphasis on Nigeria and comparable Sub-Saharan African contexts. Over 50 peer-reviewed studies were reviewed. Evidence indicates that traditional and informal milling systems are associated with significant losses of dietary fibre, minerals, and bioactive compounds, alongside elevated risks of heavy metal contamination and microbial hazards, while modern milling improves hygiene but often exacerbates micronutrient losses due to excessive refinement. The review highlights substantial research and regulatory gaps, particularly regarding informal mills, and underscores the need for context-specific policy interventions, technological upgrading, and whole-grain promotion strategies to enhance nutrition security and food safety in Nigeria.

Keywords: *Cereal milling; Nutrient retention; Informal food processing; Heavy metal contamination; Whole-grain processing; Food safety; Nigeria; Sub-Saharan Africa*

Citation Odaudu, G., Barde, A., & Nouruddeen, Z. B. (2026). Evaluating the Impact of Cereal Milling Practices on Nutritional Quality and Food Safety in Nigeria: A Review. *Direct Research Journal of Agriculture and Food Science*. Vol. 14(1), Pp. **70-78**.
https://doi.org/10.26765/DRJAFS67808728

INTRODUCTION

Cereal grains remain central to global food and nutrition systems, providing a dominant share of dietary energy, plant protein, B-complex vitamins, and essential minerals across diverse populations. Worldwide, cereals such as maize, rice, wheat, sorghum, and millets contribute a substantial proportion of daily caloric intake, particularly in regions where dietary diversification is limited (Akplo *et al*., 2023; Maurya *et al*., 2023). In sub-Saharan Africa, cereals underpin food security and livelihoods, with maize as the principal staple, followed by sorghum and millets (Raheem *et al*., 2021). In Nigeria, cereals occupy a pivotal role in household diets, rural economies, and national food security policies. Staples such as rice, maize, sorghum, and pearl millet are widely consumed in traditional and modern food forms, including porridges, dumplings, baked products, and fermented beverages (Akinola *et al*., 2020). National development initiatives have historically prioritized cereal production as a pathway to food availability and economic resilience; however, increasing evidence indicates that post-harvest operations particularly milling are equally influential in determining the nutritional quality and safety of cereal-based foods (Nwozor and Olanrewaju, 2020; Peter and Kwanashie, 2025).

Milling facilitates cereal consumption by improving palatability, digestibility, and shelf stability, yet it simultaneously reshapes grain structure and composition. Intensive dehulling, polishing, and fine grinding often remove bran and germ fractions that are rich in dietary fibre, minerals, vitamins, and phytochemicals, thereby reducing overall nutrient density (Shahidi *et al*., 2021; Nogala-Kałucka *et al*., 2021). Conversely, minimally refined flours retain higher nutritional value but may be produced under conditions that increase exposure to microbial and metallic contaminants, particularly in poorly regulated processing environments (Adeola, 2022; Oloruntoba *et al*., 2024).

Nigeria's cereal milling landscape is characterised by the coexistence of traditional household techniques, informal community-based mechanized mills, and modern industrial processing facilities. While informal systems dominate cereal processing due to their affordability and accessibility, they frequently operate with limited hygiene control and equipment maintenance (FAO, 2019). Modern mills provide improved sanitation and process standardization but tend to favour refined products with reduced micronutrient content (Manik *et al*., 2024).

Despite extensive research on cereal composition and processing, few reviews integrate nutritional outcomes and food safety risks within a unified analytical framework, particularly in the Nigerian context. This review addresses this gap by synthesizing evidence on cereal milling practices in Nigeria and examining their implications for nutrient retention, anti-nutritional factors, and food safety, with the aim of informing policy, research priorities, and technological interventions.

Aim and Objectives of the Review

The aim of this review is to critically synthesize evidence on cereal milling practices in Nigeria and their implications for nutritional quality and food safety.

Specific Objectives

(a) To synthesize empirical evidence on the effects of cereal milling practices on nutrient retention and loss.
(b) To compare traditional, modern, and informal milling systems in Nigeria.
(C)To identify food safety risks associated with cereal milling, including heavy metal and microbial contamination.
(d) To highlight research gaps, regulatory weaknesses, and policy priorities relevant to cereal milling in Nigeria.

