World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

Causes of quality defects in cassava-based food production: An Ishikawa diagram analysis

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World Journal of Advanced Research and Reviews, 2024, 24(01), 750–758

Publication history: Received on 20 August 2024; revised on 01 October 2024; accepted on 03 October 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.24.1.2856

Abstract

Cassava is a staple crop in many African countries, contributing to the production of various food products such as gari, cassava flour, and fufu. However, quality defects in these products are prevalent, particularly at the small-scale production level. This study analyzes the causes of these defects using the Ishikawa diagram, focusing on key factors such as materials, methods, manpower, machinery, and environment (5Ms). A comprehensive literature review revealed that inconsistent processing techniques, poor-quality raw materials, lack of training, and inadequate equipment are major contributors to product defects like microbial contamination, moisture imbalances, and texture inconsistencies. The study emphasizes that small-scale producers face greater challenges due to limited access to improved technology and standardized practices, while industrial producers benefit from more control over production processes. Recommendations include improving training, access to better equipment, and post-harvest storage solutions, alongside enhanced cassava root quality management. This analysis provides a framework for addressing quality control issues in cassava-derived products, ultimately improving food safety and product consistency across both small-scale and industrial production settings.

Keywords: Quality; Cassava; Ishikawa Diagram; Processing; Agricultural practices

1. Introduction

Cassava (*Manihot esculenta*) is a staple food for millions of people across the globe, particularly in sub-Saharan Africa, where it serves as a key source of carbohydrates (1–3). Common cassava-based products consumed in Africa include gari (fermented and roasted cassava granules), fufu (boiled and pounded cassava dough), cassava flour (ground cassava for baking and cooking), tapioca (dried granules boiled in water or milk), chikwangue (fermented cassava loaf), attiéké (fermented cassava couscous), bammy (cassava flatbread), cassava chips (thinly sliced and fried cassava), cassava starch (for food and industrial use), and pupuru (smoked fermented cassava balls) (3). There are many other food products that contain cassava flour, such as bread. In addition to foods derived from cassava, there are also dishes made from cassava leaves. The best known of these categories of food in Central Africa is Pondu or Sakasaka. It is a traditional dish from the Democratic Republic of the Congo and neighboring countries. It is made from cassava leaves that are boiled and often mixed with ingredients like palm oil, spices, and sometimes fish or meat. It's commonly served with fufu, rice, or other starches and is a popular, nutrient-rich dish in Central Africa. (4). Cassava leaves are also eaten elsewhere.

Cassava is also an important source of revenue in many countries like Nigeria and Sri Lanka ((5). Its resilience to harsh environmental conditions and ability to thrive in poor soils make it an essential crop for food security (6). Despite its

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significance, cassava-based food production faces several quality challenges that affect the final products consumed. From processing techniques to environmental factors, many variables contribute to the production of substandard food products, which can affect both the nutritional value and the safety of cassava-derived goods (7,8).

The production process involves several stages, including cultivation, harvesting, peeling, fermentation, drying, and milling, all of which can introduce defects if not carefully managed (9–11). Quality defects in cassava-based food products such as fufu, gari, and cassava flour are often related to poor handling, contamination, and suboptimal processing techniques (12,13). These issues can lead to microbial contamination (14,15), undesirable texture (15), reduced shelf life (16), and off-flavors (17), among other problems. Understanding the root causes of these quality defects is crucial for improving the production process and ensuring consumer safety and satisfaction.

This study employs an Ishikawa diagram (also known as a fishbone diagram) to analyze the causes of quality defects in cassava-based food production. The diagram offers a systematic way to categorize potential problems by identifying factors related to materials, methods, machinery, manpower, measurement, management, environment, and management. Using this approach, the study provides insights into the multifaceted nature of quality control in cassava food production, offering recommendations for addressing and mitigating defects at various stages. The findings aim to inform stakeholders, including farmers, processors, and policymakers, on best practices for enhancing the overall quality of cassava-based foods.

2. Methodology

The study employed a literature review to comprehensively investigate the causes of quality defects in specific cassava-based food products, namely *gari*, *cassava flour*, and *fufu*. Data were collecting through databases like Google Research, Google Scholar, ResearchGate, PubMed, Agora and Pdfdrive and processed using Zotero, Mendeley and MAXQDA and AI assistance using ChatGpt and Quillbot.