REVIEW METHODOLOGY

This study adopted a critical narrative review approach. Literature searches were conducted using Google Scholar, Scopus, Web of Science, and African Journals Online (AJOL). Search terms included combinations of keywords such as "cereal milling", "grain processing", "nutrient loss", "heavy metal contamination", "informal food processing", "millet", "maize", "sorghum", "Nigeria", and "Sub-Saharan Africa". The review covered studies published between 2000 and 2025. Inclusion criteria comprised peer-reviewed journal articles and authoritative review papers focusing on cereal milling technologies, nutritional outcomes, anti-nutritional factors, and food safety risks. Studies addressing Nigerian contexts were prioritized, while evidence from comparable African countries and selected Asian contexts (notably India for millet processing) was included for comparative insight. Exclusion criteria included non-peer-reviewed reports, opinion pieces, and studies unrelated to milling or post-harvest processing. Following screening of titles, abstracts, and full texts, over 50 studies were retained for synthesis.

Cereals and Nutritional Value of Major Cereals in Nigeria

Cereal grains play a vital role in global food security, serving as primary sources of essential calories, B vitamins, minerals, and proteins (Raheem *et al*., 2021). Cereals such as wheat, rice, maize, barley, oats, sorghum, rye, and millet contribute to over 90% of caloric intake from cereals in many nations (Akplo *et al*., 2023; Maurya *et al*., 2023; Alkali, 2024).

Nigeria's diet relies predominantly on maize, sorghum, millet, and rice, which collectively supply a substantial proportion of daily energy intake (Akinola *et al*., 2020). These cereals are major sources of carbohydrates, although their nutritional composition varies widely due to genetic diversity, agro-environmental conditions, and post-harvest processing practices (Biel *et al*., 2020; Ramashia *et al*., 2021).

Maize serves primarily as an energy source but is limited in essential amino acids, particularly lysine and tryptophan, thereby reducing its protein quality (Ekpo *et al.,* 2019). In contrast, millets possess a superior micronutrient profile, providing appreciable levels of calcium, iron, zinc, dietary fibre, and antioxidant compounds, although their nutritional potential may be constrained by anti-nutritional factors that affect mineral bioavailability (Ramashia *et al*., 2021; Jones *et al*., Sanusi *et al*., 2019). Sorghum also contributes significantly to dietary energy and contains moderate protein and fibre levels, alongside bioactive compounds associated with health benefits (Saleh *et al*., 2013; Hassan *et al*., 2021).

Although less commonly consumed in Nigeria, cereals such as wheat, barley, and oats are important in global food systems and offer higher protein content, dietary fibre, and diverse micronutrients, depending on cultivar, agronomic practices, and processing intensity (Biel *et al*., 2020; Leszczyska *et al*., 2023; Chandrasekara and Shahidi, 2022). Across cereals, whole-grain forms generally retain higher levels of fibre, minerals, and phenolic compounds compared with refined products, supporting improved nutritional and functional value (Shahidi *et al*., 2021).

Cereal-based foods derived from maize, sorghum, and millets remain staple foods across Africa and other regions due to their affordability, adaptability, and long history of use in diverse food products (Saleh *et al*., 2013; Dias-Martins *et al*., 2018; Peter and Kwanashie, 2025). Whole-grain cereals, particularly sorghum and millets, are increasingly recognised for their nutraceutical and therapeutic potential, reinforcing their relevance in addressing nutrition security in Nigeria (Kumar *et al*., 2018; Ekpa *et al*., 2021; Dixit and Ravichandran, 2024).

Anti-nutritional Factors, Milling Practices, and Bioavailability

The nutritional value of cereals is constrained by anti-nutritional factors (ANFs) such as phytic acid, tannins, polyphenols, and protease inhibitors, which reduce mineral bioavailability and protein digestibility, particularly for iron and zinc (Akinola *et al*., 2020; Zhang *et al*., 2025). Milling intensity and fractionation strongly influence ANF distribution, as these compounds are predominantly concentrated in the bran and outer grain layers. While refining reduces ANF levels, it simultaneously removes dietary fibre, minerals, and phytochemicals, thereby creating trade-offs between nutrient retention and bioavailability.

Traditional pre-milling and milling-related practices, including soaking, tempering, germination, and fermentation, have been shown to reduce ANFs and enhance nutrient bioavailability by activating endogenous enzymes and promoting microbial degradation of phytic acid and tannins (Akinola *et al*., 2020; Inyang and Zakari, 2008).

Ramashia *et al*., 2021). Controlled milling parameters that limit excessive heat generation further preserve nutrient quality while reducing the inhibitory effects of ANFs on digestion. Emerging processing approaches such as extrusion and enzymatic treatments offer additional potential for targeted ANF reduction when optimized for specific cereal types and product goals (Zhang *et al*., 2025). Whole-grain cereals processed under optimized milling conditions retain higher levels of fibre and bioactive compounds and are associated with improved gut health and reduced risk of non-communicable diseases (Borneo and León, 2012; Malunga *et al*., 2024). However, gluten-containing cereals may pose risks for susceptible individuals, underscoring the need for balanced consumption and context-specific processing strategies (Arendt and Zannini, 2013; Pünder and Pruimboom, 2013). Integrating appropriate milling practices with ANF-reduction strategies is critical for improving nutrient bioavailability, safety, and health outcomes in cereal-based diets.

Cereal Milling Practices in Nigeria

Cereal crops such as maize, millet, sorghum, and rice constitute a major component of Nigeria's food system and contribute significantly to household food security and agro-based livelihoods (FAO Stat, 2021). These cereals are widely consumed in various forms, including porridges, baked products, and fermented foods (Adeleke *et al.,* 2023; Gana *et al*., 2010; Akinola *et al*., 2020). Milling remains a critical post-harvest operation that determines product quality, nutrient retention, safety, and market value. In Nigeria, cereal milling practices span traditional, modern, and informal systems, each characterised by distinct technologies, operational efficiencies, and quality outcomes.

Traditional Milling Practices in Nigeria

Traditional cereal milling practices in Nigeria are largely manual, labour-intensive, and rooted in indigenous knowledge systems that have evolved over generations (Nwozor and Olanrewaju, 2020). These practices are predominantly found in rural and low-income communities where access to electricity, mechanized equipment, and formal processing facilities is limited. Despite their low processing capacity and inconsistent output, traditional methods are often associated with improved nutrient retention due to minimal grain fractionation (Suma and Urooj 2017).

Stone grinding remains one of the most common traditional techniques. It employs a stationary lower stone and a rotating upper stone to grind whole grains, thereby retaining the bran and germ fractions. The resulting flour is typically higher in dietary fibre and micronutrients compared to refined products (Suma and Urooj 2017)

However, stone grinding is time-consuming, physically demanding, and highly dependent on operator skill, leading to variable product quality.

The use of mortar and pestle is another widespread practice, particularly for household-level processing. While this method is simple and accessible, it is inefficient for large-scale production and results in non-uniform particle size (Nwozor and Olanrewaju, 2020). Hand-operated mills represent a transitional technology between traditional and mechanized systems. These mills incorporate rotating plates or rollers to improve efficiency, although they still require considerable manual input and offer limited throughput (Nwozor and Olanrewaju, 2020). Although traditional milling practices contribute to dietary quality, their limitations in scalability, productivity, and consistency have driven a gradual shift toward mechanized alternatives, especially in urban and commercial food systems (Nwozor and Olanrewaju, 2020).

Modern Milling Practices in Nigeria

Modern cereal milling practices in Nigeria have expanded in response to increasing urbanization, population growth, and demand for standardized cereal products (Akinola *et al*., 2020; Tchotang *et al*., 2017). These systems emphasizes higher throughput, controlled particle size distribution, and improved product uniformity. Roller milling has been increasingly adopted for processing maize, sorghum, and millet, in addition to its traditional application in wheat milling (Pulivarthi *et al*., 2024). The process involves sequential reduction of grain size using smooth or corrugated rollers operating at differential speeds. This allows for controlled separation of endosperm, bran, and germ, enabling the production of refined and whole-meal flours. However, the removal of bran and germ may result in reduced fibre and micronutrient content (Dixit and Ravichandran, 2024). Hammer milling is widely used due to its simplicity, robustness, and adaptability, particularly in maize and sorghum processing. It relies on high-speed rotating hammers to fracture grains and is suitable for producing coarse flour, grits, and animal feed (Mundassery *et al*., 2024). Nevertheless, hammer mills offer limited control over particle size uniformity compared to roller milling.