A thorough review of the existing literature was conducted to provide context for the common quality defects in cassava-based food production. This review covered studies on the production, preservation, and consumption of cassava-derived products, as well as the factors contributing to defects such as microbial contamination, fermentation issues, and improper drying techniques. The literature review served as a basis for understanding the broader industry challenges and allowed us to compare findings from other regions with those observed in the Republic of Congo.

3. Results and Discussion

3.1. Quality Defects in Gari, Cassava Flour, and Fufu

A review of published literature reveals that *gari*, *cassava flour*, and *fufu* experience specific quality defects due to their distinct production processes, preservation methods, and environmental factors. Common defects in *gari* include microbial contamination, inconsistent grain size, and off-flavors, largely attributed to improper fermentation and drying (18–20). *Cassava flour* frequently suffers from high moisture content, spoilage, and inconsistent particle sizes due to inadequate drying methods in humid environments (21–23). *Fufu*, on the other hand, is often subject to texture defects and undesirable flavors, typically caused by improper fermentation or insufficient cooking. These defects are prevalent at the small-scale or household production level, where practices are less standardized and quality control is minimal.

3.2. Application of the Ishikawa Diagram to Cassava Products

The Ishikawa diagram was applied to identify the root causes of quality defects in *gari*, *cassava flour*, and *fufu* by focusing on five key factors: materials, methods, manpower, machinery, and environment. Poor-quality raw materials, such as pest-infected cassava roots, contribute to defects across all products. Inconsistent processing methods, particularly in fermentation, drying, and milling, result in off-flavors, moisture imbalances, and texture issues. Lack of skill and training among producers exacerbates these problems, while inadequate or poorly maintained machinery, such as milling equipment, leads to further defects like inconsistent particle size (24). Environmental factors, especially high humidity and poor storage conditions, contribute to spoilage and microbial contamination. The Ishikawa diagram effectively categorizes these causes, providing a structured understanding of the issues affecting each product.

3.2.1. Methods

Cassava cultivation is also crucial for the quality of cassava-derived products, influenced by factors like soil quality, variety selection, planting materials and methods, pest management, water management, weeding, harvesting practices, post-harvest handling, and processing methods. Soil quality, (25–27) selection, and maturity period affect the texture, flavor, and safety of cassava products (28,29). Proper planting, spacing, weeding, and harvesting practices ensure larger, healthier roots and higher-quality products.

Cassava processing techniques are crucial for quality, requiring attention to drying methods to prevent mold and contamination and rigorous fermentation control to avoid toxin production (30–34). Grinding and sieving must effectively remove unwanted particles, with proper equipment maintenance (24). Adherence to work procedures and strict hygiene practices is necessary to avoid quality defects and contamination (35,36). Regular quality control at each production stage is essential to detect defects promptly, and clear quality standards must be established and followed to minimize product variability. Proper input management, including correct use of additives and preservatives and precise ingredient dosing, is crucial to avoid quality issues. Storage methods must prevent mold and bacteria growth, and adequate packaging is necessary to protect products and prevent contamination (37). Transportation must avoid damage and maintain quality, with effective logistics optimizing the storage and distribution chain.

The quality of cassava is significantly impacted by the processes of packaging, conditioning, and transportation, which are crucial for maintaining its safety, nutritional value, and freshness (38–41). Proper packaging regulates moisture, prevents spoilage, and safeguards the product from physical damage and contamination. Effective conditioning stabilizes cassava by reducing moisture and controlling temperature, preserving its taste, texture, and nutritional content. During transportation, risks such as physical damage and exposure to temperature and humidity fluctuations can jeopardize cassava's quality. Inadequate packaging increases the risk of contamination from transport vehicle surfaces, other goods, or passengers, introducing dirt, dust, sand, microorganisms, or chemicals that compromise the safety and shelf life of the cassava. Therefore, meticulous management of these processes is essential to ensure that cassava products remain in optimal condition, retaining their nutritional benefits and marketability.

3.2.2. Machinery

Machinery, or the lack thereof, plays a crucial role in the quality of cassava-derived products. In many small-scale production environments, equipment such as milling machines, drying facilities, and roasting ovens is either inadequate or poorly maintained (42,43). This leads to defects such as inconsistent particle size in cassava flour and uneven moisture distribution in gari. Industrial operations, on the other hand, benefit from more advanced and well-maintained machinery, reducing the occurrence of such defects. The study highlights the need for small-scale producers to access better machinery and maintenance practices to enhance product quality.