Disk milling employs abrasive rotating disks and provides better control over flour texture than hammer mills. The choice of milling technology is influenced by cereal type, desired product characteristics, capital investment, energy availability, and maintenance capacity (Mundassery *et al*., 2024).

Modern milling operations are supported by ancillary equipment such as grain cleaners, sifters, purifiers, and conveying systems, which collectively enhance processing efficiency and product quality. Large commercial mills typically integrate these components into automated processing lines, while smaller mills adopt simplified or hybrid systems depending on available resources (Tchotang *et al*., 2017).

Informal Cereal Milling Sector in Nigeria

The informal milling sector accounts for a substantial proportion of cereal processing in Nigeria, particularly within local markets and community-based operations (FAO, 2019). These mills often operate outside formal regulatory frameworks, raising concerns related to food safety, hygiene, and quality assurance. A major challenge within the informal sector is inadequate equipment maintenance. Milling components are frequently repaired using improvised materials such as welded metals and substandard dehulling parts, which can introduce metallic contaminants into milled products (Singh *et al*., 2024). Poor maintenance also contributes to uneven dehulling and reduced milling efficiency. Another critical issue is the use of the same milling equipment for multiple cereals despite differences in grain size, hardness, and endosperm structure. This practice leads to inconsistent yields and variable product quality (Singh *et al*., 2024). In many cases, dehulling and polishing machines are modified versions of paddy rice equipment, which are not optimally designed for other cereals. Milling efficiency can be improved through adjustments in operational parameters such as rotational speed, abrasive grit size, number of passes, and processing duration (Singh *et al*., 2024).

Inadequate access to clean water further compromises food safety in informal milling operations, increasing the risk of contamination by heavy metals and pathogenic microorganisms. Poor line clearance practices also result in cross-contamination between batches, posing additional health risks (FAO, 2019).

The absence of standardized quality control measures, including metal detection systems and sanitation protocols, remains a significant weakness of the informal sector. Limited regulatory oversight contributes to inconsistent compliance with food safety standards, with potential public health implications (FAO, 2019).

Effect of Milling Practices on Nutrients, Phytochemicals, and Anti-nutritional Factors

Milling practices, including conditioning, dehulling, and particle size reduction, significantly influence nutrient retention, phytochemical content, and anti-nutritional factors in cereal products (Tables 1-2). Conditioning (tempering) improves milling efficiency by adjusting grain moisture to enhance kernel plasticity and facilitate separation of the endosperm from bran and germ (Mundassery *et al*., 2024; Pulivarthi *et al*., 2024). However, conditioning outcomes depend on grain type, moisture level, and processing duration, and poor water quality may introduce contaminants (Rao *et al*., 2023; Oloruntoba *et al*., 2024).

Wetting during conditioning affects phytochemical bioavailability, with moderate wetting enhancing the release of bound phenolic and antioxidant activity, while excessive soaking results in nutrient leaching and degradation of water-soluble vitamins (Shahidi *et al*., 2021; Lima *et al*., 2024). Recent advances, such as ultrasound-assisted tempering, have demonstrated improved milling yield and flour quality, particularly in sorghum (Pulivarthi *et al*., 2024).

Dehulling, which involves removing the outer layer (husk or hull) of cereal grains, is a crucial step in cereal milling

Table 1: Effects of mechanical principles on dehulling characteristics of millets.

Mechanical principle	Millet type	Key outcomes
Abrasion and friction	Pearl	The anti-nutritional properties were reduced.
Abrasion and friction	Sorghum (Jumbo variety)	Maximum dehulling efficiency of 90.10% was obtained by applying a short duration of tempering (moisturizing).
Abrasion and friction	Kodo	A 75.29% dehusking efficiency of 14% moisture content grain was obtained.
Abrasion and friction	Foxtail	Resulted 85.64% dehusking yield.
Abrasion and friction	Foxtail	Obtained 80% of deshelling efficiency.
Abrasion and friction	Pearl	Endosperm yield ranges between 83.47–90.29% under a degree of polishing of 10.72–19.56%.
Abrasion and friction	Pearl	Increasing polishing time increased degree of polishing and breakage but reduced endosperm yield.
Shearing and compression	Little millet	Dehulling efficiency of 83% and milling efficiency of 60.60% were obtained.
Shearing and compression	Proso millet	An 88% head yield was obtained after rubber roller shearing followed by abrasive polishing.
Shearing and compression	Foxtail millet	Dehulling efficiency of 81% was obtained at 640 rpm and 150 kg h^{-1} feed rate.
Shearing and compression	Proso millet	Maximum dehulling efficiency of 60% was obtained at 1.75 mm clearance.
Shearing and compression	Kodo millet	Dehulling efficiency of 47.61% with 7.48% broken grains was observed.
Shearing and compression	Browntop millet	Dehulling efficiency of 27.95% with 2.92% broken grains was reported.
Shearing and compression	Foxtail millet	Maximum dehulling and cleaning efficiencies of 82.24% and 82.47% were achieved at 12% moisture content.
Centrifugal and impact	Foxtail millet	Dehulling efficiency of 92.70% was obtained at 13.60% moisture content and 5500 rpm.
Centrifugal and impact	Little millet	Dehulling efficiency of 91% was obtained at 13.60% moisture content and 5500 rpm.
Centrifugal and impact	Proso millet	Dehulling efficiency of 93.50% was obtained at 13.60% moisture content and 5500 rpm.
Centrifugal and impact	Kodo millet	Dehulling efficiency of 80.90% was obtained at 11.10% moisture content and 6000 rpm.
Centrifugal and impact	Barnyard millet	Dehulling efficiency of 74.40% was obtained at 11.10% moisture content and 6000 rpm.
Centrifugal and impact	Foxtail millet	Dehulling efficiency of 97.17% with 1.90% broken grains was recorded.
Centrifugal and impact	Barnyard millet	Dehulling efficiency of 63.57% with 8.20% broken grains was recorded.

Source: Singh *et al*., 2024

Table 2: Effects of different cereal milling methods on nutrient retention

Milling method	Key processing steps	Protein retention	Dietary fibre retention	Mineral (ash) retention	Dominant nutritional implication	References
Traditional dry milling	Cleaning → dry grinding → sieving	High	High	High	Preserves whole-grain nutrients but variable quality	Manik *et al*., 2024; Mundassery *et al*., 2024).
Soaking and grinding	Soaking → drying → grinding	Moderate–high	High	Moderate	Improved digestibility and mineral bioavailability	Manik *et al*., 2024; Gwekwe *et al*., 2024; Singh and Rao, 2025
Hammer milling	Cleaning → crushing → hammer milling	Moderate	Moderate	Moderate	Balanced nutrient retention	Shahidi *et al*., 2021; Rao *et al*., 2023
Roller milling	Cleaning → tempering → dehulling → roller milling	Moderate	Low	Low	High starch yield, reduced micronutrients	Mundassery *et al*., 2024; Shahidi *et al*., 2021; Nogala-Kaucka *et al*., 2020; Manik *et al*., 2024.
Polishing-intensive milling	Dehulling → polishing → fine milling	Low–moderate	Very low	Very low	High caloric value, poor micronutrient density	Shahidi *et al*., 2021; Nogala-Kaucka *et al*., 2020, Manik *et al*., 2024.

(Decker *et al*., 2014; Embashu and Nantanga, 2019).Dehulling reduces anti-nutritional factors such as phytates and tannins concentrated in the outer layers of cereals, thereby improving digestibility and milling efficiency (Gwekwe *et al*., 2024; Singh and Rao, 2024; Manik *et al*., 2024) (Tables 1-2). However, it may also reduce dietary fibre, minerals, and phytochemicals, although nutrient bioavailability in the endosperm may improve due to lowered anti-nutritional interference (Dinesh *et al*., 2025; Nogala-Kaucka *et al*., 2020). The nutritional impact of dehulling depends on cereal type, dehulling method, and degree of hull removal (Rao *et al*., 2023; Malunga *et al*., 2024).