Using unsuitable equipment can compromise quality, highlighting the need for appropriate machinery (42,44–46). In many small-scale production environments, equipment such as milling machines, drying facilities, and roasting ovens is either inadequate or poorly maintained. The condition of the equipment is also important; worn or defective equipment can negatively affect quality, making regular maintenance essential. Equipment hygiene is vital to avoid contamination; insufficient cleaning can lead to cross-contamination, while food residue accumulation can promote mold growth, requiring thorough disinfection and regular cleaning. Outdated processing technology can reduce efficiency, making it important to update technology and precisely regulate processing conditions for consistent quality. For storage and packaging, equipment must manage humidity, temperature, and ventilation to prevent product deterioration, and packaging machines must provide adequate protection, requiring precise calibration to maintain quality.

3.2.3. Management

Management practices are essential for overseeing production quality and maintaining standards (47). Poor management often leads to ineffective quality control, inadequate training of workers, and suboptimal decision-making in processing. Small-scale producers frequently operate without structured management, leading to inconsistent production outcomes (48). The study emphasizes the importance of implementing better management systems that prioritize quality control measures, such as monitoring moisture levels, ensuring proper fermentation, and conducting regular inspections of machinery and materials. Effective management can greatly reduce the risk of defects in cassava products (49,50).

3.2.4. Raw Materials

Cassava variety significantly impacts the quality of processed products by affecting amino acid content, nutrient content, and cyanogen content (35,51,52). Flavor profiles, tuber texture, yields, growth rates, resistance to diseases and pests, and tuber appearance also impact the final product. Growing conditions, harvesting, handling, and transport also affect tuber quality (53–55). The quality of raw cassava roots, including starch content, cyanogenic glycosides, fiber content, post-harvest deterioration, processing efficiency, and flavor and texture, also affect the final product. Selecting the right cassava variety and harvest age is crucial for producing high-quality cassava-based products (7). Small-scale producers often face challenges in sourcing high-quality cassava roots, but improving the quality of raw materials through better farming practices, pest control, and post-harvest handling could help mitigate defects. (41,56,57).

3.2.5. Personnel

Insufficient training can significantly affect product quality at various stages of production (58). Workers' technical skills are crucial for effective cultivation, harvesting, processing, and storage, making proper training essential (59). Understanding food safety practices is also vital to prevent contamination and other quality issues (60,61). Human errors, such as improper handling or processing, can negatively impact final product quality (62). This underscores the need for standardized procedures and ongoing training (63). Deviations from work procedures and hygiene standards can lead to inconsistencies and contamination. Inadequate supervision may allow inappropriate practices, compromising quality standards, thus necessitating rigorous adherence to standards (64). Worker motivation is crucial; motivated workers are more likely to produce high-quality products(65). Poor working conditions can affect performance, highlighting the need for a supportive work environment to maintain product quality (66).

3.2.6. Environment

Climatic conditions are crucial for tuber growth and quality; extreme temperatures can harm development, requiring climate risk management to maintain quality (67). Rainfall balance is essential, as water excess or deficit can affect tuber quality. Extreme weather conditions, such as storms and droughts, can cause significant crop damage (28,68). Soil and water quality also impact tuber quality; contaminated or nutrient-deficient soil affects tubers, and clean irrigation water is necessary to avoid contamination. Pollution, whether atmospheric or from soil and water contaminants, can compromise crop quality, requiring strict pollution source control. Biodiversity is important for managing pests and diseases, with a diverse ecosystem essential for crop health. Access to appropriate infrastructure for processing, storage, and transportation is vital for maintaining product quality, and adequate storage facilities are needed to prevent tuber deterioration.

Various factors, such as humidity, dust, invertebrates, and vertebrates, can influence the cassava drying process (69). High humidity can lead to mold growth or fermentation, compromising the final product's quality (70). Dust can carry contaminants and debris, while insects can spread pathogens through their droppings, carcasses or secretions (71). Rats can introduce contaminants through their droppings, urine, and direct contact with the drying cassava. Addressing these risks is crucial for improving cassava product quality and safety.