Milling techniques, including roller, hammer, and disk milling, affect macronutrient and micronutrient availability by modifying particle size and generating process heat (Suma and Urooj, 2017; Mundassery *et al*., 2024). Fine milling enhances nutrient accessibility but may accelerate losses of heat-sensitive vitamins, essential fatty acids, and antioxidants (Nogala-Kaucka *et al*., 2020; Igwe *et al*., 2016). Protein, lipid, and fibre contents are often reduced due to the removal of bran and germ fractions, while

Table 3: Reported food safety hazards associated with cereal milling systems

Milling system	Hazard type	Specific hazard	Source	Health implication	References
Informal mills	Physical	Metal fragments	Worn grinding plates	Dental and GI injury	Adeola, 2022)
Informal mills	Biological	Microbial contamination	Poor sanitation	Foodborne illness	Oloruntoba *et al*., 2024
Semi-mechanized mills	Physical	Fine metal particles	Hammer abrasion	Chronic exposure risk	Kayisoglu *et al*., 2025 Mugume, *et al*., 2023
Modern mills	Chemical	Trace heavy metals	Equipment wear	Long-term toxicity	Kayisoglu *et al*., 2025 Mugume, *et al*., 2023
Modern mills	Biological	Low-level contamination	Inadequate cleaning	Reduced but persistent risk	Oloruntoba *et al*., 2024

carbohydrate composition and glycemic potential may also be altered (Rani *et al.,* 2018; Manik *et al*., 2024). Milling further influences phytochemical and anti-nutritional factor profiles, with flavonoids and phenolics being particularly susceptible to loss during intensive size reduction (Shahidi *et al*., 2021; Nassarawa and Sulaiman, 2019).

Food Safety and Health Risks Associated with Milling Practices

Cereal milling operations present food safety risks that are influenced by water quality, equipment condition, and post-milling handling practices. During conditioning, the use of contaminated or untreated water may introduce heavy metals and pathogenic microorganisms into grains, posing significant public health concerns (Oloruntoba *et al*., 2024).

Metallic contamination may occur during milling due to abrasion and wear of metallic equipment surfaces, particularly in poorly maintained or traditional milling systems (Table 3).

Experimental studies have shown that crushing and reduction stages during wheat milling can increase concentrations of iron (Fe) and zinc (Zn) in flour, while chromium (Cr) and copper (Cu) are often introduced through equipment abrasion rather than grain composition (Kayisoglu et al., 2025). Field studies in sub-Saharan Africa similarly report elevated levels of Fe, Mn, Zn, Pb, and Cu in maize flour processed using metallic mortars compared with wooden alternatives, with Pb and Cd exceeding recommended safety limits in some cases (Mugume *et al*., 2023).

The extent of contamination depends largely on the type and quality of milling equipment. Burr and disc mills, as well as locally fabricated grinding machines, have been reported to introduce higher metal loads than hammer mills, particularly as grinding time and friction increase (Adeola, 2022). Contamination mechanisms include mechanical abrasion, corrosion of metal components, and deposition of wear particles, which are intensified in wet-grinding systems operating under corrosive conditions (Adeola, 2022). Process variables such as milling duration, moisture content, grain hardness, and fractionation efficiency further influence metal distribution in final products. While milling redistributes intrinsic minerals between bran and flour fractions, externally introduced metals may persist in refined products if effective control measures are absent (Kayisoglu *et al*., 2025). Consequently, the use of food-grade materials, regular equipment maintenance, and metal monitoring systems is essential to minimize contamination and ensure compliance with food safety standards (Adeola, 2022; Kayisoglu *et al*., 2025).