The soaking water used in cassava retting may contain various substances that can greatly influence the quality and safety of the final product. These include organic matter, heavy metals, harmful microorganisms, pesticides, herbicides, suspended particles, mineral salts, and toxic algae or cyanobacteria (72). Excessive organic matter can promote undesirable fermentation, encouraging the growth of harmful bacteria or molds, which decreases the product's safety and market value. Heavy metals can accumulate in cassava, posing long-term health risks such as kidney damage, neurological issues, and cancer. Pathogenic microorganisms can flourish in water with high organic content, leading to foodborne illnesses. Additionally, pesticides and herbicides can be absorbed by the cassava during retting, creating health hazards. Suspended particles may lead to physical contamination, affect the cassava's appearance, and introduce harmful microbes or chemicals. To reduce the impact of these contaminants, measures such as water treatment, quality testing, sanitation, and monitoring organic content can be implemented.

3.2.7. Measurement

The "Measurement" cause refers to the lack of standardized quality checks and monitoring throughout the production process. In many small-scale operations, there is no consistent method for measuring critical factors like moisture content, fermentation time, or particle size, leading to quality variations (73). Industrial operations, however, often employ rigorous measurement and quality control systems, ensuring more consistent product quality. The study underscores the importance of introducing simple but effective measurement tools and protocols for small-scale producers to monitor key parameters during production, thereby reducing defects and ensuring better product consistency (74).

3.3. Comparative Analysis Across Production Scales

Small-scale household production offers artisan-quality cassava-derived products with potential nutritional benefits but with greater variability, shorter shelf life, and hygiene risks (13,75,76). Industrial production uses automated machinery for peeling, processing, and drying, ensuring faster, more uniform results and higher volumes of product in a shorter time frame (77). Products are more consistent in texture, flavor, moisture content, and appearance due to controlled environments, calibrated machines, and standardized procedures.

Hygiene and safety are more important in industrial production, as strict protocols minimize contamination risks and ensure product safety for mass consumption (78). Traditional methods like fermentation can enhance the nutritional profile of cassava products, while fortification can restore or enhance nutritional value (79,80). Flavor and texture are more varied and reflect local preferences, while industrial production offers a wider range of products. Self-life is limited in small-scale household production, with limited availability in rural areas. Industrial production is often more expensive due to mechanization, packaging, and distribution costs. In terms of environmental impact, small-scale household production has lower energy use but may contribute to deforestation if slash-and-burn agriculture is practiced. Industrial production may implement sustainable practices to reduce environmental impacts.

3.4. Regional Considerations

Publications from African countries like Nigeria, Ghana, and the Democratic Republic of Congo consistently highlight similar quality challenges in cassava-based products, particularly due to poor processing methods, inadequate infrastructure, and environmental conditions (67,81–85). In these regions, small-scale or household production is dominant, and the cassava value chain is often disorganized, leading to recurrent quality defects. Producers face challenges such as moisture control, contamination, and inconsistent product quality. By contrast, regions with more established industrial production have seen improvements in quality control, though issues related to raw material variability persist. This suggests that while industrialization helps mitigate some defects, systemic improvements in the cassava value chain are needed to address the root causes of quality issues.

3.5. Recommendations for Improving Quality Control

To improve the quality of *gari*, *cassava flour*, and *fufu*, several key interventions are necessary. First, small-scale producers require training in proper fermentation, drying, and milling techniques to minimize defects (86). Second, access to clean and well-maintained equipment, such as drying facilities and milling machines, is crucial to reduce contamination and improve consistency. Third, investment in better post-harvest handling and storage infrastructure, particularly in humid regions, is essential for controlling moisture levels and preventing spoilage. Finally, ensuring the use of high-quality cassava roots free from pests and harvested at the correct maturity is critical for improving product quality from the start (87). These measures will help address the root causes of defects and improve the overall quality of cassava-derived products in both small-scale and industrial production settings.

4. Conclusion

Focusing on *gari*, *cassava flour*, and *fufu* allowed for a clearer analysis of the specific quality defects affecting these products, particularly at the small-scale production level. The application of the Ishikawa diagram helped to systematically identify the key factors contributing to defects, including issues related to materials, methods, measurement, management, personnel, machinery, and environment. Improvements in training, equipment, and storage infrastructure, alongside better raw material handling, are essential for mitigating these defects (88). Addressing these challenges can lead to significant improvements in the quality of cassava-derived products, benefiting both small-scale and industrial producers across the cassava value chain.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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