Synthesis of Evidence and Comparative Insights

Comparative Risk Profile of Informal versus Modern Cereal Milling Systems

Comparative analysis of informal and modern cereal milling systems reveals distinct and opposing risk profiles shaped by differences in processing objectives, infrastructure, and regulatory oversight. Informal milling systems, which account for a substantial proportion of cereal processing in Nigeria, typically involve limited dehulling and polishing. As a result, products from these systems often retain higher levels of dietary fibre, minerals, and phytochemicals (Manik *et al*., 2024). However, these nutritional advantages are counterbalanced by elevated food safety risks associated with inadequate sanitation, worn equipment, and inconsistent process control (Adeola, 2022; Oloruntoba *et al*., 2024). Metallic contamination represents a major hazard within informal mills, where grinding surfaces are frequently repaired using improvised or non-food-grade materials, increasing the likelihood of iron, chromium, lead, and other metals entering milled products (Adeola, 2022; Mugume *et al*., 2023). Inadequate cleaning practices and shared equipment further increase the risk of cross-contamination between batches, while limited access to clean water heightens microbial hazards (FAO, 2019). Modern milling systems present a contrasting profile characterized by improved hygiene standards, mechanized cleaning, and greater process consistency. These features substantially reduce microbial and physical contamination risks (Kayisoglu *et al*., 2025). Nevertheless, the emphasis on intensive dehulling, polishing, and fine milling leads to significant removal of bran and germ fractions, resulting in reduced fibre, mineral, and phytochemical content in final products (Nogala-Kałucka *et al*., 2021; Shahidi *et al*., 2021). From a public health standpoint, neither system independently achieves an optimal balance between nutrition and safety. Informal mills pose higher immediate contamination risks, whereas modern mills contribute to longer-term micronutrient inadequacies through widespread consumption of refined cereals. Evidence therefore supports hybrid milling approaches that integrate improved sanitation and equipment standards with nutrient-preserving processing practices (FAO, 2019; Manik *et al.*, 2024).

Comparative evidence on milling-related nutrition and safety outcomes across selected countries

Comparative evidence from Nigeria, Cameroon, and India reveals a consistent nutrition–safety trade-off in cereal milling systems. Traditional and semi-mechanized milling preserves dietary fibre, minerals, and phytochemicals but is associated with higher risks of metallic and microbial contamination due to poor sanitation and equipment wear (Adeola, 2022; Oloruntoba *et al.*, 2024; Mugume *et al.*, 2023). In contrast, modern roller and polishing-intensive milling improves hygiene, uniformity, and shelf stability but substantially reduces micronutrient density through bran and germ removal (Nogala-Kaucka *et al.*, 2020; Shahidi *et al.*, 2021; Mundassery *et al.*, 2024). Across regions, evidence supports hybrid milling strategies that balance nutrient retention with food safety (Manik *et al.*, 2024; FAO, 2019).

Policy, Research, and Technological Implications

The findings of this review highlight critical gaps in Nigeria's food safety governance, particularly regarding informal mills. Strengthening regulatory oversight, promoting low-cost technological upgrades, and incentivizing whole-grain processing are key policy priorities. Research efforts should focus on quantitative assessment of nutrient losses and contamination levels across milling systems and on consumer acceptance of whole-grain products.

Conclusion

Cereal milling practices in Nigeria exert a decisive influence on both the nutritional value and safety of cereal-based foods. This review demonstrates that modern milling systems enhance efficiency, hygiene, and standardization but frequently compromise micronutrient density through excessive refinement (Shahidi *et al.*, 2021; Nogala-Kałucka *et al.*, 2021). In contrast, traditional and informal milling systems preserve nutrient-rich grain components yet expose consumers to elevated risks of metallic and microbial contamination due to limited regulatory oversight and equipment control (Adeola 2022; Oloruntoba *et al.*, 2024). Addressing these challenges requires an integrated processing strategy that moves beyond the dichotomy of traditional versus modern milling. Strengthening regulatory oversight of informal mills, promoting low-cost technological upgrades, and encouraging moderate dehulling and whole-grain processing are essential policy priorities (FAO, 2019; Manik et al., 2024). Future research should prioritize quantitative assessment of nutrient losses and contamination levels across milling systems, alongside evaluations of consumer acceptance of nutritionally improved cereal products. By aligning milling technologies with both nutritional and food safety objectives, Nigeria can enhance the contribution of cereal-based foods to public health, nutrition security, and sustainable food systems.

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